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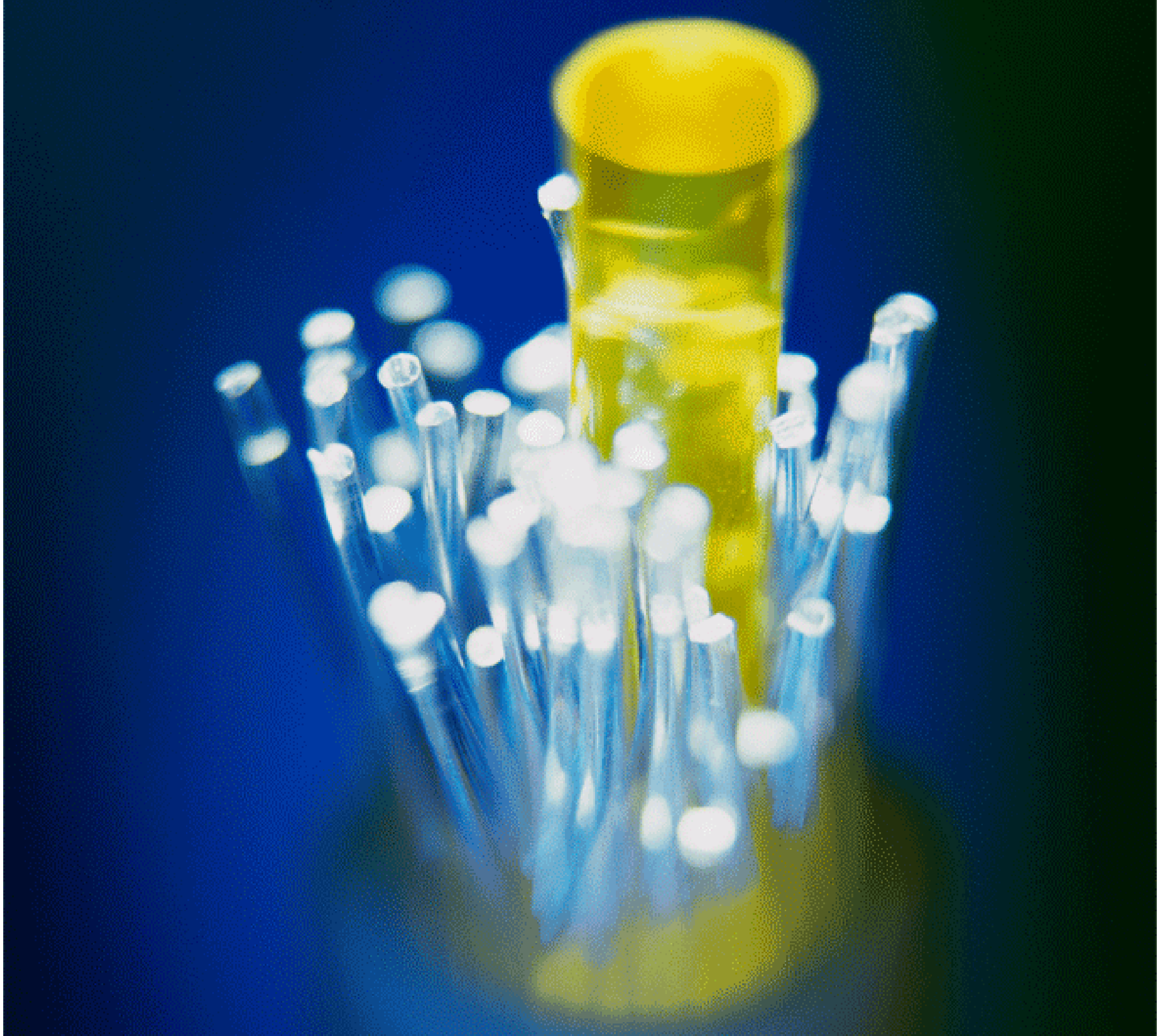

PROVIDING UBIQUITOUS GIGABIT NETWORKS IN THE UNITED STATES

An IEEE-USA Committee on Communications and Information Policy (CCIP) White Paper

14 March 2005

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A new generation of broadband, or "gigabit networks," can mean significant benefits to the United States, but our nation must act promptly to ensure that such an infrastructure is ubiquitous and available to all. If we do not act, the consequence will be to relegate the U.S. telecommunications infrastructure to an inferior competitive position, thus undermining the future of our country's economy. This issue demands the attention of policymakers as well as the public at large.

