Broadband: Bringing Home the Bits[*]

Committee on Broadband Last Mile Technology
Computer Science and Telecommunications Board, National Research Council[†]

INTRODUCTION

Broadband is a means to multiple, diverse ends encompassing family, work, and society generally. In addition to enabling entertainment and e-commerce applications, broadband can enrich the Internet's exploitation as a public space, making electronic government, education, and health care applications richer and more compelling and useful, and it can provide new modalities for communication, notably within communities or families. Broadband commands attention because it enables dramatically different patterns of use that have the potential for disruptive change in lifestyle and business.

This report from the Computer Science and Telecommunications Board's Committee on Broadband Last Mile Technology examines the technologies, policies, and strategies associated with broadband local access connectivity (often referred to as the "first mile" or "last mile" problem, depending on one's perspective) and makes recommendations aimed at fostering its deployment. The committee's findings and recommendations are confined to broadband in the United States and are focused largely on broadband for residences (with some discussion of broadband for small businesses and broader connectivity issues for communities).

Broadband service to the home depends on high-speed data transmission across local access facilities—the communications links and related hardware that link the premises and the rest of a telecommunications network, most notably between the home or small business and the set of interlinked data networks that make up the Internet. These facilities fall into two categories: (1) existing facilities built by an incumbent telephone or cable company for the purpose of delivering voice or cable TV service and (2) new facilities—such as fiber optic cable, wireless, or satellite—constructed specifically for the purpose of delivering broadband. Before broadband, dial-up connections over the public telephone network were the dominant way in which homes were connected to the Internet or other online services. The performance of these modem connections has reached a plateau defined by the bandwidth of telephone circuit switches (more than 50 kilobits per second [kbps] under optimal conditions, but possibly less depending on factors such as line, interior wiring, and modem quality), and further improvements have required new technology approaches.

At present, two access technologies that leverage existing infrastructure—digital subscriber line (DSL) and hybrid fiber coax (HFC; or cable modem)—are maturing, as evidenced by wide availability, industry standards, multiple product vendors, volume pricing, and

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[†] Committee members: Nikil Jayant (chair), James A. Chiddix, John M. Cioffi, David D. Clark, Paul Green, Kevin Kahn, Richard Lowenberg, Clifford Lynch, Richard Metzger, Elizabeth Mynatt, Eli M. Noam, Dipankar Raychaudhuri, Bob Rowe, and Steven S. Wildman. Computer Science and Telecommunications Board Staff: Jon Eisenberg (jeisenbe@nas.edu) and Marjory S. Blumenthal

deployment experience, while others—such as terrestrial wireless and fiber-to-the-home (FTTH)—are being developed and deployed on a smaller scale. The range of technology options captures part of what makes broadband vexing—fiber promises maximum bandwidth; wireless offers pervasiveness, flexibility, and potentially faster deployment; and satellite offers nationwide coverage (albeit with some gaps and limited total capacity). Today, DSL and HFC are most prominent, shape consumer experience, and fuel much of the politics that surrounds broadband. Looking forward, as other technologies such as fiber and wireless surmount cost and other deployment barriers and become more pervasive in residential broadband, providers, consumers, and policy makers alike will face new issues.

The committee's work started in late 1999 and was completed in fall 2001, a period encompassing significant broadband deployment and both boom and bust in the telecommunications and Internet markets. Until recently, only universities and large businesses and organizations had high-speed Internet access, reflecting a favorable economic return on investment in providing service to these customers. In contrast, residences and small businesses (and smaller offices of larger organizations) have been less likely to attract investment. Also, many homes are relatively distant from neighboring homes or are connected today by hard-to-upgrade telecommunications infrastructure, and some are in remote locations—all factors that entail higher per-premises costs and inhibit deployment.

