Washington Internships for Students of Engineering

Gigabit Ethernet Over Fiber Optic Cable:
Broadband for the 21st Century

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Washington Internships for Students of Engineering

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Table of Contents

About the Author

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About Washington Internships for Students of Engineering (WISE)

The Washington Internships for Students of Engineering (WISE) program annually selects 14-16 outstanding engineering students who are either recent graduates or entering their final year of undergraduate study to spend ten-weeks in Washington, DC. The students are selected through a nationwide competition, and they are sponsored by engineering societies. During the internship, students learn how government officials make decisions on complex technological issues and how engineers can contribute to legislative and regulatory public policy decisions. Meetings with congressional committees, executive office departments, and corporate government affairs offices are daily activities. The internship culminates with a student-produced presentation and paper on an important engineering-related public policy issue. For more information, visit http://www.wise-intern.org/.

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List of Terms

ATM	Asynchronous Transmission Mode
CO	Central Office (telephone company)
DARPA	Defense Advanced Research Projects Agency
DLC	Digital Loop Carrier
DOCSIS	Data Over Cable Service Interface Specification
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexers
FCC	Federal Communications Commission
Gbps	Gigabits per second
GEF	Gigabit Ethernet over Fiber
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
Kbps	Kilobits per second
LAN	Local Area Network
MAN	Metropolitan Area Network
Mbps	Megabits per second
NSF	National Science Foundation
RAN	Regional Area Network
RBOC	Regional Bell Operating Company
SONET	Synchronous Optical Network
UNE-P	Unbundled Network Element Platform
VDSL	Very High Speed DSL
VoIP	Voice over Internet Protocol
WAN	Wide Area Network

Executive Summary

Broadband technology promises to energize the economy with jobs and new services. Broadband will enable people with greater access to information and content. But broadband's benefits increase with more subscribers. Broadband policy, therefore, is at the forefront of the telecommunications industry. Policymakers, regulators, and industry professionals debate how to stimulate broadband deployment to the home. The data suggests, however, that broadband deployment has not stalled, and thus it does not need government stimulation now.

Given that consumers are adopting broadband, and enjoying its benefits, the debate continues as to what type of broadband network produces maximum connectivity benefits. Today's primary residential broadband technologies, cable and Digital Subscriber Line (DSL), are limited in their bandwidth because of their network design. A new technology, Gigabit Ethernet over Fiber, offers super-fast speeds over 1000 times the currently available cable, DSL, wireless and satellite speeds.

Unfortunately, Gigabit Ethernet over Fiber technology requires a fiber optic infrastructure that extends over the "last-mile" to reach the home directly. The lack of the fiber infrastructure will preclude GEF from supplanting current broadband technologies. It is unlikely that the fiber infrastructure will be built with direct investment from fiber-optic networking companies in the near term. At present, a fiber-optic network will be constructed by telephone and cable companies as they increase data capacity on their copper line networks. To increase data capacity on these legacy networks requires shorter copper links, hence more fiber optic cable.

In some communities, innovative strategies are underway to construct a new fiber optic network apart from the phone and cable company networks. These strategies include condominium construction, conduit construction, cooperative ownership, end-user ownership, and public utility construction. These new models should be considered in new broadband policy so that the policy does not inihbit these endeavors.

Many decisions that affect broadband deployment will soon be made by the Federal Communications Commission. The 108th Congress will likely re-energize the telecommunications debates as it considers revised measures from the previous Congress. To bring Gigabit Ethernet over Fiber technology to the broadband discussion, this paper makes the following recommendations which could promote a fiber network..

- **Recommendation #1**: *Remove barriers to municipality ownership of a network.*
- **Recommendation #2**: *Continue support for National Science Foundation (NSF) and DARPA (Defense Advanced Research Projects Agency) optical technology research.*
- **Recommendation #3**: *Do not pick technology winners and losers.*
- **Recommendation #4**: *Consider updating the FCC's definition of broadband to include bi-directional service at megabit data ratess*.
- **Recommendation #5**: *A national broadband strategy should encourage at least 100 Mbps access.*
- **Recommendation #6**: *Assess a modification of the E-rate subsidy that would allow schools to invest in network construction.*
- **Recommendation #7**: *Avoid additional subsidies for broadband deployment.*

- **Recommendation #8**: *Include content neutrality as a primary objective in a National Broadband Strategy*.

Overall, however, this paper concludes that broadband's capability to affect communication and the economy is still in its infancy. Companies are now beginning to tailor their content for broadband subscribers, and only in time will consumer demand to continue to grow. The government should be careful not to stifle any innovation with preferential technology agreements, and the government should let local communities decide how best to serve their residents.

1.0 Introduction: The Broadband Promise

Our need for telecommunications services is changing and increasing, because people are realizing the value of information and connectivity. Demand for bi-directional network connectivity no longer centers on analog voice communication, but rather on high-speed digital data communication.

A high-speed data network satisfies the need for voice communication and information retrieval. Traditional telecommunications technology, such as the phone network and cable network, are transitioning to bi-directional high-speed data networks. The phone system was designed to meet people's needs for two-way, low-bandwidth voice communication, and the cable system was designed for one-way video broadcasting. Re-engineering these systems has required massive capital expenditures by the legacy companies as they adapt to people's demands. New technologies, such as fiber optic cable and wireless networks, have helped phone and cable companies adapt their networks, but these same technologies also threaten those companies' dominance in the residential high-speed or broadband market.

Revolutions in digital technology have made communication simpler, more secure, less expensive, and faster, because compression, modulation techniques and fast processors allow more information to be transmitted per second. This digital technology has eroded the profit margins of telecommunications companies, as the relatively inexpensive equipment has enabled competitors to enter the telecommunications market and offer innovative services.

Clearly, these competitors would not have been able to enter this market if telecommunications services were not partially deregulated with the 1996 Federal

Telecommunications Act. Lawmakers envisioned this act as promoting the deployment of new telecommunications services such as residential broadband and competitive phone service. The 1996 Act charged the Federal Communications Commission (FCC) to oversee deregulation and promote the deployment of high-speed and advanced telecommunications services.

