"Report from the Workshop[1]: This Decade's (R)evolutionary Telecommunications Paradigm"

On June 17-18, 2002, the IEEE-USA, in association with Cornell University, held a Workshop in Washington, D.C. The objective of the Workshop was to provide a technology roadmap for broadband deployment in the U.S.A. Through the Workshop, follow-on teleconferences and this "Report from the Workshop", we embarked on this task.[2]

The conclusion of the Workshop and its follow-on analyses is that, given policy decisions to facilitate the transition, the goal of widely-available, truly broadband telecommunications is within our nation's reach through a combination of proven technologies: optical fiber and Ethernet. We have called this combination, "Advanced Fiber Network (AFN)" -- i.e., Ethernet networks over fiber infrastructure capable of supporting gigabit speeds. In combination these technologies promise great economic advantages and social benefits from widely deploying a truly broadband infrastructure capable of gigabits, rather than the kilobits or megabits currently offered by incumbents. This infrastructure provides the opportunity for competitive open access to end users, to suppliers, and each to the other, and provides an opportunity for freedom from arbitrary limitation of such offerings. On the basis of our analyses we urge that the nation explicitly include the AFN technology in the current U.S. policy debate on accelerating broadband deployment.

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[1] An approved IEEE-USA position statement, "Accelerating Advanced Broadband Deployment in the U.S." dated February 2003 is available on this subject. That position statement was based on a joint IEEE-USA/ Cornell University workshop of June 2002, combined with subsequent discussions and analyses by technology, policy and economics experts. This paper, "Report from the Workshop," records more fully the analysis resulting from the workshop. The Report is authored by workshop chair, Professor Alan McAdams, of Cornell University with the interaction and critique of workshop volunteers. This Report does not require IEEE-USA approval and therefore has not been reviewed, approved, or disapproved by its Board of Directors.

[2] Other technologies had been addressed by earlier IEEE-USA taskforces. The morning Workshop session was devoted to this AFN task, plus earlier Technology Task Group (TTG) Reports and discussion:

TTG-5:	Advanced Fiber Network (AFN) (incorporating also **TTG-1:** Optical Fiber Overview)	Luke Maki, *The Boeing Co*
TTG-2:	Hybrid-Fiber-Coax/ Cable Modem	Michael Bloom, *Communications Strategies and Planning*
TTG-3:	A) Two-Way Wireless	Ferdo Ivanek, *IEEE Microwave Society*
	B) Satellite	Ramesh Gupta, *SatTelLink,Inc.*
TTG-4:	DSL – Digital Subscriber Line	John Cioffi, *Stanford University*

These and other Workshop presentations are available at: http://ieee.johnson.cornell.edu

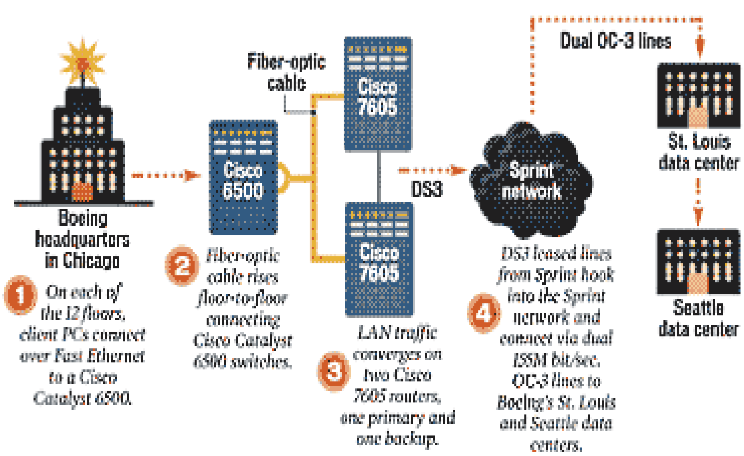
Further, we endorse the recommendations of the IEEE-USA presented in its Position Statement, "Accelerating Advanced Broadband Deployment in the U.S." of February, 2003:

(1) Policymakers must ensure that AFN technology, complemented by broadband wireless technologies, be fully considered and fairly evaluated for a prominent role in accelerating advanced broadband deployment in the U.S.

(2) Government policies at the Federal Communications Commission, Department of Justice, and Federal Trade Commission, as well as at state and local regulatory and enforcement agencies throughout the U.S, must be established, and actions must be taken to ensure that AFNs, together with complementary broadband wireless networks, are given a fair marketplace opportunity to prove themselves on their merits as contributors to enhancing the country's national productivity, homeland security and international competitiveness. This will require that possible, non-market, anticompetitive blocking actions by rivals be foreclosed.

Advanced Fiber Networks (AFNs)

In this decade AFN is a leading candidate for the best available technology for rapid broadband deployment. Individually each of its underlying technologies is well proven and understood. Boeing



Source: www.computerworld.com, July 30, 2001

Diagram 1. Boeing owns its own AFN-LAN (Chicago) and AFN-MANs (Seattle, St. Louis) that connect multiple LANs to the Legacy Network at 45, 155, and 155 Mbps, respectively as shown in Diagram 1, is now able to deploy for its own use local area networks (LANs) [and metropolitan area networks (MANs) that integrate more than one LAN], based on the infrastructure for an AFN.[3] It can do this at a fraction of the cost required for it to access services from an infrastructure of similar capability if that capability was provided as a service through networks owned by legacy telecom firms. This is because AFNs employ Ethernet and fiber technologies in ways that together represent a fundamental shift: increasing the capabilities, lowering the costs and facilitating the deployability of the telecommunications infrastructure. Although these new combinations are in their youth, even today they allow end-users to carry out for themselves, in addition to functions of the past, many functions not previously possible.

The AFNs illustrate the new paradigm of user-owned infrastructure: infrastructure that is owned/controlled as assets of individual entities (such as Boeing), or groups of end-users (see below). Organizations with campus-like facilities, including private sector firms, schools, government agencies, and municipalities, are adopting this new paradigm. They are taking control of their telecommunications infrastructures as assets that they own/control (thus the growing use of the term "asset-based" telecom). This trend is gaining momentum and spreading to a wider market as customer equipment becomes less costly, easier to install and use, and more fully-featured.

The Incumbents vs. User Owned/Controlled AFNs

Today, the telecommunications paradigm involves incumbent local exchange carriers (ILECs) using voice-centric, circuit-switched, narrowband infrastructures, or the cable modem suppliers using TV-centric, broadcast-oriented infrastructures, to provide connectivity services to end-users along with selected content, applications, and services (CAS).[4] The legacy infrastructures are copper (or copper with fiber), and as noted, are circuit-switched or broadcast-based. Each is in a late stage of its lifecycle. The ILECs and cable-modem network operators (i.e., cable television companies) each own the respective infrastructures through which they supply connectivity as well as their respective selections of CAS for use by end-users. These suppliers have yet to demonstrate their ability to provision data, voice, and video economically through a single connector, much less to represent a venue for open, competitive provisioning of CAS.

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[3] We use Boeing to illustrate this rapidly growing networking approach of this class of network owner-users.

[4] A CAS provider is an entity that provides Content (including content created by individuals), Applications (including teleconferencing, advanced telecommuting, individualized distance learning, and server-based remote applications), and/or Services (including information services, communications services, and access to information services [sometimes called ISPs, or Internet Service Providers]).

In contrast, a user-owned AFN infrastructure permits end-users to access the converged provisioning of data, voice, and video through a single physical network connection. It also presents an opportunity for end-users to choose among open, competitive offerings of CAS from multiple suppliers based on "competition on the merits" of those CAS offerings.

In the US the greatest capacities of today's most advanced copper-based residential DSL services are tens of megabits per second with asymmetric bandwidth (greater downstream than upstream). Cable network-based data services are also provisioned with asymmetric bandwidth. Yet both are plagued with practical performance problems. DSL speeds degrade considerably with increasing distance and cannot function at more than about 15 kilo-feet due to signal loss and external interference, especially from nearby T-1 circuits. Coaxial cable is shielded from most external interference, but still cannot be used over large distances; in addition, it inherently does not scale easily to large numbers of users because it is a shared communication medium and therefore is prone to congestion.

Table1. Summary Comparison of Network Characteristics

	Network		
Characteristics	**ILECs**	**Cable TV HFC with Cable Modem**	**AFNs**
Focused on	Voice	Video	Converged Media
Method of providing data services	Asymmetric DSL (ATM over point-to-point digital circuit) or dial-up (FSK on voice channel)	Asymmetric Ethernet over cable modem	Symmetric Direct Ethernet (native)
Switched	by circuit	broadcast	by packet
Bandwidth	narrowband (voice)	broadband (RF to 1 GHz)	Broadband (>1 Gbps capability)
Principal market for data services	Business	Residence	Emerging
Predominant Medium	narrow-gauge copper	coaxial cable	Fiber
Predominant Backbone	64 kbps PCM[5] multiplexed carrier on fiber and copper	QAM (OFDM)[6] carriers on Fiber	Ethernet/IP over fiber

[5] Pulse code modulation (PCM) is the technology used to digitize voice and transmit synchronous Time-Division-Multiplexed (TDM) streams. This is standardized as ITU-T G.711.

[6] Quadrature amplitude modulation (QAM) and Orthogonal Frequency Division Multiplexing (OFDM) are the approaches used by the cable industry in most of the world to impress digital video signals on cable TV Networks for distribution to customers.

Empirically, users often observe the speed of these services to be between one and two orders of magnitude less than the "peak" or even "advertised" performance .

In stark contrast, fiber infrastructure is well suited for gigabit broadband and beyond. Inexpensive laser equipment can already transmit 10 Gigabits per second on each available wavelength of a single fiber (i.e., two orders of magnitude higher on each wavelength than the current capacity of DSL or cable modem). The signal fidelity of fiber is unsurpassed, allowing transmission over tens, even a hundred miles without regeneration. A summary of comparisons is presented in Table 1.