Following roughly a decade of development and experimentation, residential (and small business) broadband services have been available in selected markets for several years and more recently have become mass-market. Cable operators, incumbent local exchange carriers (ILECs), and competitive local exchange carriers offering data services (data CLECs) have been the largest players, complemented by overbuilders (using HFC, wireless, or fiber) and satellite-based providers. The past couple of years have been a period of dramatic growth in broadband deployment—by summer 2001, more than 8 percent of U.S. households were subscribers to broadband service (only a comparative handful had service in 1999). Mid-2001 data also indicate that broadband-capable cable systems reach roughly 60 million households and that a substantial fraction of telephone company central offices support DSL (DSL availability for individual customers is subject to line-to-line variability). At the same time, many communities, especially smaller or more remote ones, lack broadband today, and some households in communities with general availability cannot obtain service owing to particular conditions (e.g., telephone line condition or length, or residence in a multidwelling unit without broadband).

The study period has also been marked by deployment difficulties. There have been numerous reports of poor customer service in terms of both installation delays and poor operational reliability, with charges and countercharges as to whether the data CLECs or incumbents were responsible for reported difficulties and delays in establishing DSL service. The 2001 wave of CLEC bankruptcies and shutdowns called into question the unbundling strategy contemplated in the Telecommunications Act of 1996.

If the committee had completed its work in mid-2000, it might well have done so with a rosier assessment of prospects for investment, strength of broadband overbuilders and competitive local exchange carriers, and so forth. In formulating its recommendations, the committee was mindful of how much the situation had changed just during the course of its work and of how these changes underscore the perils of basing policy on short-term trends (either positive or negative).

Broadband deployment has been the subject of scrutiny by legislators, regulators, communities, the computing industry, and the public at large, and a number of potential barriers have been noted by these groups. Political attention has escalated along with that devoted to the Internet; like the Internet, broadband is linked to social and economic benefits. With sustained improvements in the Internet's core and in network connectivity within many businesses and other organizations, the last mile to residences and small enterprises has come to be viewed by some as a critical bottleneck. Key questions include these:

- What is broadband?
- Why do people need it?
- How much demand is there for broadband?
- How important and urgent is deployment of broadband?
- What is the likely shape of broadband deployment in the coming years?
- Is the pace of deployment reasonable and adequate, or are there failures that necessitate intervention?
- How will broadband deployment be paid for?
- How might the present policy regime for broadband be made more effective?

The multifaceted and dynamic future anticipated by the committee in the findings and recommendations below will be troublesome to regulators and policy makers. This future implies that different forms of intervention will be required in different geographical regions; that intervention should change over time as players enter and leave the market and as the working definition of broadband changes (which could change the number of real options); and that problems will arise, given the typical slowness of the policy-making process. Finally, the ebb and flow of competition will inevitably lead to claims and recriminations of predatory pricing, obstructionist incumbents, partial regulation, and so on. The remainder of this summary presents the committee's key findings and recommendations with respect to these vexing questions.

FINDINGS

Finding 1. Broadband Is a Convergent Platform Capable of Supporting a Multitude of Applications and Services.

Although broadband can also be used to refer to other services, such as digital television, which are not necessarily carried using Internet technology, the main focus of this report—and the issue of most interest to service providers, consumers, and policy makers alike—is broadband Internet connectivity. Although broadband is often associated with particular facilities or transmission technologies used for its implementation, it is a more general concept. With convergence, everything—video, audio, text, and so forth—has become a digital stream that can be transported across the Internet. Taken together with the Internet's layered design, this phenomenon makes broadband Internet a platform that is capable of supporting many different types of applications—the familiar e-mail, World Wide Web, games, audio, and video; new applications not yet in widespread use; and applications yet to be invented. The Internet's design also permits broadband Internet to be run over many different types of communications links—DSL, HFC, fiber, wireless, and so forth. At present, however, such services as television and telephony are different products employing distinct facilities.

The convergent nature of broadband will permit, if not foster, industry convergence and consolidation across traditional industry lines—cable television and telephone service are viewed today as separate markets, but the distinction will make less sense over time. Convergence is a potential enabler of competition: with multiple broadband providers that compete in terms of performance and services, users can switch providers to find the most attractive combination of price and performance. A stovepiped policy environment—where different rules apply to broadband services depending on whether they are provided using cable, public telephone network, wireless, or other technologies—will come under increasing pressure. Technology trends suggest another mismatch between present policy and the nature of broadband services. To obtain greater performance, access networks will likely converge on similar architectures in which fiber reaches close to premises, and high-speed coax, upgraded DSL, or wireless links connect to the premises themselves. Another option is for fiber to be run all the way to the premises. In either case, treating different "flavors" of broadband under disparate regulatory regimes becomes more problematic.