Deregulation, digital communication technology, new technology and fierce competition have resulted in a variety of new telecommunications services for consumers. These same revolutions have also created an era of uncertainty in the telecommunications market, as some telecommunications companies are burdened with heavy debt loads, low margins, competing technologies, and changing regulations. Network technologies that used to have separate and distinct markets, such as twisted copper wires for phone service and coaxial cable for cable television, now support voice, data and video after substantial upgrades.

As old and new companies expand their upgraded networks, they enable more homes with broadband (or high data rate) connectivity. Since the 1996 Telecom Act, broadband services have been a focal point of Congress and the FCC.

Some current telecommunications experts allege that broadband deployment has stalled, and thus we need to stimulate deployment. Some legislators argue that the United States needs a comprehensive national broadband strategy. Senator Joseph Lieberman introduced legislation in June 2002 that required the President to develop that national strategy.[1] Many other telecom initiatives are being discussed at the dawn of the 108th Congress.

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[1] S.2582, 6/5/02

Experts at the FCC, however, point to Section 706 report data[2] and claim that broadband deployment has not stalled.[3] Andrew Odlyzko of the Digital Technology Center at the University of Minnesota argues that broadband is still in the upward sloping part of the "S"curve that can be used to describe the adaptation of technology. Figure 1 shows the deployment of high speed[4] and advanced[5] services over the past 2 ½ years.

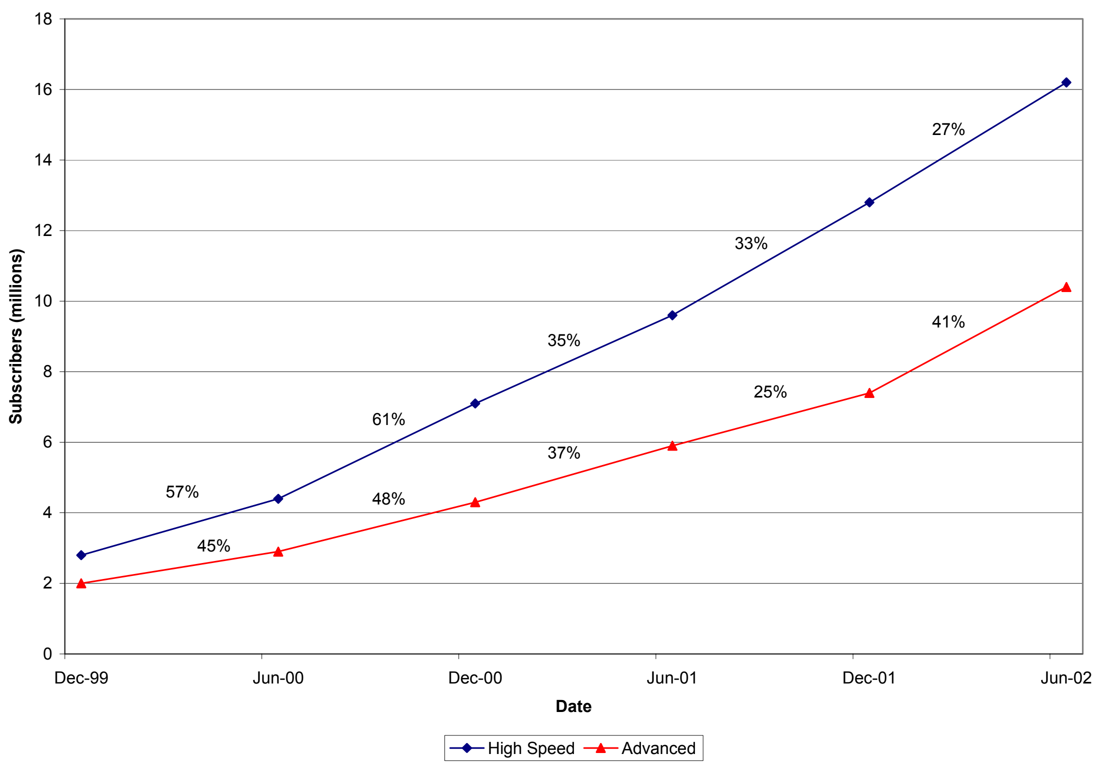

Figure 1: Number of High Speed and Advanced Services Subscribers

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[2] Section 706 reports analyze the deployment of high-speed and advanced telecommunications services.
[3] Marcus, Scott, and Ghaffari, Behzad.
[4] "high-speed" services involve data communication in excess of 200 kbps in *one direction* (includes advanced services).
[5] "advanced" services involve data communication in excess of 200 kbps in *both directions.*

The decline in the subscription rates for high speed and advanced services between December 2000 and December 2001 (June 2002 for high speed services) arouses concern among some telecommunications professionals and technologists. They point to these trends to justify actions to stimulate broadband deployment (tax credits, subsidies, government programs, and changes in regulation). But, despite the decrease in subscriber rates, the actual number of subscribers per period has been increasing. Additionally, the most recent data between December 2001 and June 2002 shows a 60 percent increase in the subscription rate for advanced services. Currently, 100,000 new households are signing up for broadband each week. By the end of 2003, 20 million households – almost 19% of the 107 million U.S. households – will have broadband.[6] An almost 20% subscription rate by the end of 2003 confirms that deployment is proceeding steadily. Clearly, without evidence of a deployment problem, massive government action is not necessary to stimulate broadband subscription.

An additional trend that might arouse concern is the divergence of high-speed (downstream only high-speed) services from advanced services (bi-directional high-speed). Advanced connections are imperative to realize maximum benefits from network connectivity because advanced services permit greater access to information. With advanced services, network users can produce and distribute content, and thus everyone has access to more sources of information. Peer-to-peer services that allow a user to directly connect to another user's computer to share information will flourish with advanced connectivity. Advanced services promote telecommuting, which can lower commuting costs and provide a flexible work environment for employees.

[6] Grant.

Data from the first half of 2002 indicates that the gap between advanced services and high-speed services might be closing, because almost 90% of the new high-speed service subscriptions were advanced services. High-speed-only services (not including advanced services) increased only 7.4% during the first half of 2002, compared to percentages not less than 30% in previous reporting periods. Because the majority of high-speed subscriptions are advanced services, and because the high-speed-only subscription rate has been declining, the divergence between advanced and high-speed services deployment should not arouse concern. The divergence likely occurred because the dominant residential broadband network, cable, was not designed for high-speed two way communication. As consumers demand more upstream bandwidth, broadband providers are modifying their networks accordingly.