Accordingly, this paper briefly covers the nature of gigabit networks and the telecommunications infrastructure, followed by principles that should be observed in achieving these new networks. The rest of the paper presents key propositions that establish the benefits, and hence the need, to build out such networks, and it explores the competitive threat from other countries and some current U.S. broadband initiatives.

In short, the paper advocates widespread deployment of wired and wireless gigabit networks as a national priority, to be facilitated by legislative and regulatory action, and achieved through mobilization of resources by users and incumbent suppliers alike.

> **What Are Gigabit Networks?**
> Digital data rate is measured in bits per second, usually expressed as megabits (one million bits) per second (Mb/s) or gigabits (one billion bits) per second (Gb/s). It is also colloquially characterized by the terms "bandwidth" or "speed."
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> Gigabit networks are primarily based on optical glass fiber links. Large enterprises that today operate networks for their own use typically deploy networks of 1 to 10 Gb/s capability, with symmetric (that is, equal) upstream and downstream speed. Where available, some small offices, including those in residences, are already using 1 Gb/s symmetric. Residences of the future are likely to expect 100 Mb/s to 1 Gb/s. Although such data rates may not be used continuously, that capability is essential for particular applications, as described in the text. Networks such as these are gigabit networks.
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> In stark contrast, current broadband based on copper wire or coaxial cable links, such as Digital Subscriber Line (DSL) or cable modem, has a nominal (and asymmetric) speed of, say, 2 Mb/s. Thus, typical data rates on gigabit networks range from 50 to 5,000 times as speedy as current broadband networks, which include Wi-Fi and third-generation mobile networks.

Gigabit Networks and Telecommunications Infrastructure Explained

Gigabit networks, in contrast to current broadband networks, provide symmetric data transport capable of gigabit-per-second (Gb/s) speed and beyond. The first sidebar defines their concept and uses.

The Federal Communications Commission (FCC) uses the terms, ''…*advanced telecommunications capability* and *advanced services* to describe broadband services and facilities with an upstream (customer-to-provider) and downstream (provider-to-customer) transmission speed of more than 200 kilobits per second (kbps)" (Federal Register, 2004). This definition is clearly inadequate.

Nonetheless, the FCC concludes, "…that advanced telecommunications capability is indeed being deployed on a reasonable and timely basis to all Americans" (FCC, 2004). This paper emphatically rejects that conclusion. On the contrary, broadband deployment in the United States seriously lags in satisfying the needs of the world's strongest economy —despite the fact that wired and wireless technologies, in which the United States is the world's leader, are available to redress this situation. Previous IEEE-USA advocacy of broadband deployment in the United States included a position statement (IEEE-USA, 2003), and comments in response to the FCC Notice of Inquiry on Broadband Deployment (IEEE-USA, 2004).

The telecommunications infrastructure refers to the system that carries all information in electronic form. The second sidebar briefly describes the several-layered elements of that infrastructure.

The existing infrastructure includes broadband upgrades to copper local loops (for example, digital subscriber lines and T-1s), data modems and cable networks, and fixed and mobile broadband wireless systems. Even power lines can transmit broadband as defined by the FCC, although this use is still controversial and unimplemented. All these facilities are lower in cost, but also lower in capability, than optical fiber. Although fast technological progress is being made across the board, the copper-wire based alternatives cannot reach fiber speeds.

Extending optical fiber access to end users is progressing. However, it is slowed in part by the high cost of capital expenditures and in part by non-market and anti-competitive business actions (and inactions) by incumbent service providers.