While the similarities are more important than the differences, there is a complicating factor: the capabilities of broadband services based on different access technologies will vary somewhat—e-mail is possible over almost any sort of link (though the experience will be better over a faster link), while high-quality video streaming demands a high minimum speed. The higher ultimate capacity and lower cost associated with providing high downstream capacity mean that the cable operators using HFC would have an easier time entering the telephone market than ILECs would have delivering high-quality video over present-generation DSL, and the latency inherent in geosynchronous satellite services makes them less suitable for telephony, videoconferencing, or games that require low transmission delays. More generally, access technologies have cost and performance trade-offs that vary across different deployment scenarios.

Finding 2. Broadband Should Be Defined in a Dynamic and Multidimensional Fashion.

Policy makers and others have struggled to come up with reasonable definitions of broadband (versus narrowband), and many groups have an interest in such definitions. Broadband definitions are important for monitoring deployment progress at the national, state, or local level. Definitions are also an important component of specific policies, such as eligibility for tax credits or compliance of providers with build-out mandates.

One should view broadband development, deployment, and adoption as an ongoing process that works through several mechanisms: incremental upgrades in the broadband infrastructure, reallocation of existing capacity to broadband, improved end equipment that permits faster performance over the existing infrastructure, and installation of new infrastructure. Today's first-generation broadband technology is not the end point in terms of performance—what is considered broadband today will not be viewed as broadband in the future, much as 300-baud modems appear inadequate compared with today's 56 Kbps modems. Upgrades may or may not require the development of new technologies, but all require investment premised on market demand and willingness to pay. Much like dial-up, which went through a succession of upgrades until it reached the limits imposed by the capacity of telephone switches, broadband has launched a new cycle of incremental upgrades and opportunities for yet more new infrastructure deployment. Unlike dial-up, where the carrier and the Internet service provider (ISP) were distinct and upgrades required only new modems at each end, broadband requires more extensive upgrades to facilities and terminal equipment.

An examination of local access technologies on the horizon, other computing and communications capabilities, and potential applications makes apparent several quantitative performance and application clusters. Today's residential broadband capabilities, which are typified by several hundred kilobits per second to several megabits per second downstream and several hundreds of kilobits per second upstream, support such applications as Web browsing, e-mail, messaging, games, and audio download and streaming. At downstream speeds of several tens of megabits per second, new applications are enabled, including streaming of high-quality video, download of full-length (70- to 90-minute) audiovisual files in tens of minutes rather than hours, and rapid download of other large data files. Reaching this plateau would enable true television–personal computing convergence. With comparable upstream speeds, computer-mediated multimedia communications become possible, including distance education, telecommuting, and so forth. With FTTH, a new performance plateau with gigabit speeds both up- and downstream would be reached; what applications would take full advantage of this capacity remain to be seen.

This interplay between technology capabilities and application requirements is captured in a more general fashion by the two complementary approaches to defining broadband presented below.

Broadband Definition 1. Local access link performance should not be the limiting factor in a user's capability in running today's applications.

For example, today's typical Web browsing is not significantly improved by speeds in excess of 1 megabit per second (Mbps) because of speed-of-light limits on round-trip travel time across the Internet. In other words, upgrading a user's 1-Mbps link with one 10 times faster would not speed up the transfer of a typical Web page. To take another example: for streaming media, increasing local access performance significantly above the rate at which such content is typically streamed today would not improve the user's experience (though, per definition 2, increased capabilities would help spur higher-quality streams).

Broadband Definition 2. Broadband services should have sufficient performance—and wide enough penetration of service reaching that performance level—to encourage the development of new applications.

Capacity improvement and application innovation are tightly coupled in "chicken-and-egg" fashion: an application will not be made available until a critical fraction of subscribers receives a high enough level of performance to support it, yet service providers will not deploy higher-performance broadband until there is sufficient demand for it. The performance of a broadband service should, therefore, be good enough and improve sufficiently to facilitate this cycle and not impede it. Definition 2 also implies a broadband penetration threshold effect: enough users must have a good enough service to provide a sufficiently large market to attract application developers.