Clearly, broadband deployment has not reached a plateau. The steady increase in the number of subscribers is promising for our increasingly networked world. Most everyone agrees that broadband will transform our lives, and that it should be deployed ubiquitously.

Ubiquitous deployment brings many benefits to the economy. Broadband will create jobs and stimulate economic growth. Broadband build-out will create jobs both directly through infrastructure construction and indirectly through new online services. Stephen Pociask of TeleNomic Research estimates that over 1.2 million jobs could be created with the expansion of broadband.[7] Charles Ferguson estimates that "failure to improve broadband performance could reduce U.S productivity growth by 1% per year or more, as well as reducing public safety, military preparedness, and energy security."[8]

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[7] Pociask.
[8] Ferguson.

In addition to jobs and economic growth, many social benefits arise from a fast, high-capacity broadband network. Metcalfe's law states that the value of a network goes up by the square of the number of users. The value of a broadband network is clearly enhanced with more users, because people can share information with other people. The Pew report on the Internet points out that people's use patterns change with broadband, and over 56% of broadband users have been producers of content.[9] The Pew report states that broadband customers often 1) become creators and managers of online content, 2) satisfy a wide range of queries for information, and 3) engage in multiple Internet activities on a daily basis. Clearly, equivalent high data rate residential and enterprise broadband access will facilitate communication, and allow people to work and learn remotely.

Broadband access will change the way people interact, because fast information networks provide information on demand rapidly. Fast networks will enable new services, such as telecommuting, virtual reality, video on demand, voice services, high definition digital television (HDTV), telemedicine, distance education, and music on demand.[10] Clearly, broadband will change the education, healthcare and entertainment industries as fast networks allow new forms of market interaction (e.g. live video of a doctor, pharmacist, music artist, professor, and CD-quality streaming music).

A high-speed network has market value. Presently, many consumers purchase cable television, telephone service, and Internet service from several companies and the average household bill for all these services is roughly $200 per month.[11] With a high-

[9] Horrigan.
[10] For a description of these services, see *Broadband: Bringing Home the Bits.*
[11] Thatcher.

speed broadband network, convergence[12] of these services is likely, and consumers will have many options to choose from for television, voice, and services-on-demand. Receiving these services over one platform could potentially lower their cost.

But true convergence of services requires a network with enough bandwidth. Current technologies are limited in their bandwidth capability, and only realize incremental improvements.

Today's debate partially focuses on how the government should define broadband, because the government's definition establishes a threshold for these fast services. How fast is fast? The only theoretical speed limit is the speed of light. Fiber optic technology allows near speed of light data transmission, and thus essentially unlimited bandwidth. How much bandwidth, or data capacity, do we need? Policymakers continue to debate these questions. The FCC defines broadband services as data communication in excess of 200 kilobits per second (kbps) in either one or both directions. Most experts agree, however, that true broadband service requires orders of magnitude more bandwidth such as 100 Megabits per second (Mbps) or even as much as 10 Gigabits per second (Gbps).

With gigabit networks, advanced data and communications services can thrive at both the enterprise and residential markets. Gigabit Ethernet over Fiber (GEF) technology promises significant cost and speed advantages for broadband. GEF far surpasses the most popular current broadband technologies of cable and digital subscriber line (DSL) in speed and quality. The challenge posed with GEF is the lack of a fiber optic infrastructure. The lack of a fiber optic infrastructure and the current depressed

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[12] Convergence refers to the ability to provide all telecommunications services (television, video-on-demand, telephone, high-speed Internet access, etc.) over the same network platform.

state of the telecommunications market raises one key question: Who can afford to build the network?

The telecommunications market today is not on the top investment list, as everyday new news of bankruptcies, numerous layoffs and debt-laden incumbents appears. Without new investment, telecommunications network providers will not be able to build a new gigabit network. The major incumbent local exchange carriers (ILECs) such as SBC, Verizon, Qwest and BellSouth are burdened by heavy debt loads such that it will be nearly impossible for them to construct a new network right now.[13] BellSouth's second quarter 2002 earnings report indicated overall revenue losses. These losses continue as the ILECs' coveted profitable voice network transforms into a less profitable data network.

Bell South's CFO in July 2002 said, "In terms of capex, our investment is down over 40% in the last two years from 6.7 billion – to about 18% of revenue. We will reduce capex by another 500 million. Reducing capex right now is the right move."[14] He countered that a reduction in capital expenditures does not mean that the company will "stop investing in the growth areas of DSL, data and wireless and long distance," but a reduction in capital expenses implicitly means that investment will slow in these areas. Unfortunately, without more investments in fiber optic network expansion, DSL broadband service cannot be enhanced.

Without private sector investment in a new fiber infrastructure, does government have a role? The government can act to put GEF technology on the same playing field as other broadband technologies. Government will play a role in the deployment of

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[13] Cook.
[14] Dykes.

broadband and fiber optic infrastructure because the government regulates the telecommunications industry. Current regulations distinguish between different services for voice and data access. Our reliance on voice-centric networks, however, is eroding as more and more networks become data-centric. These digital, data-centric networks view voice as just another form of data, and thus it is not clear that different regulations need to exist for different network platforms. Government will have to deal with this reality as more consumers demand large bandwidth connectivity.

For the telecommunications industry, innovative business strategies and a clear regulatory framework are necessary for new investment and the optical network construction. This paper will describe the clear advantages of GEF technology and it will present policy recommendations to promote GEF and broadband.

2.0 Gigabit Ethernet over Fiber Technology Overview

Gigabit Ethernet over Fiber technology promises to revolutionize Internet and telecommunications networks. The technology boasts a time tested networking communications standard, Ethernet, and it allows speeds upwards of 1000 times more than current broadband technologies. With the recent approval of the Institute of Electrical and Electronics Engineers (IEEE) 802.3ae standard, GEF technology is ready to deploy in both the enterprise and residential markets.

2.1 Gigabit Ethernet over Fiber Technical Advantages

GEF technology has several advantages over the current broadband networks. First and foremost, it is a gigabit network with roughly 1000 times more speed and available bandwidth than current popular DSL and cable systems. With this bandwidth, GEF will be able to provide new services well into the future. Convergence of voice, data, video, and television services will likely occur with GEF technology.