Asset-Based Telecom Continues a Trend

Bill St. Arnaud (a lead technologist of the CANARIE Group, Canada) was one of the earliest to recognize the significance of the paradigm shift introduced by the AFN technology. He likens it to the transformation that has already taken place with computer systems that are currently owned and operated by their end-users (that is, they have long been "asset-based") and constitute a global user-owned infrastructure. Every user of a standard desktop computer today is performing the functions previously known only to, and carried out only by, an elite and centralized corps of systems programmers working with mainframe computers. Improvements in technology, cost, and ease of operation are fueling the analogous trend to user-ownership and user-operation of telecom.

Some Imperatives

Two characteristics inherent in networks, including AFNs, are: (1) the inevitable susceptibility of a network to natural monopoly status, and (2) the fact that the network can be implemented in such a way that the marginal cost of its use can approach zero.[7] These factors are of fundamental importance to an analysis of deployment approaches appropriate to an AFN.

In order to achieve the benefits potentially available from the AFN, the ownership incentive structure for the network must simultaneously:

- Neutralize the potential for a natural monopoly to become manifest in the network and to be exploited.

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[7] This is a key characteristic of what economists call a "public good." Such goods (e.g., information, national defense, or pollution) are nondepletable -- they are not depleted by use -- and nonexcludable -- if made available to one, are available simultaneously to all, and therefore cost society nothing to provide for a next user; i.e., they have a marginal cost of zero. AFNs present two apparently incompatible characteristics: that of a natural monopoly along with that of an economic public good. This complexity helps explain the industry's difficulty; first, in understanding, second, in accounting for, and finally, in deploying such Networks.

- Enable the "economic public good" character of the network by ensuring that the marginal cost of its use is driven to approximately zero, and the price of such use is set to marginal cost.

These two objectives can be achieved by invoking a simple approach for AFN deployment: "Only Too Much Is Enough." While this approach may at first appear enigmatic, it is both powerful and necessary, as we establish below (see section entitled "Driving the Marginal Cost of AFN to Approximate Zero").

Neutralizing the Natural Monopoly

Depending on who owns various elements of the network infrastructure and the scarcity of some of its key resources (such as fibers, conduits, rights of way, and easy connectors), the natural monopoly may eventuate at different physical locations in that infrastructure. The AFN requires only one connector per user, and that connector could be the locus of a natural monopoly. We note, however, that the emerging AFN telecommunications paradigm permits the end-user, itself, to own/control the network, as described previously. Alternatively, as we see below in an illustrative 4-Way Ownership Baseline Example ("**Baseline Example**"[8]), the end-user can at least own/control its own connectivity to the network. This ownership/control forecloses the connector from becoming a possible point of monopolistic exploitation; one does not exploit oneself.

However, when foreclosed at one location, the natural monopoly may well re-emerge at another. Note that as with Boeing in Diagram 1 (an example of asset-based telecom), the end-user builds, owns, and uses an infrastructure for itself. Because it controls the infrastructure, it therefore directly controls and blocks the natural monopoly, not just at the connection point, but wherever it might eventuate. Under full ownership conditions (A-1, -2, and –3, below), generally the same situation exists. A single entity owns/controls, for its own use, the infrastructure of the network that it uses; it can directly neutralize the potential for exploitation.

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[8] A detailed discussion of an illustrative **Baseline Example** that can be invoked is included in Appendix A for those instances in which a given end-user entity, for whatever reason, is not of sufficient capability effectively to own or control the network infrastructure for itself for its own use. Where an entity does have the capability to own/control an AFN for itself for its own use, it is very likely to do so. Where it does not have the capability, it can join with other entities jointly to avail themselves of the benefits of an AFN. The interested reader may skip forward to preview Appendix A, or await its discussion where it is presented in context.

Do-It-Yourself, for Yourself

Own-it-yourself and do-it-yourself telecom comes in many "flavors." Below we discuss five somewhat different approaches. The approach that is in the hands of large public and private organizations today, approach A-1, involves the creation of a private Ethernet network over fiber infrastructure; this solution is capable of gigabit speeds and is owned/controlled by a single entity, such as the corporate example previously discussed. The various other models or approaches (A-2, A-3, B-4 and B-5 below) sequentially include more and more players and increasing complexity of ownership.

The direct approaches (A1-A3) to ownership of the network infrastructure by the end-user for its own use are:

A-1. You as a single entity build it, own it, and use it: initially as an AFN Local Area network (LAN); then perhaps more than one AFN-LAN (Figure 1 for Boeing shows three groups of LANs); then with LANs integrated into a virtual (or real) AFN Metropolitan Area Network (MAN, and even an AFN Regional Area Network (RAN). (Examples at different stages include: The Boeing Company, Dow Chemical, most Canadian universities, University of Western Missouri, Case Western Reserve University, Charles Schwab Corporation, and Oracle Corporation.)

A-2. Jointly build the network as a "condominium;" own/control your portion; operate your own AFN-LAN, but as part of an AFN-MAN -- the "Condominium Network." (See examples http://www.canarie.ca/canet4/library/customer/frequentlyaskedquestionsaboutdarkfiber.pdf)

A-3. Institutional end-users build-out sequentially or jointly, following the "Institutional Network model"[9] – with each entity controlling its own AFN-LAN, owning its own connection to the AFN-MAN, and successively adding connectivity and LANs of new participants. As participation grows, it evolves into the "Community AFN-MAN" or even "AFN-RAN." (See, http://www.canarie.ca/canet4/library/customer/frequentlyaskedquestionsaboutdarkfiber.pdf and statement from Robert Proulx, of XIT Telecom, Inc. [then-IMS-Experts] reporting to our Workshop on build-out in 2001 of 8000 km of AFNs to the schools of the Province of Quebec, alone; See also stories of Provo, Utah and Utopianet, Utah http://worldwidepackets.com/; http://www.utopianet.org/).

[9] Institutional Networks – networks for municipalities, universities/utilities, schools, and hospitals. An alternate sequence of build-out would be – networks for schools, hospitals, universities/utilities, municipalities. Often, as in Quebec, financing for school networks is the most readily available.

Municipalities are active under each of the above approaches as well as those below.

A major analytic break-point occurs with approaches B-4 and B-5, in which none of the direct participants in the AFNs is of sufficient size (or perhaps economic coherence) to own or control the operation of the network it uses, and thus none is able, alone, to obviate its potential for natural monopoly. Nonetheless, for such networks an incentive structure based on a rational separation of ownership elements of the network can still make it possible to neutralize the potential for natural monopoly. An illustrative mechanism of this kind for providing small entities (including small businesses, and even individuals) with access to fiber networks -- e.g., with fiber to the home (FTTH) -- is introduced below and presented in detail in Appendix A. It is this illustrative mechanism that we refer to as a "Baseline Example" to which other approaches to the task of neutralizing the natural monopoly can be compared. It also provides a basis for comparison of characteristics with the networks of the current incumbents (see, for example, the discussion in Appendix A, page 25 below). Municipalities or similar not-for-profit public agencies are likely to be the key agents -- the neutral agents -- required to make it possible for the infrastructure of such AFNs to be deployed effectively as asset-based telecom for end-users under approaches B-4 and B-5.

The "Baseline Example" for AFN relies on different players to own respective elements that together constitute that network. The players are: (1) end-users, (2) CAS providers, (3) a neutral party (as noted, most likely a municipality or municipal authority) and (4) an AFN integrator and network operator. Together these entities represent an integrated, interrelated system with mutually compatible incentives for each respective player. Together they constitute a mechanism for foreclosing the emergence of a natural monopoly in much more complex AFNs.

- B-4. Extend the Community AFN-MAN to medium- and small-size businesses by means such as the Baseline Example (see Appendix A) to permit individual end-users to participate in AFNs over the existing backbone of the Institutional Network organizations. (See prototypes of fiber to small end-users: Grant County, WA; Hudson Valley DataNet in Newburgh, NY; as reported at http://worldwidepackets.com/ and of end-user ownership of connectivity in Provo, Utah as reported by CeriStar, Inc.)
- B-5. Extend the Community AFN-MAN to homes by means such as the Baseline Example to permit individual end-users to participate in AFNs over the Institutional (including municipality) network organizations' backbone as the Community backbone. (Again, see FTTH prototypes in Grant County, WA; Provo, Utah; Palo Alto, CA as reported at

http://worldwidepackets.com/, also http://www.pa-fiber.net and of end-user ownership of connectivity in Provo, Utah as reported by CeriStar, Inc.)

The most difficult approach is approach B-5, that includes Fiber to the Home (FTTH). As noted, the detailed analysis of this approach is presented in Appendix A.

Complementary Broadband Wireless Networks

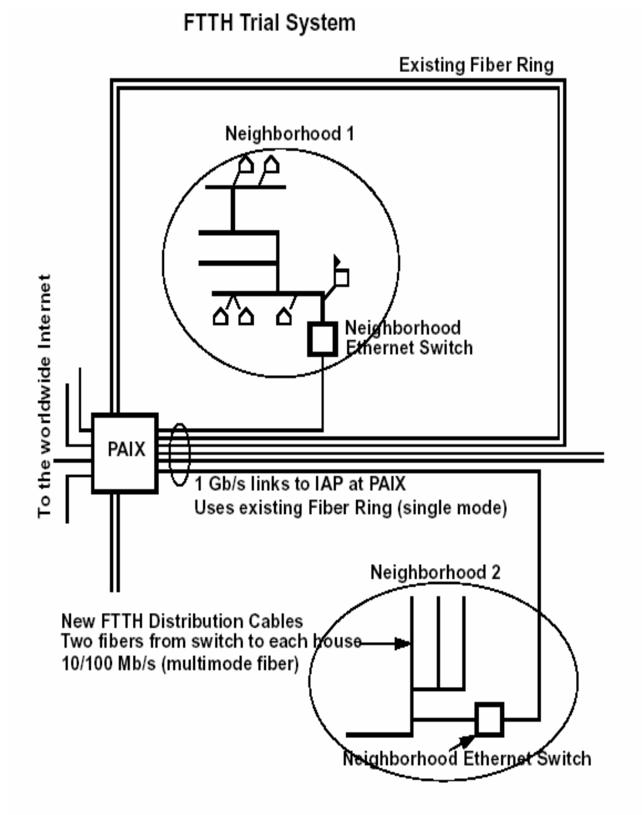
A variety of wireless implementations of broadband access are in operation, and new systems and network configurations continue to be introduced. Existing broadband wireless access (BWA) systems using either millimeter-wave radio or free-space optical (FSO) transmission are both compatible with and complementary to AFN systems. The ability to implement hybrid fiber-wireless networks -- and to select among AFN and BWA systems depending on the specific application requirements -- greatly enhances the deployment versatility of AFN.