Two different notions underlie these definitions. Under definition 1, the presumption is that existing applications and capabilities of the rest of the network will be unleashed by improvements in the local access segment. The presumption of definition 2 is that application innovation will materialize if performance constraints are eased. The implications of definition 2 are familiar today—current broadband service offerings do not provide high enough performance to support applications such as high-quality video, while investment in higher performance awaits demonstration of demand and willingness to pay. The parties demanding improved performance include, along with segments of the public, applications developers and content suppliers that see the potential for new markets that they might serve (but for the availability of more bandwidth) and policy makers who project potential social and economic benefits that would result from deployment of higher-performance service.

While bandwidth is the most significant performance parameter in terms of enabling new applications, others are also important. "Always-on"—a characteristic of almost all broadband services today—is important to enabling certain types of applications. It changes the way in which people experience broadband as a service. Symmetry, which refers to the relative down- and upstream bandwidths, also has implications for the types of applications that are supported. Some applications, such as Web browsing, make modest demands on the upstream channel as they require receipt of much less data than they transmit, while others, such as videoconferencing, require more symmetric bandwidth. Delay affects the performance of time-sensitive applications, notably, applications such as telephony and online games that involve real-time interactions with people.

Finding 3. Demand for Broadband Is Evident.

In the United States, some form of broadband is reportedly now available to more than half of U.S. households, and subscription rates grew rapidly during the period from 1999 to 2001. Penetration rates have grown much higher than the average in markets where broadband has been available for several years. For example, in Portland, Maine, an early test market for Time Warner Cable, about one-quarter of households are cable modem subscribers—a mass market that illustrates the appeal of broadband well beyond a handful of early adopters. Similarly, in the current worldwide leader, Korea, where favorable conditions have already made broadband available to much of the population, broadband subscription rates are reported to be even higher: more than one-quarter of households. In the United States, numerous anecdotal reports of frustration about delays in obtaining broadband service, reliability problems, and nonavailability all support a view of a rising tide of demand and use (as well as problems). These developments indicate that broadband access is valued by a broad base of Internet users, not just a small group of technology lovers, and that broadband is viewed as an important communications service. At present, it is difficult to forecast what the ultimate total "take-rate" will be, though the 1990s penetration of personal computers (PCs) and Internet service to roughly half of U.S. households suggests growth at least up to this level.

Notably, today's demand level has been based mainly on a limited set of applications (e-mail, Web browsing, file sharing, and limited audio and video streaming). Indeed, there is a significant gap between the capabilities of current broadband services and some of the cutting-edge applications that have been touted but are not generally available to the public. One can foresee continued growth in demand for higher-speed services based on applications being used or tested by early adopters in enterprise and campus networks, experimental initiatives in both industry and academia, and the possibilities afforded by increasingly cheap home networks and specialized consumer electronics. With new applications, wider penetration, and broadband's use as a convergent platform for multimedia content delivery, much wider demand and use can occur.

Finding 4. Deployment As a National and Local Imperative

Today, broadband is for the most part an adjunct to home PC use and a means of faster Web browsing, and narrowband alternatives provide some measure of access to commonly used content and services. Thus, one cannot say with confidence today that broadband access in the home is critical to being a functioning member of society. But in light of robust demand and the likelihood that with growing use, new content and applications will make use of broadband capabilities, it is reasonable to project that broadband will take on increasing socioeconomic importance in the future.

There are several principal arguments for taking steps to foster broadband deployment:

- *Spillover benefits*. Because broadband can support many different types of applications and services, its full potential is unlikely to be apparent from scrutiny of any one category. When one looks at a promising individual application today, such as telework, it is easy to see that what exists—in terms of capabilities, use, or benefits—falls short of what some have forecast. But what broadband promises, because of its capacity and general-purpose nature, is the chance to try multiple applications of different types and to provide various mixes that can be valuable to different users. The economic and social benefits in the aggregate will, therefore, exceed those of one application, giving rise to spillover benefits not readily captured by any one stakeholder. For example, broadband deployed for mass entertainment can also carry noncommercial content. To the extent that broadband providers themselves are not able to fully capture the benefits of investment in performance, a broader societal interest in promoting broadband performance improvements arises from these spillover benefits. The willingness of broadband providers to invest will be less than that implied by the broader societal interest arising from these spillover effects.
- *The link between performance and applications innovation and ties to other high-technology sectors*. If broadband is to support new, rich multimedia applications, the gap between computing and deployed last mile communications performance will have to be closed. In the short term, this would translate into upgrading from today's hundreds of kilobits per second to tens of megabits per second— which all of the present generation of wireline broadband technologies can