What Is the Telecommunications Infrastructure?
Physical facilities, such as copper, cable, wireless, satellite, and optical fiber, comprise a basic layer of the so-called telecommunications infrastructure. Fiber greatly surpasses the limited capability of copper media. Accordingly, the core of the global telecommunications infrastructure is fiber. Fiber backbones of high capacity are essential to aggregate traffic and interconnect these other facilities.

Various transport modes, in many analog and digital representations, ride on the telecommunications infrastructure, using a layer of logical devices such as switches and routers. Applications, such as telephony, data, and broadcasting, are layered above the transport modes and delivered by them. Finally, meaningful content, such as voice conversations, Internet pages, and video programs, constitutes a layer carried by these applications.

For reference, Appendix A tabulates available broadband access technologies with some current and emerging capabilities. These various technological options are still ahead of market penetration. A prerequisite for gigabit progress is a proactive climate for market-driven, technology-neutral, open-access competition.

How Can We Bring Gigabit Networks into Being?

To secure the benefits essential to U.S. competitiveness and quality of life, we must adopt principles leading to ubiquitous, symmetric gigabit availability as a national priority.

Congress should articulate such a goal in legislation, with associated executive branch responsibilities and private sector incentives (Lieberman, 2002). It should not prescribe the design and specifications of such a network infrastructure. Rather, Congress should prescribe its functionality and performance to achieve U.S. preeminence (or, at the least, parity) compared to the best of our global competitors, as well as the capacity for long-term growth. The current momentum toward legislative and regulatory telecommunications reform should be completed, incorporating the following mandates:

- Recognize and encourage the convergence of voice, data, image and video information into bit streams
- Ensure the greatest possible regulatory flexibility, to allow for unpredictable future service needs, market developments and technological innovation
- Reduce barriers to competition and deployment of user-owned networks, to facilitate continuing market restructuring in the public interest
- Guarantee open access to the networks by content providers competing on their merits
- Improve both the licensed and unlicensed models of spectrum use to increase spectrum efficiency
- Implement the original words of the Telecommunications Act of 1934, namely, *"to make available…to all the people of the United States, without discrimination,…a rapid, efficient, nationwide…communication service with adequate facilities at reasonable charges…,"* in the 21st century context of gigabit speeds

Such a national priority would encourage large end-user aggregations to join in building nationwide gigabit networks. The expertise and resources of incumbent telephone, cable and other experienced providers could be available by contract for network design, construction and operation. Upgrading existing networks would proceed toward electronic and optical gigabit capability as a vital goal. Clear policies as to competition, monopoly, ownership, openness and access would temper the economic forces that might otherwise produce market structure and pricing that do not serve the public interest.

Such reform will take time. Meanwhile, government and corporate bodies are already deploying broadband and gigabit networks to satisfy needs unmet by incumbent telecommunications providers. Regrettably, as already noted, some of these end-user deployment initiatives are being blocked through non-market, anticompetitive actions of rivals — resulting in legislative or litigation impediments. The following immediate actions would protect and encourage such deployments:

- Eliminate anticompetitive legal and regulatory challenges to the deployment of end-user owned networks
- Give municipalities that deploy gigabit networks broader access to such programs as the Rural Utility Service and the Universal Service Fund

What Are the Benefits of Ubiquitous Gigabit Networks?

Policy and investment decisions rest in part on benefit considerations, both qualitative and quantitative. So, first we recapitulate qualitatively the benefits to be expected from ubiquitous gigabit networks. Decisions also rest on quantitative cost. However, until designs and specifications are set, costs are undetermined, although they will be high. Nevertheless, this paper assumes that the long-run economic and social benefits will exceed the investment costs. This assumption relies on the technology advances, which continually reduce cost and expand performance.

That said, ubiquitous gigabit networks are a goal achievable with the deployment of optical fiber and high-speed wireless. During the transition to that deployment, incremental steps in transport speed are likely to include existing and emerging systems, such as hybrid fiber copper or coax, very high bit rate digital subscriber line (DSL), and high-speed microwave.