There are many user requirements at lower data rates that a variety of wireless systems can satisfy until an upgrade of some sort is needed, wireless or wireline. An example of such can be found at http://www.sopris.net/wirelesscost.html.

The existing BWA applications range from small scale to large scale and from entirely wireless to hybrid fiber-wireless. The subscriber data rates are growing with market demand. While 622 Mbps is the current maximum subscriber data rate, BWA systems with data rates up to 1 Gbps are becoming commercially available. Wireless networks present their own set of design issues and tradeoffs to be resolved in relation to network security, reliability and economics. The decisive criteria in the selection of wireless or hybrid fiber-wireless systems are usually cost and deployment versatility. For an example of "do-it-yourself, for yourself" wireless applications that can interconnect with AFNs, refer to Allegany County Net at: http://prime.allconet.org/allconet2/allconetprop.pdf.

A Recent Deployment

A community entity in Palo Alto, California has established a FTTH trial network that is expected to be made available to the entire community (Diagram 2). This network replaces an HFC cable modem network that the community entity sold to a commercial provider in anticipation of moving to a symmetric, all fiber network to serve the community. The trial network has received strong positive comments from its users. The operators of the network report the "killer app" to be the "rock-solid stability" of the network, a characteristic that contrasts sharply with their experience with the cable modem network. Each neighborhood LAN is served by a Gigabit Ethernet switch currently



Source: www.pa-fiber.net

Diagram 2. Palo Alto FTTH AFN-LAN's & MAN Connect to Internet at 1Gbps

offering 10/100 Mbps (symmetric) to each home. The network connects into the Palo Alto Internet Exchange at Gigabit speeds, as shown in the Diagram 2 schematic.

Note that, since fiber is brought into the house, the potential for significantly greater bandwidth is possible with future upgrade of the network electronics. Even approaches based on the latest copper media that also offer 100Mbps, while being attractive currently, will ultimately be more limited in capability.

Driving the Marginal Cost of Use of an AFN to Approximate Zero

To gain the benefits of AFN use and enable the economic public good aspect of these networks, the marginal cost of their use must approximate zero. As a practical matter, this can be achieved by ensuring that bandwidth is not scarce in the network; in turn, this is ensured by providing "too much" bandwidth, since only too much is "enough" for this purpose. Fortunately, as noted above, AFNs are capable of providing copious amounts of bandwidth and new increments of bandwidth at very low cost.

As documented in the report of Technology Task Group 5 (TTG-5),[10] the AFN is a young network, a work-in-progress. Many of the network management systems techniques developed for legacy systems are not yet available for the AFN. On the other hand, because of its simplicity and high bandwidth, many such tools (other than, e.g., those required to repair breaks in the cable or isolate electronic malfunctions) are not necessary. As the AFN provides "too much" bandwidth for its currently-anticipated purposes, simultaneously it limits, for a large variety of (but not all) applications, the need for Quality-of-Service (QoS) traffic management tools. Certainly, many of the tools used to assure – to for QoS for existing data and voice-applications in legacy networks (whose economics and engineering are predicated on the available bandwidth being constrained) are not necessary for AFNs -- because bandwidth is unconstrained.[11]

Potential for Rapid Deployment

Our analyses, and the experience of current private sector equipment providers, suggest that in four out of the above five approaches to the ownership of asset-based telecom, the costs of that ownership can be justified by the owner-users based on implementation of cost, efficiency and productivity improvements for voice and data (plus in some cases video conferencing -- a form of data transmission) alone. This is true for most, if not all players in the respective groupings during the early build-out of AFNs, implying the potential for rapid build-out of the AFN in most communities. This includes even rural communities throughout the country. In Canada and in some US

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[10] Report of Technology Task Group 5 (TTG-5) "The Advanced Fiber Network (AFN)." http://ieee.johnson.cornell.edu

[11] QoS issues are an important class of problem because they come into play as users begin to employ packet networks to carry legacy-network traffic. A Voice-over-Internet-Protocol (VoIP) "session" is initiated by a setup signal that must be essentially complete and accurate, something that is not automatically generated over an Ethernet network or the public Internet. However, the software for today's VoIP applications mitigates the problems that can arise during call setup and effectively overcomes their impact. In any event, for those applications that might still need QoS, the management tools available are proving to be more dynamic, 'autosensing' and transparent to the user and simpler for the administrator.

communities, build-out has been initiated and is likely to continue to be initiated with the schools; support-funding has been available from multiple sources for broadband connectivity to schools.[12]

It is important to note further that with each sequential iteration of the build-out of the condominium, metropolitan, and community networks, the backbone and network junction infrastructure required for FTTH will gradually come into being. More and more junction points at more and more locations throughout each community will be built and placed into service. The distance between the homes and the nearest junction point in the region will diminish, thus improving the economics for FTTH connectivity. As proximity to the network node increases, costs fall and demand for CAS to the home increases; simultaneously, the likelihood of full-fiber connectivity increases, its costs to connect to the home fall, and its benefits grow as new and enhanced, true-broadband CAS develop.

The Incumbents'/Society's Dilemma – Paradox 1:

Throughout the Workshop, we learned of cost comparisons between deploying AFNs and deploying "Telco Networks," that is, networks based on ATM/SONET technologies and exhibiting the ILEC characteristics described in Table1. The "ballpark" figure is a factor of 8 to 10: the AFNs have costs approximately 1/8th or 1/10th of those of a telco network for similar bandwidth.

Above we stated that for the use of the AFN, a marginal cost that approximates zero is required for efficient operation of the network. This is achieved by providing a plethora of bandwidth -- as contrasted to a scarcity of bandwidth. From the point of view of an organization that fully owns and operates its own infrastructure for telecommunications – as in ownership approaches (A-1), (A-2), and (A-3) above – this is the case. The plethora of bandwidth implies that the efficient price to charge internal users for use of that network can be and should be zero. Such a price is a boon to internal users, especially in contrast to the prices they otherwise would pay to an incumbent supplier of telecom network connectivity. Further, since the capital cost to create the AFN is but a fraction of the cost of provisioning a network with similar bandwidth under the ILEC paradigm, the life cycle costs of the AFN also represent significant savings to the entity that owns the network infrastructure as an asset of the organization.

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[12] See Appendix C. In NY State: SCT BOCES (Schuyler-Chemung-Tioga Board of Cooperative Education Services) "Diffusion Network" through which Verizon provides 1 Gbs connectivity to all schools and district offices in 8 school districts using, in part, Federal "e-rate" funds, NY State funding and in part, Verizon's Diffusion Fund funding. Neighboring BT BOCES (Broome-Tioga BOCES) uses similar funding to provide CWDM – coarse wave division multiplexing -- to deliver 1 - 4 Gbs over its dark fiber and is investigating 8-way WDM for its users. See appendix C and http://ieee.johnson.cornell.edu/cases.html.

These facts also imply that any party attempting to use an AFN to generate revenues from the use of the network for transport services will, in the presence of competition, be unable to do so. Why? Because under competition, price is driven down to marginal cost. This is a stark reality for both the ILECs and cable modem service providers should they contemplate, themselves, deploying AFNs in the future *using their existing business models*. Their existing infrastructures are barely adequate for the marketplace in which they now are attempting to compete; yet, their business models foreclose their adopting the AFN technology that is appropriate to the new telecommunications marketplace. It is unlikely that the incumbent paradigm of telecommunications provisioning can persist over the long term in the new marketplace.

If, on the other hand, the incumbents could be assured by actions of regulators that each would be free of regulation and effective competition in its main geographic region of operation, then each could institute (or activate) in that region the natural monopoly that is inherent in its network. Each would be free to charge a price above marginal cost even for transport services. Each would also be free to select and limit the CAS that it permitted to be available to its captive end-users. It is likely that capital markets would find such conditions attractive for funding. The US telecommunications fiber infrastructure could well be on its way to such entrenched, regional monopoly conditions -- similar to those enjoyed by ILECs in their local copper loops since the beginning of the twentieth century. But this time, the traffic of the regional monopolies would be carried at prices above marginal cost over networks based on AFN technology (rather than their customary networks). This would be true despite the fact that the AFN technology is designed for and is inherently capable of open, competitive provisioning of CAS and transport priced at marginal cost -- with a marginal cost of transport approximating zero.

Paradox 2: The Incumbents Inadvertently Can Help Cost-Justify AFNs

We established above that pricing at marginal cost for use of the AFN makes it virtually impossible for a private sector provider to deploy such a network with the expectation of generating revenues from transport alone sufficient to recover the cost of that deployment. On the other hand, an unintended symbiotic relationship exists between the legacy suppliers of telecommunications services and those who seek to deploy an AFN as an asset that they own/control of their own use. The latter are able to achieve cost savings from payments forgone to the legacy telecom and cable modem providers; that is, they can reprogram funds budgeted for monthly purchases of telecom services from telcos or cable firms, as offsets to the cost of build-out of their AFNs.[13] There are further savings available from user-owned telecom, itself. An example is organizational efficiency from owning/controlling one's own network. This is expressed in part through the gain in flexibility in modifying and extending bandwidth and telecom services within one's own organization and in part through more efficient management and back-up of local servers that can be centralized and centrally administered. User-owned telecommunications infrastructure endows its owner with greater productivity through lower total costs of operation.