support, with appropriate investment (shorter loop lengths in the case of DSL and smaller cluster sizes and/or more spectrum dedicated to broadband in the case of HFC), and which are well within the capabilities of FTTH. Although the performance of broadband services today nearly always exceeds that available through dial-up access, the first-generation systems frequently only provide modest speed improvements over older technology, and sustained upgrades would be needed to satisfy both broadband definitions 1 and 2.

- *Per-passing costs of initial investment*. Some infrastructure costs must be borne regardless of how many customers in a given area actually subscribe to a service. Because of the major, even dominant, role of these per-passing costs for wireline infrastructure, investment becomes, in essence, a decision contingent on a finding of collective demand. For wireless, the penalty can be somewhat but not fully offset via a strategy whereby the cluster size served by a common feed is decreased as subscription rates and demand increase. (A similar principle also applies to wireline technologies that permit such clustering, such as HFC, but with less impact on the per-passing costs than in wireless.) Also, early adopters will not be able to obtain broadband service until a service provider decides to make an investment deemed capable of attracting a broad subscriber base. As a service provided over a network, broadband stands in marked contrast with computers, which individual consumers can purchase as the need arises, and which providers produce for a market not tied to a geographic area. Similarly, an individual can upgrade to a higher-performance computer to meet individual demand, whereas broadband services will tend to have capabilities aimed at the average user.

The committee took note of the fact that other countries, similarly recognizing these arguments and the potential societal importance of broadband, have opted for more active strategies than those of present U.S. policy or those that the committee's recommendations below would contemplate, especially at the national level. These national strategies in other countries do not match the U.S. context, in terms of political system, the historical private sector role in telecommunications, geographic diversity and population dispersion, or the nature of the existing telecommunications infrastructure. That is not to say that the goals and means of these strategies are not appropriate in their own contexts.

Finding 5. Many Factors Pace Deployment.

There is a sense in some quarters that something is "broken" with respect to broadband rollout. There are several areas of frustration: concerns over an insufficient rate of penetration of some form of broadband; associated concerns that some areas will end up being left out; concerns that the process of upgrading broadband service could stall, leaving consumers with only the performance offered by first-generation technology; concerns about business failures leaving customers with no broadband alternative; and concerns that the quality of what is being deployed will be inadequate in terms of performance, reliability, or customer service. Given the realities of the situation, what is reasonable to expect with respect to deployment?

Finding 5.1. Broadband deployment will not occur overnight.

The rapid evolution of some aspects of the Internet can lead observers to think that if something does not happen within 18 months, it will not happen. But the phenomena associated with deployment cycles measured in months have generally been in the non-capital-intensive software arena (even here, real change may lag perception) in a sector unconstrained by regulatory uncertainty. In contrast, even with a conservative estimate of the average cost of wiring an individual residence, $1,000, the total cost of building new broadband infrastructure—such as rewiring to provide FTTH to all of the roughly 100 million U.S. households—would be $100 billion. A major portion of this figure is in construction costs that are not amenable to dramatic cost reductions. Even for cable and DSL, where delivering broadband is a matter of upgrading existing infrastructure, economics constrain the pace of deployment. Some broadband deployment will be accomplished as part of the conventional replacement and upgrade cycles associated with telephone and cable systems, but providing broadband also requires additional investment in infrastructure upgrades and broadband-specific equipment. In either new builds or incremental improvements, an accelerated pace of deployment and installation will be associated with an economic opportunity cost.

The bottom line is that broadband deployment and upgrading are gated by a complex policy and economic context, not just—or even mainly—by technology. Furthermore, it is early in the diffusion process, and too soon to judge the final outcome. Thus, today's frustrations do not necessarily justify heavy-handed intervention.