Ubiquitous gigabit networks will provide superior ability for the U.S. economy to compete globally

The U.S. economy is based on knowledge — its creation, dissemination and application. A knowledge economy uniquely creates new wealth through invention and innovation. Development depends on research that depends on access to the entire body of existing knowledge and the rapid exchange of new knowledge throughout the economy and the society. Modern research typically retrieves, creates and exchanges massive information files at gigabit rates. After the research, many follow-on functions will benefit from gigabit networks, including computer-aided design; integration of design, manufacturing, sales, and distribution; and collaboration among all through high quality video conferencing.

Seamless and rapid communication permits easy access to all knowledge — scientific, medical, economic, commercial, educational, political and recreational. Through ubiquitous gigabit networks the entire U.S. population, urban and rural, could contribute fully to developing our nation's standard of living while overcoming a digital divide that now forecloses productive activity by those without such access.

An explosive emerging application with great stimulative economic potential is digital home entertainment

The incipient convergence of voice, data, music and video bit streams onto a single high-capacity physical medium will expand to provide cost economies impossible to ignore. Apple Computer provides a wonderful example of the symbiosis among three elements: advanced technology, the scale-up of operations to massive markets, and new design. These elements are exemplified through the run-away success of the iPod music player. Apple is contributing to the expansion of the information technology industry, the demand for novel products, and the resulting increase in earnings and corporate value.

Economies of scale occur through fiber, in part because the cost of transporting one more unit of use (that is, its marginal cost) becomes very small by virtue of its huge capacity. For example, future access to a menu of 100 simultaneous video channels at the high definition (HD) digital rate of 20 Mb/s per channel for a diverse audience of end users requires 2 Gb/s capacity. The infrastructure necessary to support facile interaction among the members themselves of such a broad audience demands even greater capacity — a capacity easily available through fiber. Data, music and voice can be added, once such an infrastructure is deployed because these elements have relatively small bandwidth requirements.

Some regional telephone companies (Verizon and SBC Communications) and large cable system operators (Comcast, Time Warner and Cox) have current plans to deliver what they call “triple-play” (video, voice and data) services to selected markets. However, most of these efforts are not capable of serving as a component of a gigabit infrastructure. (All these firms propose residential access through copper-to-the-home except Verizon, which is working on fiber-to-the-home (FTTH) in the wealthiest counties within its operating area.) Further, none is capable of ubiquitous service to its customers, even in its service area. Rather, as quite appropriate to private sector corporations, each proposes service only “where profitable” (which Qwest, in its service area, has concluded is nowhere). Implicit in these business models is limited deployment that would aggravate, rather than eliminate, the digital divide.

Entrepreneurs are already proposing television availability over the Internet. Demand for television in HD format will not be far behind — except for one small matter: no initiative proposed by an incumbent would permit this format. None is an open network infrastructure; each incumbent retains the power (and the clear incentive) to block access to such an Internet service for customers in its region — a power that threatens the very potential of the Internet itself.

The deployment of a proper fiber infrastructure would facilitate and support demand for new consumer electronics such as flat-panel television sets, high-capacity hard disks, and wireless home networking devices. Lack of upgraded networks to carry the traffic would stunt the potential of these products, whereas their combined demand would create new manufacturing and maintenance jobs, both onshore and off. A ubiquitous fiber infrastructure would motivate the creation of more content by motion picture and television studios, performing artists, and World Wide Web sites — all to be indexed by ever more sophisticated search engines. More important, as pilot installations such as the one at Grant County, Wash., have demonstrated, symmetric high-bandwidth capability to the home catalyses a new form of content: end-user created and shared information, extending the need for and the scope of indexing (Grant County Public Utility District, 2004). But U.S. incumbent networks that are asymmetric, low-bandwidth and closed will cripple such content in advance. In contrast, competitor nations are moving rapidly to the superior symmetric networks and fiber-to-the-home with gigabit capability.