AFN Interconnectivity

The genius of the Internet is that it is a "Network of Networks" with distributed intelligence. This contrasts with the legacy networks that have centralized intelligence and a tight hierarchical structure of connectivity. Internet networks are egalitarian and connect with each other and with other networks opportunistically through the lowest cost-connectivity available in their regions.

The AFN is an Internet network. Its technological characteristics are laid out in the early pages of this document. Each AFN can exist as a stand-alone network, transferring its traffic where possible through peering arrangements, and where necessary through transport mechanisms with fees that the carrier strives to minimize.

We saw for Boeing's networks in Diagram 1 that their three networks, the Chicago LAN and the Seattle and St. Louis MANs, each connect idiosyncratically with the others through a national network "cloud." The Chicago headquarters connects at DS-3 (45Mbps), and the Seattle and St. Louis MANs each connect through the "cloud" at OC-3 (155Mbps), although all are limited to DS-3 when connecting to Chicago.

Large players are seeking to be able to interconnect their enterprise gigabit Ethernet LANs and MANs with each other at gigabit speeds. End-users seek long-haul networks or possibly long-haul, single wave lengths or "colors" (lambdas) with capabilities, costs, and efficiency comparable to those of their gigabit Ethernet LANs and MANs. The most efficient way to do this is with AFN-technologies through gigabit RANs (or perhaps through individual lambdas). With the approval of the IEEE 802.3ae, 10 GIG-E (Ethernet) Standard in June 2002, both are beginning to happen.

[13] For example, Robert Proulx of XIT Telecom (then-named IMS-Experts) reported that the roughly 1000 schools in Quebec that were included in the 8000 km AFN build-out to schools in 2001, were able, through such savings, to participate in the network project at negligible incremental cost to their budgets.

The opportunistic character of connectivity for AFNs is further illustrated in the case of the community network of Palo Alto, California (Diagram 2). We note that the Gigabit switch in each neighborhood LAN connects to a fiber ring and that fiber ring provides transport at gigabit speed to the Palo Alto Internet Exchange (PAIX). It is not every community that has the opportunity to provide its internet connectivity at gigabit speeds, as does Palo Alto. Others would be delighted to emulate Palo Alto. Hopefully, in the future, they will be able to do so.

AFNs will proliferate and gradually come to be pervasive throughout the nation. They are likely to interconnect through a growing, evolving "mesh" of interconnectivity, rather than through a fixed, hierarchical structure as do legacy networks.

Backbones

Today backbones of inter-exchange carriers (IECs or IXCs) are already being provisioned as Internet Protocol (IP) networks. At the interfaces of these carriers between 10 Gbps Ethernet customer networks and the carriers' OC-192 Networks, AFNs can smoothly interface to these backbones.

There is a problem, however. IP networks provisioned over fiber also have a marginal cost of use of approximately zero. Competitive networks are positioned such that they are likely to gradually drive the price they can command also to zero – as is already happening with long distance voice in the US. That raises sustainability issues. It also appears likely that the IXCs will be transformed under the new paradigm into owned (perhaps "collectively" owned) asset-based networks, or, as implicit in the models of Canada's CANARIE, they might well be replaced by a mesh of peering relationships among regional area networks (RANs) built-out under a next generation of asset-based AFNs.[14]

The Interim Period

Given that it will be some time before AFNs are built-out to reach all potential end-users, the welfare of our economy and of our nation will be greatly influenced by the manner in which the incumbents interrelate with the adopters of the new paradigm during the interim period.

Deployment of the AFN can be blocked for a time in this country by vigorous anti-competitive actions of the incumbents and for a greater time through political action, but it can not be stopped everywhere throughout the world. Blocking it (or supplanting it with regional monopoly networks,

[14] For a relevant discussion see, The Cook Report on the Internet, "Economics of IXs, Peering and Transit," Volume XI, No. 8, November 2002.

as discussed above) in the US would come only at great cost to US international competitiveness and domestic economic growth.

Clearly it is preferable, during the transition phase, to find ways to facilitate efficient use of the existing infrastructures of telcos and the cable modem suppliers for functions complementary to those of the AFNs. In any case, in the intermediate period, the legacy telco providers constitute a reservoir of telecommunications expertise. At the networks' physical layer, much of this expertise is fully transferable; significant transfer is possible also at other layers. This expertise is likely to be attractive to the entities that are would-be deployers and direct-owner/controllers of AFNs for telecom-platform use internal to their organizations. This is likely to be especially true on operational questions for which experience is likely to be the best – if not the only – teacher.[15]

Cable modem providers have similar expertise that is transferable to the new players through various mechanisms.

Policy Dilemma

There is a dilemma facing policymakers who undertake policies to facilitate more rapid build-out of broadband technologies such as the AFNs. It is an appropriate role for government: (1) to facilitate such a fundamental transformation to a new paradigm for telecommunications. Unfortunately, this simultaneously contributes to the "creative destruction" of the infrastructure deployed under the incumbent paradigm. The dilemma is that a further role for government is: (2) to mitigate a disruption such as that brought about by a fundamental paradigm change of this magnitude.

In any case, the legacy infrastructures will be replaced only gradually and most likely on a spotty region-by-region basis. The transition from the legacy to the AFN-paradigm would require careful, dispassionate, and neutral, but imaginative study. Perhaps such a study would best be carried-out at an international level. Canada appears to have a head-start in thinking through implications of user-owned telecom. Korea, Japan, Sweden, New Zealand, Singapore, the Netherlands, the United States and others could well contribute significantly.

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[15] The focus of the analysis in the current paper is on the creation and implications of the physical AFN with its necessary support structures. There is an additional level of support elements required for the efficient operation, first, of individual AFNs, second, for integration of groups of AFNs in a given region, as well as for inter-regional groups of such Networks. Various operational matters, such as procedures appropriate to recovery from cataclysmic failure of a Network or parts of Networks, heuristics for dealing with demand spikes resulting from external events perceived by the public to require emergency communication, etc. – all are matters that will afflict AFNs, once deployed, just as they afflict legacy Networks today. There is much that is transferable on such issues from the legacy-world to the AFN-world. Mechanisms must be found to facilitate and expedite transfer of knowledge of this kind, a matter we leave for others and for the future.

The fundamental paradigm shift in the provisioning of telecom today is well underway. Unfortunately, however, this fact appears not yet to have been fully recognized at policy levels in the US. Given the rapid pace of deployment under the AFN-paradigm elsewhere throughout the world, the United States could find itself in a precarious situation if no action is taken.

Governments and regulatory bodies at every level in the U.S. must recognize that the national telecommunications infrastructure is of vital national security, strategic and competitive importance, especially to Homeland Security. The competitive health and security of the nation requires attention and follow-through by Policy Makers at the highest levels of government, industry and the public. One important role for policy makers is that of enforcer of the rules of the game. Policy Makers must ensure that law enforcement and regulatory agencies strictly enforce existing prohibitions of predatory and anti-competitive practices by incumbent players, or by national, state or local agencies, or by regulatory bodies, at any level of national or state government, to ensure that the new technology can be deployed with a timing and scale based "on its merits."

Rebooting the High-Tech Revolution

We are poised at the brink of a vast economic and technological opportunity. Implementing the fundamental paradigm shift will require huge investments in telecom infrastructure, equipment, and expertise, the vast bulk of which must be purchased from the private sector. We must also recognize that from the suppliers' side, the process of building-out broadband AFNs by direct owners (as well as under the Baseline Example [or equivalent] separation-of-ownership approach) implies an enormous demand-potential for the goods and services produced by the private sector. Significant portions of that demand will both require the expertise of the legacy players, and will compete in the market for it.

Conclusions

AFNs represent vital infrastructure for enhancing the productivity of the US economy on multiple dimensions.[16] They are likely to provide the foundation for Homeland Security's Emergency First Responder Networks, databases and deep analyses. Large entities can initiate, build-out and operate (or out-source) their own asset-based telecom. Groups of sophisticated entities can jointly build out condominium infrastructure with each member owning and operating (or out-sourcing) its own

[16] Many Broadband Wireless Access (BWA) systems are compatible with AFN systems; they are often complementary to AFN systems and in particular applications, preferred to them; in others, they are interchangeable with them in portions of hybrid AFN-BWA deployments.

LAN(s) and MAN(s) after the build-out. Institutional entities can build-out their networks either as condominia or individually, and own/control and operate (or out-source) their own LAN(s) and MAN(s) after the build-out.

But an important focus must also be on reaching small and medium-sized businesses, more-rural communities and other areas with populations potentially to be left on the wrong side of the "Digital Divide" that could rapidly grow into a "Digital Chasm." For such players the Baseline Example (or an equivalent) model of AFN deployment can and must play a role.

Within that model, the role of the neutral agent, charged with neutralizing the potentials for natural monopoly by ensuring that competition reigns throughout the AFN, is vital. It is the key to accelerating widespread deployment of AFN broadband networks to all corners of the country.

We as a nation must seek to accelerate the deployment of AFNs wherever possible so as to benefit from both their direct and indirect effects. These benefits accrue through the open, competitively accessible attributes of AFNs. But as just noted, benefits can and must also reach the "far side" of the Digital Divide. AFNs must, e.g., be available to the SOHO (small office, home office), medium-scale businesses, plus rural and underserved areas in general. This can be achieved through use of the Baseline Example, or a similar approach (Appendix A), to ensure that CAS are provided under competitive conditions to end-users in every "tier" (density region); and further that pricing for use of the AFN is consistent with that of an economic public good.