Another principal advantage of GEF is its working distance of 40-70 kilometers (km). The IEEE 802.3ae standard calls for a minimum working distance of 40 km; however, the network implementation can increase this distance. With this working range, GEF technology is ready for the metropolitan area network (MAN) environment, because it can most certainly reach many office buildings in a metropolitan area. For the wide area network (WAN) environment, GEF can interface with the fiber backbone of current long-haul network infrastructures such as Synchronous Optical Network (SONET) and Asynchronous Transfer Mode (ATM). GEF can achieve distances of over 110 km with extenders and wavelength division multiplexing.[15] This long distance results from the transmission properties of fiber optic cable.

The other technical advantages of GEF stem from its reliance on the time-tested Ethernet communication protocol. Several studies have shown that Ethernet ports have a significant cost advantage over SONET ports, perhaps as high as an 8:1 cost advantage. Part of this cost savings results from the volume of Ethernet products. Unfortunately, 10 Gigabit Ethernet does not presently have this same cost advantage, partly because the volume of production of 10 Gbps equipment is low.[16] Once GEF is adopted en masse, the Ethernet cost advantage could develop. Because Ethernet technology is used in many applications, it is a true ‘plug and play’ technology that makes networks simple to setup and maintain.

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[15] Maki.
[16] Maki.

Additionally, the switching capabilities of Ethernet have evolved such that switched Gigabit Ethernet provides both layer 2 Ethernet bridging functions and layer 3 Internet Protocol (IP) routing functions. This layer 2/3 switching means a simpler network that is easy to manage.

Finally, depending on the application, fiber optic cable has a lifespan of 25-40 years. As engineers develop new optical components, upgrades at the ends of the fiber will enhance transmission capability. With speeds in excess of 90% the speed of light, fiber optic cable is the ideal choice for transmitting information quickly over short and long distances.

2.2 Gigabit Ethernet over Fiber Technical Disadvantages

The main disadvantages to GEF are the lack of fiber infrastructure and cost of the optical components. Optical transmission equipment (lasers, repeaters, transceivers, media converters) is expensive now, but presumably as standards are created, and the technology becomes more widely used, the cost will drop. Current optical lasers have been reduced from large expensive gas lasers to small, inexpensive diode lasers with advances in semiconductor technology. Fortunately for GEF, IEEE has approved a standard for GEF network equipment.

Unfortunately for GEF, the technology still has some limitations. Some of these limitations are inherent in the intended design and use of Ethernet. Ethernet is a relatively inexpensive technology that was not designed for redundant telecommunications networks with fast restoration times. The restoration time is the time required to restore network connectivity in the event of a network segment or component failure (e.g. a cut line). GEF technology needs a restoration time of roughly 10 nanoseconds to be listed as carrier grade[17]; GEF's restoration time is currently 1 second or longer.[18] Thus, to make Ethernet carrier grade and to solve its disadvantages over current SONET and ATM infrastructures for telecommunications services, GEF might prove just as expensive as these architectures.[19] Both SONET and ATM carrier switches have redundant circuitry built-in that makes them more reliable. The Ethernet port cost advantages mentioned in the previous section might evaporate with the necessary modifications.

Additionally, GEF does not scale to large extents as easily as other copper Ethernet networks, and this scalability issue will have to be addressed as GEF is used in MAN and WAN environments. Finally, the Quality of Service provisioning and traffic prioritization will have to be enhanced to ensure that no information is lost and that voice traffic experiences no delay. Nobody wants to experience delays in voice communication on the phone. GEF has difficulty determining between voice traffic and data traffic, and thus GEF could prioritize data traffic above voice traffic and cause a delay in a conversation. That issue is central to Voice over Internet Protocol technology that is currently being enhanced and deployed today on cable and wireless networks. Engineers are working to solve GEF's technical limitations. Future IEEE standard revisions will address these limitations.

Beyond the networking limitations, however, building the fiber optic infrastructure is the central challenge to GEF's success. If there were a fiber infrastructure in place today, GEF technology could possibly supplant current communication systems. But, some analysts allege that the cost of building fiber to the

[17] "carrier grade" certifies technology as ready to handle live communication without loss.
[18] Maki.

home (FTTH) or fiber to the curb (FTTC) over the last-mile[20] is prohibitively expensive (on the order of $10,000 per mile).[21] Clearly, last-mile fiber deployment costs must decrease for a company or government to build that last-mile.

2.4 GEF Advantages over Current Technologies

While there are other broadband technologies, such as Digital Subscriber Line (DSL), cable, and wireless solutions, pushing fiber closer to the subscriber will definitely enhance these technologies and improve their performance. Fiber will eventually trump these technologies at both the residential and enterprise levels as it reaches buildings.

One major advantage of GEF is that it can offer gigabit symmetric broadband service. Symmetric service means that both downstream (provider-to-subscriber) and upstream (subscriber-to-provider) data transmission occurs at the same gigabit rate. Most available broadband technologies at the residential level are highly asymmetric, and this reality impedes the development of new applications. Certainly, most people do not prefer to communicate asymmetrically.

2.4.1 Digital Subscriber Line (DSL)

About 30% of residential broadband users connect through DSL. Asymmetric DSL (ADSL) is currently the most popular form of residential DSL service, and almost none of the ADSL lines provide more than 2Mbps upstream or downstream. Most of the ADSL services do not even provide more than 1Mbps upstream.[22] The most current

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[19] Banerjee.
[20] "last-mile" refers to the distance between a central location and a customer's home. Many phone companies have fiber optic cable up to a central point, and then copper between this central point and the neighborhood. The length of the copper severely limits DSL speed.
[21] Newman.
[22] FCC, 3rd Report on Advanced Telecommunications Capability.

generation of DSL provides 8MBps downstream and 800 kbps upstream.[23] A typical DSL subscriber is lucky to experience 1.5 Mbps downstream, and 384 kbps upstream.

A subscriber's DSL data rate is highly dependent on his distance from the Central Office (CO) because of copper's signal loss. Improvements in DSL rely on expensive equipment upgrades with Digital Subscriber Line Access Multiplexers (DSLAM), Digital Loop Carriers (DLC), and extending fiber closer to the subscriber. Essentially, fiber optic cable has to be extended closer to the subscriber for substantial speed increases.