Gigabit networks would enhance education and training

First, distance (on-line) learning enlarges education markets, bringing opportunity to those to whom it is otherwise inaccessible because of location or schedule. For example, in Fiscal Year 2004, the University of Maryland University College had 126,341 worldwide online course enrollments — probably the largest number of online enrollments in the world. Let that be matched by another hundred institutions and it is easy to see how the reach of education may be extended. Second, broader bandwidth would enhance educational content by using video clips, video chats and ultimately, even holographic images. Fast links to the world's knowledge would enable rigorous and comprehensive curricula development and easy student access to study material. By definition, education is a good knowledge — of special significance for U.S. competitive advantage, and thus to its economic growth. The economic benefits described above are vital to the nation's ability to maintain and improve its standard of living.

Gigabit networks would facilitate health care delivery

Remote diagnosis and consultation, or telemedicine, is a well known telecommunications application. Telemedicine's utility would increase with the real-time transfer of high-resolution images and video from every medical clinic, urban or rural. National availability of medical records to qualified physicians is an initiative already proposed by the current administration. Although such a system is not yet in place, it would certainly benefit from ubiquitous, high-speed connectivity. Home monitoring capability, ranging from low bit rate summaries of movement to full video, may provide full time links to a family caregiver. This application could be a strong motivation for investment in broadband, because it has both qualitative human and quantifiable economic returns if the elderly can stay longer in their homes.

Even Further Benefits
A number of technologies, such as Gigabit Ethernet, are available now for use on existing fiber networks at very little cost premium over upgrading bandwidth-limited copper loops. The capacity of such networks would provide for future demand that will inevitably grow. Investment in nationwide gigabit networks would create jobs and innovation in the troubled telecommunications industry itself. The adequate capacity and interoperability of gigabit networks would also greatly reduce present challenges in emergency response and homeland security.

The Competitive Threat from Other Countries

Yet, U.S. broadband networks badly lag behind those of many other countries. By one measure, 19 countries have broadband service superior to that of the United States (Perlman, 2004). U.S. maximum public broadband capabilities by DSL and cable modem are in the range of 1 to 5 Mb/s downstream to the user, but generally 500 kb/s or less upstream. By contrast, most South Korean residents have access to 50 to 100 Mb/s, which in many cases is symmetric. South Korea achieved this infrastructure through a government policy supporting deregulation, competition and investment.

That policy jump-started its economy, especially in the information technology sector. Japan, likewise, adopted competitive policies leading currently to widespread 50- to 100-Mb/s symmetric capability and low prices (Conyers, 2004). There is movement already to symmetric optical fiber networks connected to (as opposed to just passing) two million homes, with expanded gigabit availability to homes in 2005 (Optoelectronics Industry Development and Technology Association (Japan), 2004).

In Korea, penetration is in the neighborhood of 85 to 90 percent to businesses and 70 percent to individuals. In Japan, it is approaching 70 percent across the board. The literature also cites the advanced broadband capabilities of Sweden, Denmark, Taiwan, Hong Kong and Singapore.

The aforementioned countries achieved the high penetrations and high capabilities partly because of high population densities and short copper loops, conditions that are more favorable than those in the United States. Nonetheless, these countries have set the bar and we must surmount it, if we are to maintain our current world lead in the creation and use of knowledge goods.

Some Current U.S. Broadband Initiatives

Currently, there are a number of current U.S. broadband initiatives, most of which fall short of ubiquitous gigabit networks, however. In March 2004, President George W. Bush said, “This country needs a national goal for…universal, affordable access for broadband technology by 2007” (*The Wall Street Journal*, 14 September 2004). He did not specify the speed he had in mind, nor did he note that his target of 2007 would be likely to put the United States three more years behind South Korea and Japan.