The role of the neutral player is the vital element required for extending and "democratizing" the impact of AFNs. To ensure that these networks can be deployed, the Federal government in particular must provide support structures for the neutral Player (the municipality, municipal authority or similar not for profit agency continually open to public scrutiny), as provisioner of the support structures vital to these functions of the AFN.

Accordingly, we join the IEEE-USA in recommending:

1. **Policymakers must ensure that Ethernet networks over fiber infrastructures capable of gigabit speeds complemented by broadband wireless technologies, be fully considered and fairly evaluated for a prominent role in accelerating advanced broadband deployment in the U.S.**

2. **Government policies at the Federal Communications Commission, Department of Justice, and Federal Trade Commission, as well as at state and local regulatory and**

enforcement agencies throughout the U.S, must be established, and actions must be taken to ensure that Ethernet networks over fiber infrastructures capable of gigabit speeds, together with complementary broadband wireless networks, are given a fair marketplace opportunity to prove themselves on their merits as contributors to enhancing the country's national productivity, homeland security and international competitiveness. This will require that possible, non-market, anticompetitive blocking actions by rivals be foreclosed.

Appendix A: A 4-Way Ownership Baseline Example ("Baseline Example")

This appendix presents a **Baseline Example**, or model, is likely to be required in rural areas and other situations in which it is necessary to reach what would otherwise represent the "far side of the Digital Divide" with AFNs. [Again note, however that this is the case only where the entity (or group of entities) that seek(s) to benefit from an AFN is (are) not of such scale as to own/control the AFN for its (their) own use.

To benefit from use of an AFN, such entities including small organizations, small businesses, individuals, groups of individuals can come together to create a shared ownership structure that provides incentives mirroring those available to end-users of an individual entity that owns/controls a network for its own use. In the Baseline Example:

1. The end-user owns (or long-term leases)/controls its own fiber connectivity to the Network.
2. The content, application, and service providers (CAS providers) competitively provision the respective offerings that each owns, markets, and provides to end-users for selection by the end-user.
3. A "neutral" player owns, controls, and deploys support structures (e.g., rights-of-way, conduit, poles, etc.) proactively and in a timely fashion so as to create and enforce competitive conditions and thus neutralize the potential for the emergence of a natural monopoly.
4. A fourth party integrates and operates the infrastructure of the AFN(s) as a LAN, or LANs plus MAN, within the structure, incentives and the constraints enforced within the Baseline Example by the neutral player.

As noted in the Baseline Example analysis, outlined in Figure A-1 below and illustrated in Figures A-2 and A-3, the end-user owns and controls its own fiber connectivity to the network at a network junction point ("Junction"). The CAS providers competitively provision their wares to groups of end-users (EUs) through such Junctions. It is not in the self interest of either of these players to use its connectivity to the network as a choke-point. It is in the interest of the EUs -- and of society -- to have CAS provisioned competitively at the Junctions so that the EUs can select among the CAS offerings based on the merits of each respective offering.

The structure of the Baseline Example further relies on minimizing the potential natural monopoly element by localizing it to the network support structures in the particular geographic location in question. Further, it then requires a neutral player to own, control, and proactively provision the support structures on a timely basis; this will guarantee avenues for rapid, easy entry of a new player or players to the market (Junction) in question. That is, as long as conditions for easy, swift entry can be guaranteed by neutral Player 3 for the Junction-marketplaces at which the end-users meet with CAS providers (see FigureA-2), then competitive conditions will prevail at the Junctions; the ability of new players to avail themselves of rapid, easy entry guarantees that competition will prevail in those "markets." In this way the neutral player must and does act to neutralize the potential for natural monopoly at the Junctions.

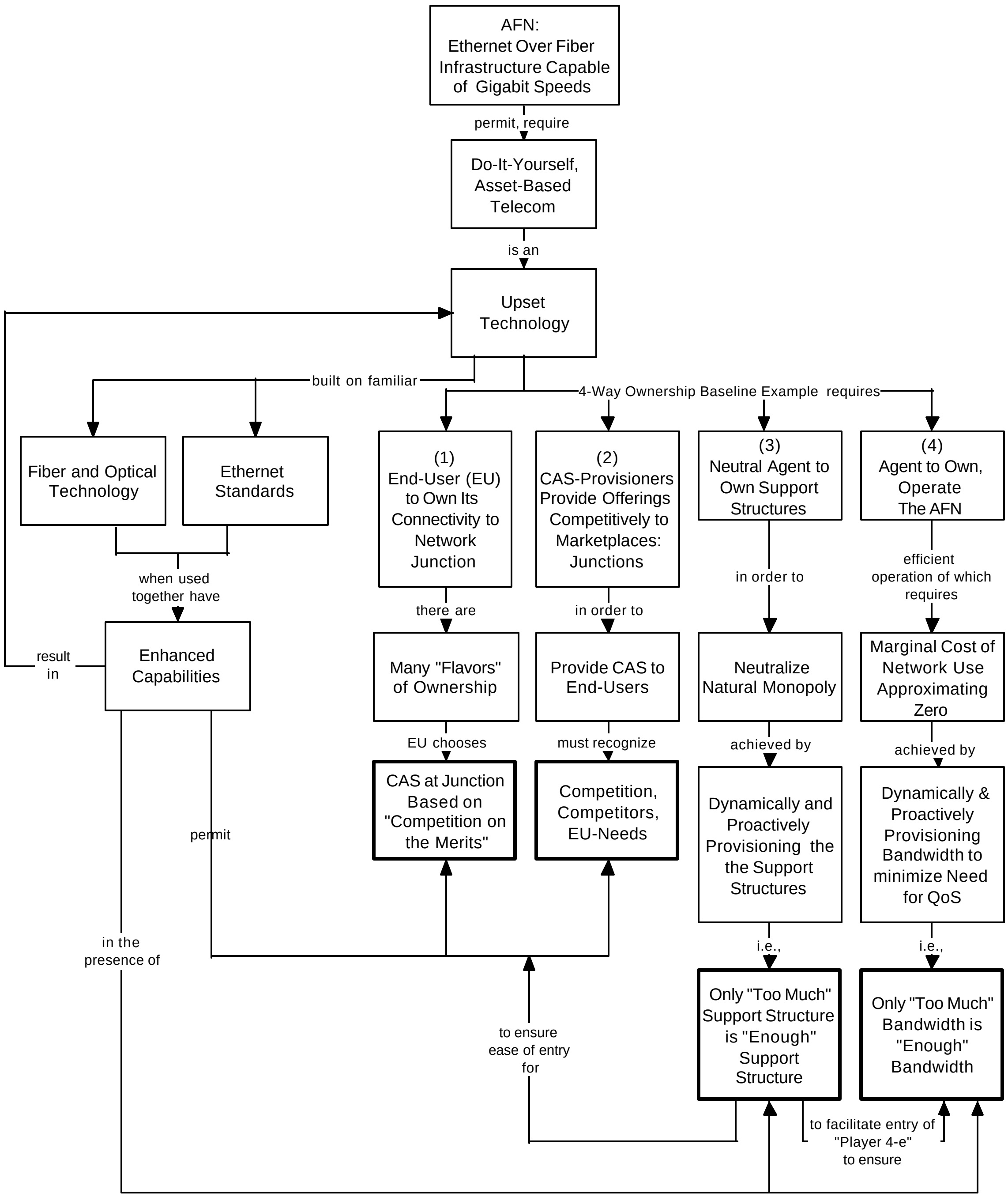
As illustrated by comparing Figures A-2 and A-3, the Baseline Example creates strong market incentives to attract a "Player 4." This player will provision an AFN as a LAN, or LANs plus a MAN. Player 4 will deploy as components of its AFN infrastructure, particular Junction Point/s called "Optimal Interconnect Point(s)" (OIPs). It does this to make it possible for each CAS provider to be able to reach all of the "junction-markets" (each identified in the Figures as "Junction") and thus all end-users in a given region. CAS suppliers can originate anywhere as long as each finds a way to reach an OIP of the AFN in question. Note also that an end-user (EU) of the given AFN can itself choose to be a CAS supplier and still reach all other EUs.

It is also the role of neutral Player 3 to ensure that "enough" support structures are provisioned at the time of the build-out of Player 4's infrastructure. It does this to permit an overbuild of Player 4's AFN, should that become necessary. The ability of a new player to avail itself of rapid, easy entry against Player 4 guarantees that competition will prevail in relation to Player 4. Should Player 4 attempt to use its AFN in such a way as to gain monopoly (i.e., excessive) returns, then such behavior would trigger the entry of a competitive AFN entrant (a Player 4-e) to displace Player 4 and dissipate those excess returns. This entry would be effectively subsidized by the support structures pre-positioned by Player 3. This market, as well, then becomes a "contested market."

These observations also carry with them the implication that if Player 4 limits its returns to normal returns, then it *can* protect itself from such entry. The fact that Player 4 *can* protect itself from competitive entry by a "4-e" Player implies that Player 4 can earn a normal return under the explicit competitive conditions of the Baseline Example.

To reiterate, the guarantee of "too much support structure" (ensured by Player 3) will successfully neutralize the potential for natural monopoly at the two points where it is most likely to eventuate

Figure A-1: The 4-Way Ownership Baseline Example (Baseline Example): For Situations Where a Given End-user Cannot Alone Own/Control AFN for Its Own Use.



under this reference structure (at the network Junction points at which EUs select among CAS options and at the site of deployment of the AFN itself), while the presence of "too much bandwidth," required for efficient performance of an AFN provisioned by its owner (Player 4), will guarantee that the marginal cost of use of the AFN approximates zero.[17] That is, this network will function in accord with its potential, if and only if, "too much" (in the way of both support structures and bandwidth) is present and proactively maintained as "enough" to ensure competitive outcomes throughout.