The most optimistic predictions for the future of DSL claim that DSL will achieve 100Mbps symmetric service to all.[24] But, DSL's primary technical challenge is still crosstalk. Crosstalk refers to the interference that is created when two adjacent copper lines transmit data. Crosstalk interference increases with the frequency of transmission and hence the data rate. High speed transmission on one line can reduce the speed on an adjacent line. Short lines can generally achieve higher data rates than long lines, but technology improvements are being developed to control the rate on the short line so that it does not interfere with the long line. Asymmetric service, therefore, reduces crosstalk, and thus symmetric DSL service will require short links.

Reducing the link size of copper phone lines for DSL enhances the prospects for Very High Speed DSL (VDSL). VDSL has become a reality in Japan where most homes receive up to 7 Mbps over DSL service.[25] U.S. phone companies, particularly the Regional Bell Operating Companies, claim that they can roll out 15 Mbps DSL service in the near future that will be able to offer video. The RBOCs argue, however, that Unbundled Network Element Platform (UNE-P) regulations inhibit their investment in

[23] Computer Science and Telecommunications Board.
[24] Cioffi.

these new capital intensive technologies, because UNE-P forces them to lease their lines to competitors. The FCC is currently undergoing a triennial review of UNE-P, and could potentially overhaul and reduce UNE-P obligations of the Bell companies. With reduced UNE-P obligations, Bell companies may make the fiber investment necessary to expand VDSL service. If UNE-P remains, then Bells and Competitive Local Exchange Carriers will have to figure out how to co-exist and compete with cable.

Fiber is the ultimate solution to DSL, because clearly, the copper links between the central office and the subscriber must become shorter for faster, symmetric transmission. Fiber optic cable is the solution to bring transmission from the central office closer to the subscriber.

2.4.2 Hybrid Fiber Coax network (HFC/Cable)

Roughly 70% of the residential broadband service is provided by cable service that tends to mimic DSL in service quality. The cable network, however, is designed as a shared architecture, and thus it is a great network for sending programming to many subscribers (one-to-many). This shared architecture, however, limits the upstream capacity, because the network was not designed to have many users sending content upstream (many-to-one). The newer hybrid-fiber-coaxial cable network attempts to solve some of those problems. Hybrid-fiber-coax technology describes a network that is comprised of fiber for most of the distribution path (from the headend to the local hub and from the hub to the nodes) and coaxial cable from the nodes to homes. Figure 2 describes an HFC network.

[25] Huber.

The cable industry is completing a massive upgrade to a 750MHz two-way network (hybrid-fiber-coax) that is capable of offering broadband over the cable modem.[26] The former networks were 200-350 MHz one-way networks without fiber extensions. The new network can support many services for today and the future, as Table 1 describes.

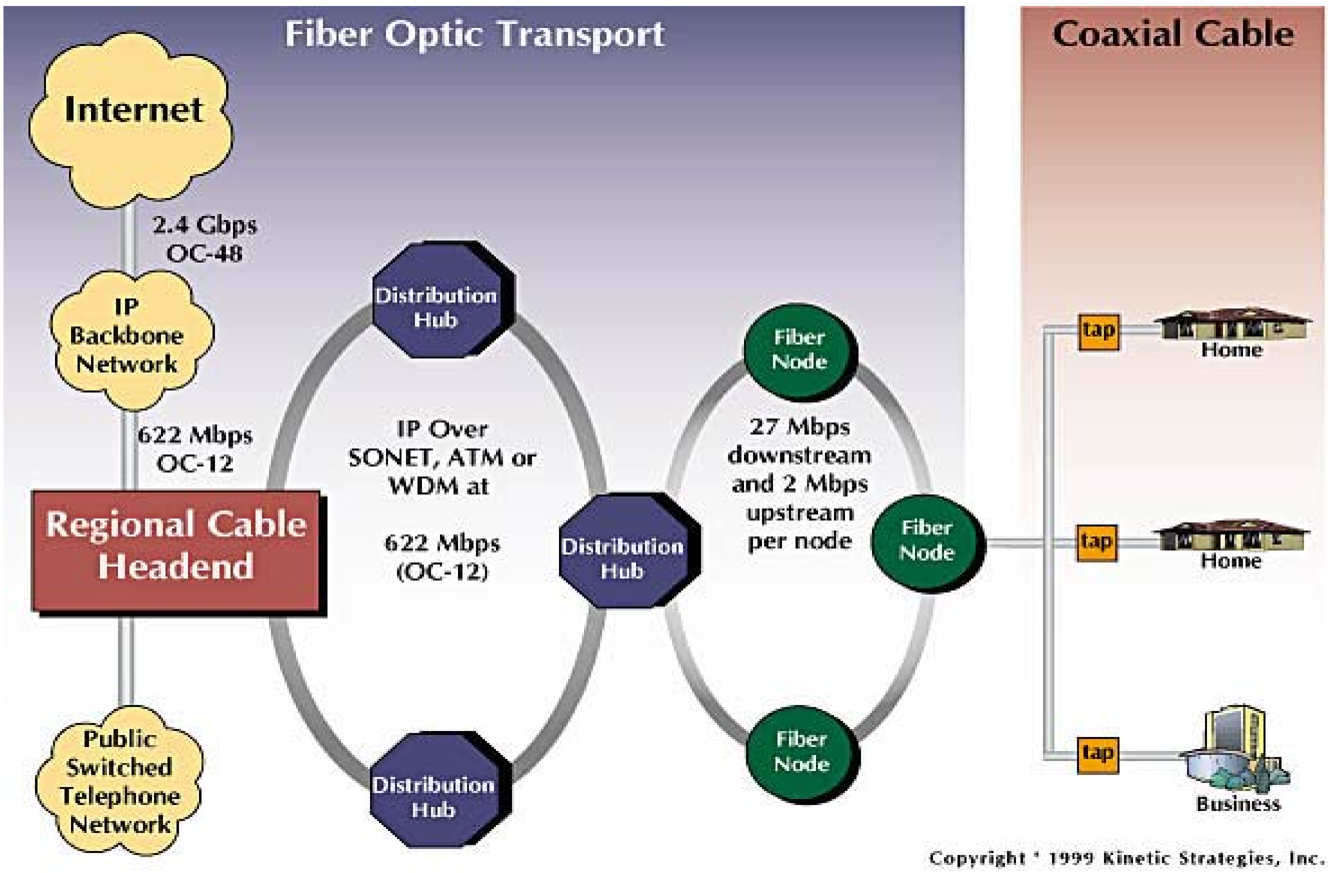

Figure 2: A Hybrid Fiber Coax Cable Network

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[26] Newman.