Verizon Communications is investing $2.5 billion in a large-scale trial to pass three million residences with optical fiber by year-end 2005. SBC Communications will bring fiber to nodes in the neighborhoods, connecting to advanced DSL serving individual residences (Rhoads, 2004). SBC’s DSL initiative is expected to cost $4 to $6 billion over five years. (But, where will Japan and Korea be in five years?) Even advanced versions of DSL have serious bandwidth limitations for the long-term in a continental nation such as the United States, because copper pairs reach absolute physical bandwidth limits that depend on wiring lengths. While the Verizon initiative will use fiber, it will be implemented by means of a ten-year-old “passive optical network” technology that has well recognized range limitations.

Large cable system operators, such as Comcast and Cox, are rapidly upgrading their “last mile” plant to digital transport, typically capable of providing a shared 3- to 5-Gb/s data rate downstream for the whole cable. This capacity will deliver reasonably high-speed connectivity to each subscriber’s premises, but with limited upstream speed. As noted above and fully appropriate to private sector responsibilities, these initiatives will be deployed where profitable, meaning “fiber to the dense” or, realistically, “fiber to the rich.” Again, doubtful profitability would foreclose penetration to non-affluent and dispersed U.S. premises throughout the country. Further, “the money” is in content, not carriage (except under monopoly conditions). So these initiatives rely for profitability on control of content by the network provider, rather than open access by competing service providers. Diversity of information would be limited. The result would be closed networks and restricted content, aggravating the digital divide and limiting the engine of innovation that could otherwise exist. In a word, these initiatives will fall short of providing an adequate nationwide gigabit infrastructure.

Conversely, some current broadband initiatives, clearly demonstrating U.S. technological capability, already approach desirable gigabit network deployment. Governments, corporations, municipalities and universities have by now built their own gigabit networks to serve their end users. These networks are analogous to end-user owned private branch exchanges (PBX), although of far greater speed, coverage and versatility:

- Since 2001, Boeing has provided an example of an early corporate gigabit network. It connects 2.5-Gb/s metropolitan area networks in Seattle and St. Louis to each other, and to its headquarters gigabit facilities at Chicago. It does so through commercial Sprint facilities, but only at 155 Mb/s (Hochmuth, 2004).

- The Utah Telecommunication Open Infrastructure Agency (UTOPIA) is a pioneering municipal initiative of 14 Utah cities, working with DynamicCity as consultants, to bring at least 100 Mb/s to homes and 1 Gb/s to businesses through fiber. They have obtained $85 million initial financing through revenue bonds and are progressing rapidly in deployment (UTOPIA, 2005).

- A number of other end-user owned initiatives reinforce the trend, although we consider it unnecessary to describe them in detail.

Other User-Owned Initiatives

- The Global Information Grid–Broadband Enhancement (GIG-BE) at tens of Gb/s by the Department of Defense, for its own use
- The 40-Gb/s National LambdaRail Network (NRL) by large research institutions such as Cornell University and the University Corporation for Atmospheric Research, for its end-users. (National LambdaRail, 2005)
- The 10-Gb/s Northeast Education and Research Network (NEREN) by New York, Massachusetts, and Connecticut with a spur connecting at Cleveland to Ohio's Third Frontier Network (NEREN, 2005)
- Ohio's 40-Gb/s Third Frontier Network (TFN) "…the most advanced statewide, fiber-optic network for education, research and economic development…" (TFN, 2005)
- Some 200 other fiber communities in the United States (Broadband Properties, 2004)

Also as previously stated, the huge capacity of gigabit networks contributes significantly to the marginal cost of transport, which is close to zero. The economics of competitive markets demonstrates that, under effective competition in any market, prices are forced down to marginal cost — in this case, near zero. That means when marginal costs approach zero, if several suppliers try to compete with each other in transport and in fact establish effective competition, prices will also approach zero. So, nobody will profit and the weaker suppliers will have to consolidate with the one with the deepest pockets. The resulting monopoly will control output and either extract economic (above normal) profits, or be regulated — each choice with its own attendant inefficiencies and inhibitions.