What a Baseline Example Is and Is Not

The reader must be aware that the illustrative Baseline Example is intended as "a model." It is a particular manifestation of how an AFN can be deployed to achieve the consensus goals sought by Workshop participants when a given entity seeks the benefits of an AFN, but it alone does not have the resources to own/control an AFN for its own use. Of particular importance in the creation of this Baseline Example has been the ability of this ownership structure to isolate the natural monopoly element to a minimal representation such that the technological expertise required of the neutral agent will be clearly within the technological capability of a municipality or similar not-for-profit agent to provide. A second objective has been to limit the ownership requirement for the end-user to the minimum necessary to permit it to foreclose the potential for monopoly power to be used against it at its connection point – at least within the incentive structure of the elements of this Baseline Example.

The incentive structure implicit in the illustrative Baseline Example is mutually supportive. The outcomes of the model are robust. Nonetheless, in no way is it intended to imply that only through this model, in precisely this form, can such outcomes be achieved. The model is *sufficient* to bring about these outcomes. We do not claim that these precise characteristics are *necessary* to achieve these outcomes. Given the mutually supportive structure of incentives in the model, however, if a different approach is used, it must provide its own coherent incentive structure to eliminate or neutralize possible monopoly choke points, invoke the network's public good aspects and ensure that CAS are and continue to be, offered competitively.

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[17] As developed in the analysis above, this is an absolute requirement for efficient operation of the AFN, that implies that any revenues gained by Player 4 must come from a source other than a price calibrated to use of the Network, e.g., from hook-up fees, perhaps, rather than fees calibrated to transport over the AFN.

Illustrative Representations of the Concepts Discussed in the Text

Figure A-2: Raw Network Connecting CAS-Providers with End-Users at Junctions

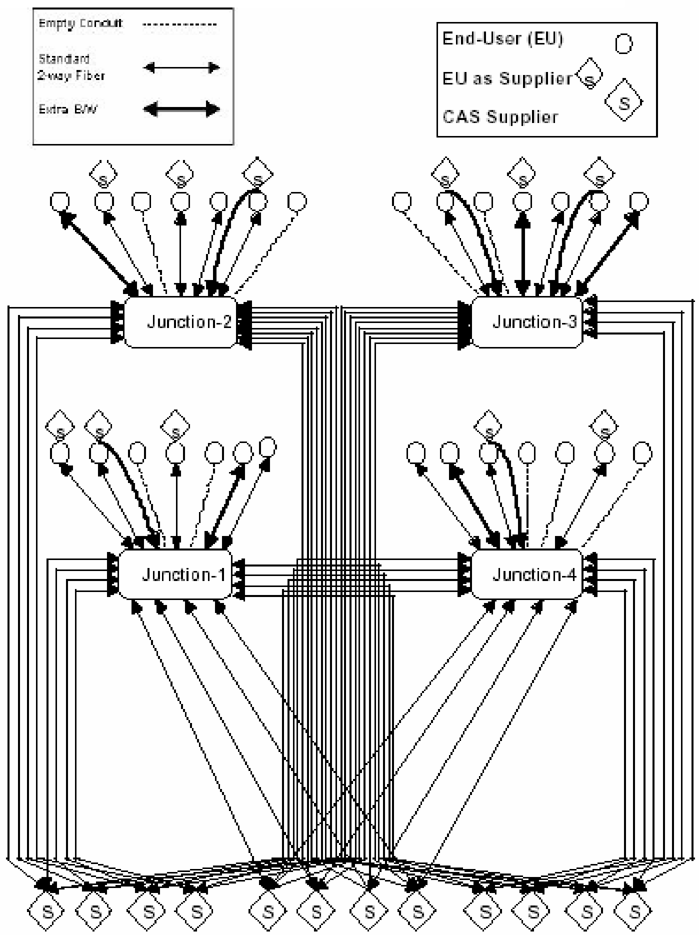
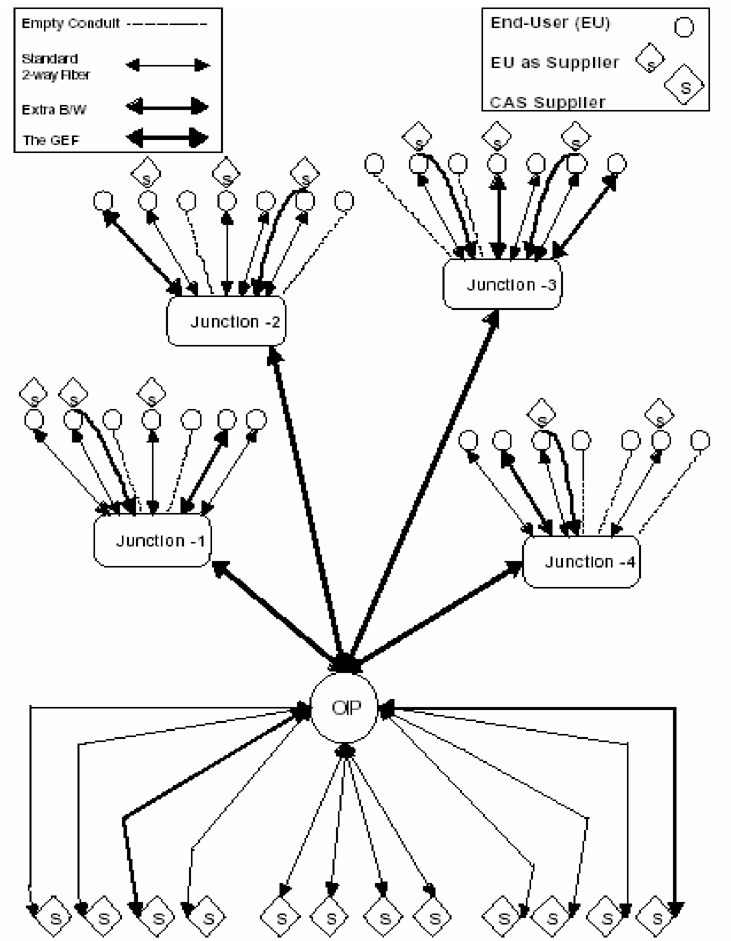


Figure A-3: AFN 4-Way Ownership Baseline Example



Note: A CAS Supplier can originate anywhere as long as it finds a way to reach the junction points of Figure A-2 or an OIP as in Figure A-3. Note also that as indicated here, an end-user may be a CAS Supplier.

As an example of the power of the illustrative Baseline Example, if we compare the incumbent ILEC network with the illustrative Baseline, we see: in the context of this analysis, the incumbents' paradigm can be characterized as an approach requiring "too little" bandwidth. A scarcity of bandwidth makes it possible for the incumbent to charge prices above marginal cost. Further it requires the incumbent to use complex and costly QoS hardware and software to try to get "too much" CAS through the "too little" bandwidth. In turn, this requires and permits complex pricing models that must be (and are) used for allocation of the too-little bandwidth. This combination of factors results in extraordinarily-high prices to "captive" end users -- users that have few options as to CAS that are provided under the monopoly (or at best, oligopoly) conditions of the offerings from Incumbents.

Appendix B: Evolution of Ethernet

Figure B-1 illustrates the evolution of Ethernet from half-duplex, shared media operation, to full duplex Ethernet bridge/switch architectures, which are collision free. The original Ethernet (1985) is shown on the top, which is a bus topology and a shared coaxial cable medium. The coaxial bus is a collision domain that needs CSMA/CD to resolve collisions. The speed of the first Ethernet was 10 Mbps and used thick coaxial cable; this system is designated type 10BASE5 (10 refers to the speed 10 Mbps, BASE refers to baseband medium and 5 refers to a 500 meter maximum segment length). A thin coaxial cable was used later, and that system is designated type 10BASE2.

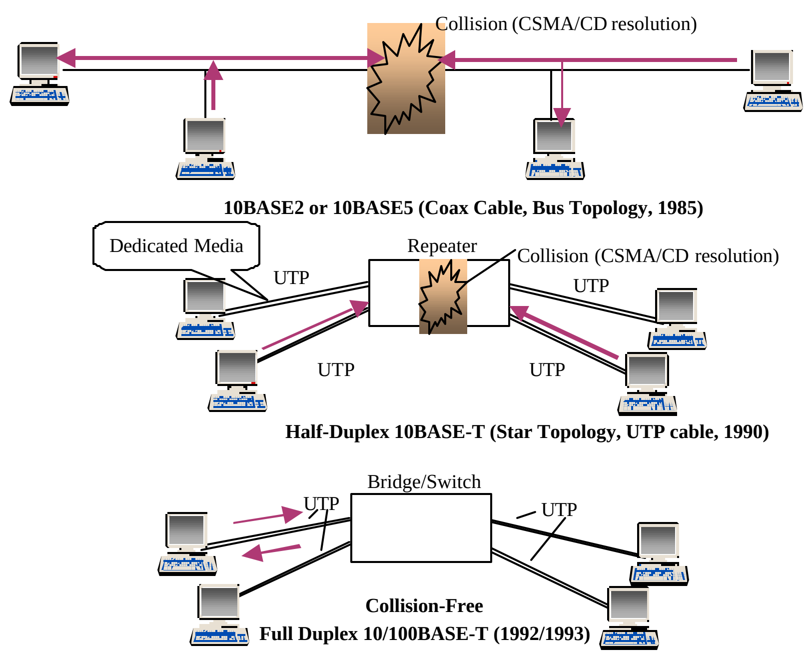


Figure B-1. Evolution of Ethernet Architecture

The next step in topology evolution (1990) was to use a hub (star) topology using Ethernet repeaters at the hub. Along with this development came the use of Unshielded Twisted Pair (UTP) cable for the medium, and the system is designated type 10BASE-T (it was still 10 Mbps baseband and T refers to twisted pair). This configuration had the advantage that UTP is widely used in office buildings, and a fault in any cable would not take the whole LAN down like a coax cable cut would in the bus topology. The repeater is a layer 1 device that would simply take bits off the incoming port and pipeline them to all outgoing ports except the port the bits were coming from. Thus, even if the UTP pairs were set up so there was a pair for each direction of transmission (duplex), the repeater would itself continue to be a collision domain. Thus CSMA/CD was still required.