Table 1: Cable services with HFC network.[27]

COMMON SIGNALS		
SERVICES PROVIDED	CHANNELS AND/OR BANDWIDTH REQUIRED	CHANNELS REMAINING
Standard Analog Television	20 channels (120 MHz) for NTSC signals	92
Digital SDTV	20 channels (120 MHz) for 200+ programs of compressed digital video format	72
Digital HDTV	10 channels for 20 programs (60 MHz)	62
DEDICATED SERVICES		
SERVICES PROVIDED	CHANNELS AND/OR BANDWIDTH REQUIRED	CHANNELS REMAINING
Telephony	1 channel (6 MHz) for 300 DS0s (voice channels)	61
IP Data – Standard Service	20 channels (120 MHz) - 10 Mbp/s data rates	41
IP Data – Very High Speed	3 channels (18 MHz) - 100 Mbp/s data rates	38
Video on Demand	20 channels (120 MHz) for 200+ programs of compressed digital video	18
Future	18 channels, services as needed (108 MHz)	0

Cable service tends to be highly asymmetric because it carries information downstream to the end-user in excess of 2Mbps; however, virtually no cable service carries data upstream in excess of 2Mbps.[28] Upstream capacity is limited because of noise aggregation problems that arise when many users attempt to send data to the same place over a shared physical network.[29] Cable's performance at the residential level depends on the number of users connected to a node. A larger number of users per node results in decreased performance for each user. To increase cable performance, therefore, the number of users per node must be decreased. Decreasing the number of users per node requires extending the fiber optic cable to bring the nodes closer to homes. The

[27] Chiddix.
[28] Computer Science and Telecommunications Board.
[29] Hatfield.

National Academies report concludes that "by using fiber instead of coax to feed into neighborhoods, the system's performance and reliability is significantly improved."[30]

Cable passes 97% of homes in the United States, and over 70% are served by the upgraded HFC cable network.[31] Clearly, this extensive network plays, and will continue to play, an important role in the future of broadband and telecommunications. Cable's capacity, however, is limited to 1 GHz of bandwidth and some video traffic will have to be replaced with Internet Protocol (IP) traffic for a substantive increase in capacity.[32] The DOCSIS (Data Over Cable Service Interface Specification) standard governs cable technology, and the current standard supports 40 Mbps downstream and 10 Mbps upstream. Because of the DOCSIS standard, the cost of cable access technology has dropped significantly in the past several years.[33]

Cable's Voice over Internet Protocol (VoIP) capability is limited,[34] and thus true convergence of services cannot occur until VoIP service is resolved. Overall, cable will continue to play a large role in broadband access, because upgrades can be financed by the digital video service. Cable access is predicted to climb to 20.2 million subscriptions by the end of 2005 from 3.7 million in 2000.[35] The target market for cable broadband access is the residential market, because the data rates are insufficient for medium and large enterprises. For higher data rates, dedicated lines or fiber to the building is essential. As the cable network expands, fiber will likely be pushed closer to the home as demand for bandwidth increases.

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30 Computer Science and Telecommunications Board.
31 Computer Science and Telecommunications Board.
32 Bloom.
33 Chiddix.
34 Newman.
35 Newman.

2.4.3 Wireless and Satellite

Wireline networks have one clear advantage over wireless networks: they do not have to acquire bands of spectrum to operate. Spectrum management and allocation policies are complicated issues and deserve lengthy analyses of their own. Commercial spectrum interests compete with government spectrum interests, and neither side wants to relinquish what they have for reassignment. But one point is clear: both government and commercial interests want more spectrum for their communication uses.

Unlicensed spectrum for commercial use is a promising spectrum allocation method for new technology development. Wireless networking IEEE 802.11 devices have sprung up in homes and neighborhoods throughout the country as people purchase these unlicensed devices for an instant infrastructure and limited mobility. Wireless networks clearly have mobility and instant infrastructure benefits over wireline networks.

Wireless solutions, however, suffer from a lack of available bandwidth and interference and thus wireline networks trump wireless solutions for fast data transmission. Wireless solutions cannot compete with fiber, as the radio frequency (RF) signals are subject to interference from nearby devices such as microwaves. While the 802.11 standard has been revised to transmit data up to 50 Mbps in the 5 GHz range, real transmission rates will be a fraction of that speed. Spectrum has many competing uses, and wireless solutions will be great for mobility and omnipresent access at modest data rates today (10-50 Mpbs).

Wireless point to point networks are growing, and showing strength over point to multipoint networks. Interference issues need to be resolved, such as the alleged interference between satellite radio and 802.11 devices. New technology such as software defined radio permits the automatic negotiation of interference-free communication channels, and this technology combined with more unlicensed spectrum (a spectrum commons idea) will be increasingly deployed in the future. Property rights for spectrum allocation are also being discussed at the FCC.

Satellite technology also benefits from a wide reaching instant infrastructure when launched. Interference questions between satellite and terrestrial wireless solutions need to be resolved before a final verdict on satellite technology is rendered. Satellite transmission is subject to extensive delays that can impede voice and data communication. The cost of launching a satellite is high, the equipment is expensive, and thus the cost per user for satellite service is high compared to superior DSL and cable solutions.[36] Satellite solutions are perhaps best for rural communities or those communities where an instant infrastructure in a large coverage area is necessary.

Satellite broadband has been slow to take hold not only because of the high costs of launching a satellite, but also because of the lack of dedicated satellite spectrum. Terrestrial users fear interference from satellite users, and thus satellites are subject to interference regulations. New spectrum allocations for satellite and terrestrial services are being considered at the FCC. Satellite spectrum decisions require international coordination through the International Telecommunications Union (ITU), and this process has delayed the availability of satellite and fixed wireless spectrum.