In contrast, the benefit of transport costs that approach zero can be and are being passed through to end users in end-user owned and controlled networks. (Note: It is not economically or structurally possible for end users to monopolize themselves.) Further, end users have the incentive to keep their networks open to content, application and service providers. As a result they can benefit from competition among such service providers, with resulting innovation and lower costs.

Wireless local area networks are being upgraded and someday may satisfy our gigabit definition, especially for mobile users. Already, AllCoNet 2 is a high-speed microwave network intended to provide access to the Internet to approximately 85 percent of the residents, 95 percent of the businesses, and 100 percent of the government and industrial parks in Allegany County, Md. (Marconi, 2003). The wireless industry is developing standards (for example, IEEE 802.11n) aimed at shared speeds in the neighborhood of 100 Mb/s. Although an initiative in Philadelphia, Pa., is not in the gigabit range, that city has undertaken to provide Wi-Fi (IEEE 802.11b) coverage at 11 Mb/s to the entire area. Philadelphia expects benefits from economic development and helping to bridge the digital divide. Wireless facilities, such as fixed microwave, millimeter wave, and Free-Space Optical systems, already meet or approach gigabit speeds. They can complement an overall gigabit network deployment.

Conclusions

Two major conclusions flow from the foregoing analysis:

- A new gigabit infrastructure is readily achievable to meet the nation's needs, given a sense of national priority, regulatory flexibility, and mobilization of user and incumbent resources.

- The consequence of inaction would be to relegate the U.S. telecommunications infrastructure and U.S. innovators to positions inferior to those of competitor nations, thus undermining all aspects of the nation’s current and future life that depend on it.

Appendix A

A number of broadband access technologies are in use in the ongoing evolution — from the public switched telephone network to Internet Protocol based multimedia networks. Table 1 compares some of their current and emerging transport capabilities.

Table 1. Some properties of broadband end-user access technologies

Broadband end-user access technology	Typical data rates	Typical distance limits (order of magnitude)	Comments
Single-mode fiber	10 Gb/s per wavelength Symmetric Dedicated	Up to 100 km without regeneration	Worldwide distances with regeneration
DSL (current)	1 - 10 Mb/s, Asymmetric Dedicated	Up to 6000 m	Data-rate vs. distance trade-off
DSL (emerging)	10 - 100 Mb/s, Some symmetric	Up to 1000 m	Data-rate vs. distance trade-off
Cable modem	1 - 10 Mb/s Asymmetric Shared	Up to 10 km with amplifiers	Higher data rates emerging Data-rate vs. distance trade-off
Wi-Fi	11 or 54 Mb/s Asymmetric Shared	Up to100 m Proprietary up to 10 km	Stand-alone hot spots Networked hot spots Data-rate vs. distance trade-off
WiMAX	75 Mb/s Symmetric optional Shared	Up to 50 km	Data-rate vs. distance trade-off Pre-standard current deployment
Microwave	1 Mb/s - 1 Gb/s	Up to 50 km	Pre-standard current deployment
Millimeter wave (current)	155 Mb/s - 1.25 Gb/s	Up to 5 km (for 155 Mb/s) Up to 2 km (for 1.25 Gb/s)	Point-to-point and networked Data-rate vs. distance trade-off Complements free-space optical
Millimeter wave (emerging)	1.25 - 10 Gb/s	Up to 2 km (for 1.25 Gb/s Up to 1 km (for 10 Gb/s)	Point-to-point and networked Data-rate vs. distance trade-off
Free-space optical	100 Mb/s - 2.5 Gb/s	Up to 2 km (for 100 Mb/s) Up to 1 km for 2.5 Gb/s)	Point-to-point and networked Data-rate vs. distance trade-off Impaired by fog Proprietary deployment

Notes: Symmetric data rates have equal downstream and upstream speeds; asymmetric data rates have unequal speeds.

Dedicated data rates are available to one user exclusively; shared data rates are available to many users in common.

For various technical reasons, distance limit decreases as data rate increases. Therefore the higher estimated distance limits tabulated correspond roughly to the lower data rates as shown, and conversely.

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