The next step was to run full-duplex UTP links between the host and the hub, and at the hub is a LAN bridge. The bridge is a frame store-and-forward device, so it would buffer incoming frames and wait until the outgoing ports were free to transmit them. Thus, with this development it was possible to avoid collisions and CSMA/CD would not be required. This was first implemented at 10 Mbps (1992) and a year later 100 Mbps Ethernet (100BASE-T) was available. Note that an Ethernet switch is an Ethernet bridge with more than two ports.

It is this full-duplex switched/bridged Ethernet topology that is the critical development that makes Ethernet capable of evolving from a LAN technology to an enterprise and carrier networking technology. First of all, with the elimination of the collision domain in the hub node (i.e., the switch/bridge), the speed of the switch-to-switch trunks become independent of the NIC speeds on the LAN hosts. Secondly, the use of full-duplex trunks between switches allows efficient bandwidth usage and eliminates CSMA/CD length limitations on trunks between Ethernet bridge/switches. The standard for GbE allows for half-duplex links, but they have never been implemented. 10GbE does not allow half-duplex links. Therefore, for all practical aspects, GbE and 10GbE networks can be considered as collision-free topologies that are based on Ethernet bridging and switching. There is no CSMA/CD in these networks. There may be LANs terminating on an Ethernet switch that is a collision domain, and CSMA/CD would be used on those switch ports to interact with the LAN. But switch-to-switch GbE links are full duplex, and there is no CSMA/CD in the switch-to-switch trunking part of the network.

Source: Excerpted from TTG-5, IEEE-USA Workshop
http://ieee.johnson.cornell.edu/index.html

Appendix C: Case Studies

Case Study I: SCT-BOCES – Current Site of a Gigabit Ethernet over Fiber (AFN) Network

The Schulyer, Chemung and Tioga Board of Cooperative Education Services (SCT-BOCES) has a fully functional Gigabit Ethernet network in place, which covers counties, serving 8 school districts, 49 schools, and a total of approximately 80 buildings. This network is supplied as a service by Verizon under special funding known as the Diffusion Fund. The Diffusion Fund was created as a requirement of the New York State Public Service Commission (PSC) under conditions established through a court order. The network is known as the "Diffusion GIGE."

This GIGE network provides the service of gigabit connectivity to every school in each school district and to several other locations. The network is organized as a series of Local Area Nets (LANs) running over IP and Ethernet, serving particular groupings of schools plus the campus of SCT BOCES itself (that has its own pre-existing LAN). In turn, these LANs are interconnected into a Metropolitan Area Network (MAN) connecting the LANs, also at gigabit speeds, in a very "flat" topology. A physically distinct Gigabit LAN serves a local hospital and another serves the Chemung County government. The Diffusion GIGE contract was recently extended from 5 years to 7 years. The contracts for gigabit service to all three entities were negotiated with Verizon as part of the same agreement. Verizon built, owns, and manages the GIGE network and its ancillary networks.

While communication among participating entities within the Diffusion GIGE network is at gigabit speeds, the entities in the GIGE network also connect to a separate OC-3 (155 Mbps) Metropolitan Area Network (MAN) linking Verizon central offices (COs) in Corning, Elmira, and Horseheads plus the SCT BOCES Headquarters identified as "Building 4." The Diffusion GIGE Network has access to the Internet also through an OC-3 connector to the Internet at Building 4.

This configuration of networks fits a growing pattern. Organizations and their constituent elements are interconnected through LAN's at gigabit speeds. The LAN's may also be interconnected into a MAN, again at gigabit speeds, but more often the MAN service available from the legacy ILEC is at significantly lesser speed, as here, at OC-3. Connectors from this and similar MANs to legacy backbone facilities and to the Internet take place at OC-3 speeds.

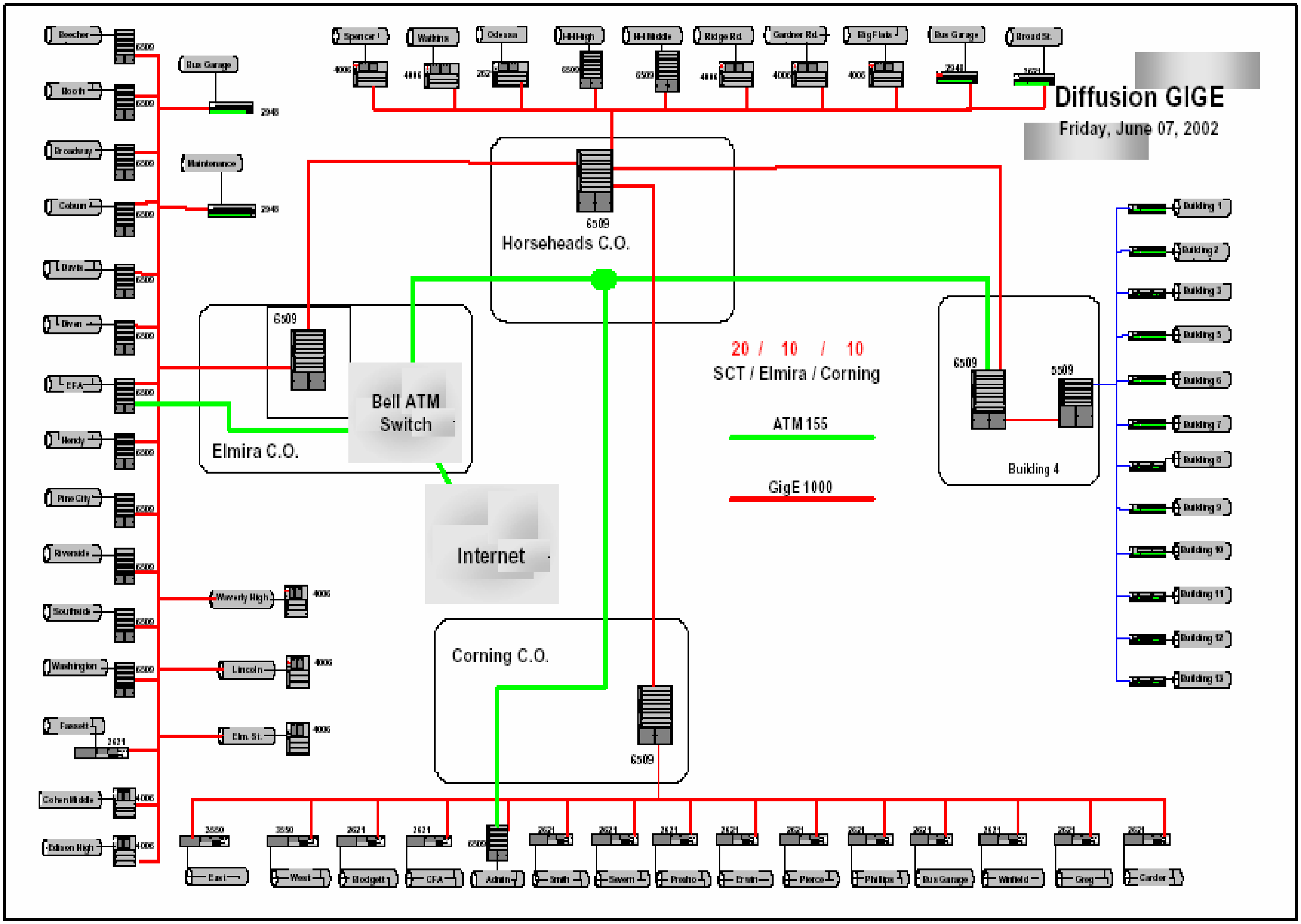
The SCT-BOCES and its constituent school districts are in the early stages of exploring the capabilities and uses for the GIGE Diffusion Network. They have the opportunity to develop and deploy innovative services and to make other innovative uses of this high capacity facility.

For example, the Elmira School District is preparing to substitute VoIP through the GIGE network for its current STAR topology of T-1, POTS leased-lines connecting its headquarters to each of the schools in its district. It expects to retain its POTS, OC3 connection to the Verizon ATM switch and cloud, at the Elmira CO.

As a "bonus item" in its contract with Verizon, SCT BOCES has negotiated access -- without time or distance charges -- to any and all NYS facilities reachable through the Verizon ATM switch (that integrates the OC3 Man in the region) located in the Elmira CO. This opens the possibility of substantial sharing of distance learning material among many NYS school districts.

Funding Issues

For a BOCES or school district or library to be eligible to receive funds through the federal government's Universal Access Fund ("e-rate" funding) it must contract for telecom services from an authorized service supplier e.g., in this case, Verizon. In turn, the service supplier must be certified and provide proof of certification: what is called a "Spin Number." The user of service must apply annually and be granted partial reimbursement for those services; the particular e-rate discount is calibrated to the proportion of students in the district or other jurisdiction that are eligible for the subsidized school lunch program. For districts served by SCT BOCES the e-rate ranges from 60%-75%. In New York state schools and libraries are eligible, through their local BOCES, for a state subsidy for telecommunication services at a percentage of the monthly fee, net of the e-rate subsidy, payable by the entity to its service supplier.