Essentially, both satellite technology and wireless solutions will complement a wireline network, and they will be able to provide service to places where it is uneconomical to lay fiber optic cable. As one telecom executive quipped, “There are just some places where fiber will not be laid. For example, fiber can be laid up to one side of the Grand Canyon, a wireless system can bridge the gap, and then fiber can continue from there."

2.5 Condominiums and Municipalities

Some market-based solutions to fiber expansion involve user ownership of fiber optic cable. User ownership allows regional area networks (RANs) to be developed that particularly suit a specific area. User ownership of fiber includes condominium builds in which a user leases or purchases the fiber between his home and a central office. User ownership models allow the users to internalize the cost of fiber optic expansion; however, incremental builds in neighborhoods might actually increase the cost of fiber expansion and interconnection in a neighborhood, as scale economies might not be realized.

Additionally, many consumers are unlikely to desire to own their own fiber simply because it would be another household item to manage. A user would have to contract with a company to maintain the fiber, because in the event that something goes wrong with the fiber connection (a break or a cut) the average user will not know how to repair the fiber. Furthermore, the user would need permission to conduct any fiber repairs off his property.

End-user ownership does not appear as an attractive option for fiber expansion right now; however, it has had some success in Canada (with Canada's CANARIE organization), and thus is not entirely without merit.[37] Canada has incorporated end-user

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[36] Newman.
[37] St. Arnaud.

ownership into its condominium arrangement. A condominium fiber optic arrangement is when the user leases or buys the fiber from a central point to his home.

Canada's condominium builds have been successful in part because they focused on connecting schools and large users first, and then connecting other residential users to these large hubs. Corporations are allowed to purchase their own strands of fiber to manage for themselves or broadband customers. Additionally, municipalities are allowed to build conduit so that fiber can easily be run to new locations without the added construction expense of digging a trench each time. The condominium and conduit models allow many companies to own their own facilities into neighborhoods and schools, and thus the construction costs for a fiber infrastructure build-out are shared among many users. These models allow incremental construction costs, as opposed to a one-time massive installation expense. In the United States, building conduit in new construction might be profitable to developers for later fiber expansion.

In some areas in the U.S., municipalities have entered the telecommunications market by constructing a fiber optic network. Grant County in Washington State is perhaps the most famous municipally owned fiber optic network. The Public Utility District has developed the Zipp network to connect its residents to an entirely fiber optic network. The fiber network provides voice, video, and data services to consumer. As of October 28, the Zipp network had 3,000 subscribers out of 8,400 potential subscribers (36% take rate). The number of subscribers increased from 2,000 in April. Clearly, municipalities can provide reliable, quality service. Many schools, businesses and homes are all subscribers to the Zipp network. A current fiber optic broadband connection costs about $25.00 per month, or 50% of current DSL and cable modem prices. Other municipalities have attempted to build a network, but their efforts have been stalled by the current telecommunications companies who do not want to compete with a municipality. Clearly, municipalities can make a fiber optic network a reality.

3.0 Consumer Demand and Intellectual Property

A discussion on broadband policy is incomplete without a discussion of consumer demand. Some argue that the slowdown in the subscription rate for broadband is due to a lack of consumer demand. Without adequate consumer demand for broadband, companies will not invest in broadband networks. But others argue the contrary: without the broadband networks, investment in new broadband services will not happen. This classic "chicken and egg" problem is real, as there are other issues that need to be resolved before some new services can be launched.

A generation gap affects demand for broadband services. Today's college students are broadband intensive consumers, and as they graduate, they will likely demand broadband because they are used to having it. Today's homeowners are less likely to have broadband if they have not experienced it. Some argue that broadband access at work is a substitute for broadband at home, because people can do broadband-intensive web surfing during the workday.[38] New studies conclude, however, that people's use patterns change with broadband access.[39] This reality suggests that broadband access at work will stimulate demand for residential broadband access, as people experience the benefits of broadband. Additionally, the increase in corporate

[38] Thierer, "Paradox".
[39] U.S. Dept. of Commerce; Horrigan.

monitoring of employee Internet access decreases the likelihood for recreational Internet access at work.

Perhaps the most obvious issue facing policymakers is copyright control and intellectual property rights. FCC Chairman Michael Powell acknowledged in October 2001 that

> much of the broadband-intensive content that is likely to be the core of broadband applications (like movies and music) is in the hands of major copyright holders that are unlikely to make it widely available without stringent protections and a way to profit from its distribution (see, for example, the Napster experience).[40]

Movies and music services are becoming available very slowly despite huge consumer demand, because the Motion Picture Association of America and the Recording Industry Association of America want to ensure that they can maintain control over copyrighted movies and music. The popularity of Napster and peer to peer networking services indicate that consumer demand for music and file sharing services is high. Holding back music and movie services likely reduces demand for broadband, because these services require high bandwidth. Copyright issues, digital rights management, and intellectual property protection are subjects for another debate, and much discussion is currently underway to deal with these issues.

4.0 Policy Recommendations and Analysis

Fiber is the ultimate solution for telecommunications networks; however, reaching this ultimate solution in a competitive environment will require a combination of business and legal strategies. Without a government sanctioned monopoly to invest billions of dollars in a new telecommunications network, a fiber infrastructure construction needs private investment. Investors expect a return on their investment, and thus the telecom market must be attractive for investment. Inconsistent and incomplete policies only decrease investor confidence. The following policy recommendations can serve as lobbying strategies to promote Gigabit Ethernet over Fiber technology and broadband adoption.

Recommendation #1: *Remove barriers to municipality ownership of a network.* Incumbent local exchange carriers have been known to sue municipalities to prevent them from entering the telecommunications market. In some communities, municipality ownership of the fiber optic infrastructure might be a good option. The municipality can then lease the lines to service providers. The specific action might be a congressional resolution clarifying that "local entity," as referred to in the 1996 Federal Telecommunications Act, includes cities, towns, school districts, and other local government bodies, as well as cooperatives. Allowing a municipality to invest in broadband networks could stimulate fiber optic construction (see Grant County, Washington).

Recommendation #2: *Continue support for National Science Foundation (NSF) and DARPA (Defense Advanced Research Projects Agency) optical technology research.* Improvements in optical technology will lower the deployment costs for optical networking when the need for optical services arises. Both NSF and DARPA have been at the forefront of optical networking research. Advances in optical technology will continue to prove the superiority of fiber optic technology. With a fiber infrastructure, capacity upgrades can be made simply by making upgrades at the end of the cable.

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[40] Powell.

Recommendation #3: *Do not pick technology winners and losers.* Government's track record at picking winning and losing technologies is not good. Clearly, fiber optic technology is superior to other technologies for data-centric networks; however, the deployment of this technology will be determined in the marketplace. Additionally, a combination of technologies will comprise our broadband infrastructure.

Recommendation #4: *Consider updating the FCC's definition of broadband to include bi-directional service at megabit data rates*. While the FCC presently defines broadband – advanced telecommunications services – as at least 200 kbps in both directions, this definition is inadequate. Most industry experts acknowledge that megabit speeds are essential for true broadband services. The actual number (200 kbps, 10 Mbps, 100 Mbps) is arbitrary, and will change as new services and consumer demand for services changes. It is vital, however, that the definition of broadband encourages the development of new services that meet users demands. Most broadband users value bi-directional high-speed service; however, the dominant cable broadband technology inhibits nearly symmetric service.[41] The definition of broadband plays an important role in the lives of consumers, service providers, application and content developers, policymakers, regulators, and public interest groups.[42] Adopting the term bi-directional for broadband encourages the development of networks that will allow telecommuting, peer to peer file sharing and increased end-user interaction. Near symmetric service encourages the development of fiber optic networks, because the capacity of current wireline broadband solutions can only be enhanced with fiber optic upgrades.

[41] Horrigan.
[42] Computer Science and Telecommunications Board.

Recommendation #5: *A national broadband strategy should encourage at least 100 Mbps access.* For broadband to revolutionize communication today, 100 Mbps access is the minimum for a variety of service offerings. Policymakers must avoid short term solutions that only prop up existing technology, because these incremental improvements will only hinder the construction of a new fiber infrastructure.

Recommendation #6: *Assess a modification of the E-rate subsidy that would allow schools to invest in network construction.* A facilities-based ownership subsidy for schools would allow them to construct their own fiber optic networks and perhaps serve as community network access points. The E-rate program currently mandates that schools use the money to purchase services from telecommunications service providers. The network elements must be leased from telecommunications companies. This program is simply a cross-subsidy for telecommunications companies. With ownership options that provide less-expensive telecommunications services in the long run, last-mile fiber optic infrastructure construction will occur.

Recommendation #7: *Avoid additional subsidies for broadband deployment.* Let the market work for fiber optic build-outs. Supporting subsidies in Congress just opens the door for more pork-barrel spending that could lead to the politicization of technologies and perhaps more regulation.[43] Subsidizing certain technologies might prevent the development the optimal broadband technology.

Recommendation #8: *Include content neutrality as a primary objective in a National Broadband Strategy*. With a content neutral network, users have access to any and all information that they choose to view. Only a high capacity network can satisfy this demand.

5.0 Conclusions

Given the array of technology choices for broadband, fiber optic technology is the clear winner because of its superior data capacity capabilities and available bandwidth. Getting the fiber to the home is the principal challenge.

The Ethernet data-link layer for GEF is a time-proven data-link layer that might eventually trump current data-link layers such as SONET and ATM. GEF technology is a compelling new technology that is clearly ready for data networking and data services, and may end up as the clear technology choice within a few years. Now that it is standardized, GEF technology can confidently enter the market. Government must make sure that it has a level playing field, and that it can compete against cable, DSL, wireless, and satellite technologies.

The first step to GEF is building the fiber infrastructure, and the marketplace is realizing that fiber is the "ultimate end game." New trenching technology called micro-trenching can lay small amounts of fiber at moderate costs (as compared to laying large amounts of cable at once and leaving much of it unused for future use). The glut of capacity in the long-haul end of the network came about because at the same time that fiber was laid, technology improvements such as Dense Wavelength Division Multiplexing increased the amount of data that could be transmitted on a fiber optic cable. These technology improvements resulted in much unused fiber (also called dark fiber). Clearly, incremental fiber builds today will prevail as more dark fiber turns bright. Incremental builds can tap into the dark fiber to enhance current technology.

No private investor is willing to invest billions of dollars for a fiber infrastructure build-out when it has to compete against other wireline technologies that provide

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[43] Theirer, "Cyberpork."

adequate services. Much of the fiber optic expansion will continue to come from cable companies as they increase the hybrid-fiber-coax infrastructure. Telephone companies will continue to enhance their networks with fiber backbones as they attempt to compete with cable for voice and data services.

At present, fiber to the home remains a risky investment, simply because the value proposition for fiber is not much more than what the existing plant can offer (video and data services).[44] Expansion of High Definition Digital Television (HDTV) will drive fiber expansion, because HDTV channels require much more bandwidth than standard digital and analog channels. Fiber may be a worthwhile investment in new construction; however, it may also be more economical to lay the conduit for fiber to be installed later.

Because fiber optic cable is apparently a natural monopoly in the residential market, new models such as structural separation should be studied more effectively to present a clear argument for separating content provisioning from the physical network. The next generation broadband network should not only be a combination of technologies, but it should also be a content-neutral network so that the end user can produce and obtain his desired content. The user should have the ultimate choice of content, unlike cable television in which the user chooses from a set of programming. Ideally, a communications network will resemble the electric network: a user can plug anything designed for that network into a socket, and it will work. A fast, content-neutral network can be designed with GEF technology. A fiber optic network's virtually unlimited capacity allows all users to produce, distribute and choose among all content.

A fiber optic network allows endless possibilities for economic activity. Companies are realizing the benefits of broadband as they begin to distribute content online. With almost 20% of U.S. households predicted to be connected to broadband, companies are adapting their internet presence to cater to broadband users. John Skipper of ESPN.com stated, "This sounds terrible, but I'm not too worried about [alienating dialup visitors]. I do not want to program to the lowest common denominator."[45] Even as companies develop bandwidth intensive content to sell online, the network capacity is not sufficient for all ideas. Companies are ready to provide content, and consumers are adopting broadband; but only an enhanced gigabit, content-neutral network will maximize the economic benefits of connectivity.

[44] Banerjee.
[45] Grant.

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