Diffusion GIGE
Friday, June 07, 2002
Horseheads C.O.
Elmira C.O.
Bell ATM Switch
Internet
Corning C.O.
Building 4
20 / 10 / 10
SCT / Elmira / Corning
ATM 155
GigE 1000

Case Study II: Broome-Tioga BOCES (BTB) and its AFN-MAN Supporting District School LANs

The Broome-Tioga BOCES (BTB) telecommunication infrastructure serves 40 school districts in the Southern Tier region of New York State. Many of these school districts are connected to the regional network via traditional T1 or Fractional T1 data circuits utilizing point-to-point, frame relay or ATM technologies. Eleven of these districts are connected to the BTB data center with two strands of dark fiber. These connections form the BTB fiber Metropolitan Area Network (MAN). These dark fiber links are leased from private carriers and are controlled by BTB, who is responsible for attaching the telecommunications equipment necessary to "light" the fiber and make voice, video and data transmission possible. BTB also supports the individual school districts' LAN and WAN connectivity back to the regional network.

The most intriguing characteristic of the Broome-Tioga infrastructure is its control of the dark fiber. BTB has the power to increase the bandwidth on the fiber MAN made available to a school district merely by introducing more powerful electronics on the fiber. BTB has been running wave division multiplexing (WDM) on the fiber links for over five years. One wavelength of 45mbps has been running to support a full motion, 30 frames per second, distance learning system and the other wavelength of 10/100 mbps has been running to support traditional data applications and Internet access. BTB has just bid for equipment to run WDM on the fiber at gigabit speeds. Districts on the fiber MAN will be implementing this technology during the 2002-2003 school year. The regional MAN infrastructure uses high speed routing and switching technologies, and connects into the ILEC and to the Internet through a fractional T3 (34Mbps).

The regional telecommunication infrastructure supports access to the World Wide Web for instructional resources, as well as administrative and instructional services at the Broome-Tioga BOCES through resources that are shared among school districts. Broome-Tioga BOCES' objective is to provide both administrative services (e.g., on-line payroll; accounts payable; student scheduling, report card, attendance information) as well as to support instruction on local area networks within the BOCES' districts. The MAN infrastructure will also be used for distance learning, streaming video, video from the Internet as well as video on demand. However, the most pressing, immediate need for higher bandwidths comes from the changeover from traditional text-based applications and management systems to graphical, including video, approaches in both interface and content.

Some Districts in the region are also running leased fiber links between buildings at Gigabit speeds. These district MANs are utilizing IP/Ethernet protocols and support connectivity of the building LANs. The district LANs run at lesser speeds of between 10-100Mbps to the desktops.

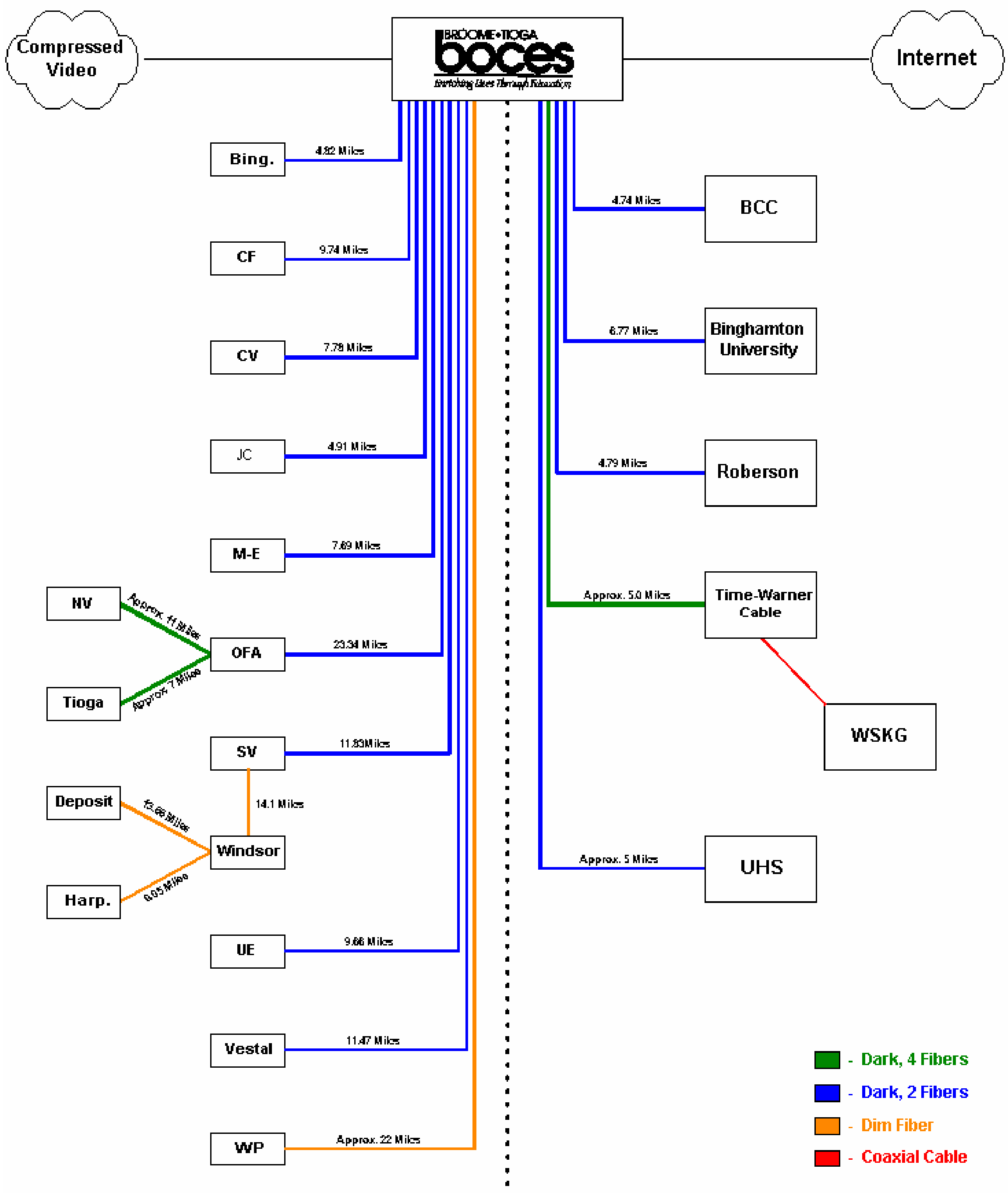
Portions of the infrastructure have been funded by; the Verizon Diffusion Fund, E-Rate (Universal Service Fund -- USF) program and New York State aid for BOCES services (see: "Funding Issues" in SCT BOCES Abstract). Further investment is intended using these funding resources. E-Rate funding can be between 30%-80%, depending on the socio-economic characteristics of the school district or library; however, on average, the BTB districts receive an E-Rate of 55% discount on telecommunications services.

BTB has already recognized that one gigabit bandwidth on a fiber strand will be inadequate to meet future needs in a number of localities and is planning to increase the capacity on the existing fiber infrastructure. For example, through the introduction of course wave division multiplexing (CWDM) it is now able to "light" four or eight wavelengths on a given fiber. This could multiply the bandwidth from 1 to as much as 8 gigabits over that fiber pair. A 4Gbps network upgrade would cost approximately $10,000 one time, for the electronics for each end, and for 8 Gbps a $25,000 one time charge per end of the fiber.

The continued growth and expansion of the BTB infrastructure is envisaged. To meet its numerous objectives and to be able to provide optimal services to the regional school districts, the BTB is in the process of leasing more dark fiber and upgrading its existing fiber. The convergence of voice, video, and data technologies is an objective that BT BOCES is seriously pursuing. The fiber portion of the BTB infrastructure, called "Luminet," is shown on the next page.

Luminet Infrastructure

3/02



Appendix V Glossary

AFN	Ethernet networks over fiber infrastructure capable of supporting gigabit speeds	
ATM	asynchronous transfer mode	
BWA	broadband wireless access	
CANARIE	Canada's public/private Networking Partnership	
CAS	Content (including individuals as content creators), Applications (including teleconferencing, advanced telecommuting, individualized distance learning, server-based remote applications), and/or Services	
CATV	community antenna television	
CLEC	competitive local exchange carrier	
Conduit	the physical infrastructure through which fiber passes to connect the end-user to the supplier of services.	
Converged Services	services encompassing video, voice and data from the Service Supplier to the OJUNCTION for selection by the end user.	
CPE	Customer Premises Equipment, the electronic and/or optical equipment required to establish a given bandwidth of transmission across the fiber.	
CSMA/CD	Carrier Sense Multiple Access/Collision Detect, the original IEEE 802.3(TM) LAN protocol used in 10Base-T. With the advent of 100 - 1000 Mbps, the CSMA/CD protocol is actually not generally used (although it is still specified) but replaced by direct data pipes to a switch. No collisions, no multiple access. Each port is full data rate and the switch (rather than repeater HUB) handles the frame routing. Because of history, this is usually still called CSMA/CD; just the term Ethernet or IEEE 802.3 may be more descriptive.	
DSL	digital subscriber line	
FAQ	frequently asked question	
Fiber	Optical Fiber, in this case that which connects the end-user to the Optimal Network Junction Point (see below) and provides the physical layer for the AFN (see below)	
FSO	free space optical	
FTTH	fiber to the home	
GEF	Gigabit Ethernet over fiber	
GEW	Gigabit Ethernet over wireless	
HFC	hybrid fiber-coax	
IEC	Inter-exchange carrier	
ILEC	incumbent local-exchange carrier	
IXC	Inter-exchange carrier	
Junction Point	network junction point	
LAN	local area network	
MAN	metropolitan area network	
OIP	Optimal Interconnection Point	
Optimal Interconnection	the particular Junction that has the function of providing simultaneous connectivity to all of the other network junction points in a given area	

Point		
QoS	quality of service	
PDA	personal digital assistant	
Service Providers	the private (and some public) sector providers of the services offered competitively at the Optimal Network Junction Point for selection by end-users who are seeking converged services.	
SOHO	small office, home office	
SONET	synchronous optical network	