Finding 5.2. The investment rate depends critically on the perspective and time horizon of the would-be investor.

For an owner of existing facilities—the incumbent local exchange carriers and cable multiple system operators—realistic investment is incremental, builds on the installed base, and must provide return on a relatively short timescale. An incremental strategy also reflects the view that there is not sufficient demand for the added bandwidth of all-fiber replacement to justify its greater capital costs compared with an upgrade of existing plant.

Once a provider has a broadband-capable system, that provider will spend on upgrades only enough to continue to attract subscribers and retain existing customers by providing a sufficiently valuable service. An incumbent will also naturally weigh the benefits of investment in new services against the cost of cannibalizing from existing ones. For example, an ILEC's incentive to invest in broadband upgrades may be diminished by the prospect that the new technology may be used to provide services that compete with the ILEC's existing voice and data services. Viewing an incumbent's incentives to invest in upgrades from the perspective of the two broadband definitions provided above, it may be hard for the incumbent to justify spending so that the local access link is not the performance bottleneck, or to be in front of the demand so as to stimulate new applications. Facilities-based competition, and associated pressures to attract and retain customers, could help propel performance upgrades.

Two types of nonincumbent investor have also entered the broadband market, tapping into venture capital that seeks significant returns—and generally seeks a faster investment pace. One is the competitive local exchange carrier (CLEC), which obtains access to incumbent local exchange carrier facilities (central office colocation space and the lines running from there to each subscriber) to provide broadband using DSL. The other is the overbuilder, which enters a market by building its own, new facilities (most commonly, HFC for residential subscribers, but also terrestrial wireless or fiber). Companies may also combine these strategies. Satellite broadband providers in essence overbuild the entire country (or regions thereof through spot beams), although with the capacity to serve only a fraction of the total number of households, and with a different cost structure from that of terrestrial providers. The drying up of Internet-related venture capital that occurred in 2000-2001—and the associated failure of several CLECs—signals difficulties in sustaining deployment efforts.

In addition to providing financial incentives for private sector investment, the public sector can complement and stimulate private sector efforts by making long-term investments in infrastructure that ease market entry and foster competition among broadband providers. Such investment is most likely to occur at the state, regional, or local level, although federal support can play an important role. But decision making for such investments is not a simple matter, and, if present trends are any indication, such investments will be confined to those locales that project the greatest returns from accelerated access to broadband, possess a greater inclination for a public sector role in entrepreneurship, and are best equipped to navigate a complex set of choices.

Finding 6. The Shape of Broadband Deployment

While the long-term outcome of broadband deployment is certainly not clear, the characteristics of the technologies and related economic factors do permit the overall shape of deployment to be predicted with some confidence in the short term.

Finding 6.1. The broadband vision is rapidly evolving and is linked to the Internet and computing.

Broadband is related to several classes of telecommunications services—some stable (telephony), some somewhat stable (entertainment television), and one that is evolving rapidly (the Internet and associated developments in computing, embedded information technology, and wireless communications). Telephony and television exist in useful forms today without needing a new generation of access technology, which suggests that the real driver of the broadband vision is the Internet and the associated computing milieu. The future form of the Internet itself is quite uncertain, with the current market downturn injecting possible uncertainty into the overall cycle of investment and the perception of overall value and utility and so on, which suggests a need for caution when making predictions. Broadband's linkage to the Internet suggests that broadband will change more rapidly—and less predictably—than what was experienced as telephony and television developed.

Finding 6.2. Current trends appear to be able to sustain deployment over the next several years, but beyond that point the outcome is less evident.

Substantial deployment of broadband has already taken place, and both cable operators and ILECs appear to have a commitment to continue along this path (though the pace may be affected by the investment climate, consumer demand, and competitive forces). Significant cost reductions in equipment as mature broadband technologies have reached the mass market are another positive indicator. These factors suggest that infrastructure and business may be robust enough to permit widespread deployment and sustained performance improvements. However, penetration may fall short of universal access, investment in additional facilities may or may not occur, and investment in performance improvements may stall.

Finding 6.3. Broadband is not a horse race among technologies.

While popular accounts tend to focus on which technology or players are "ahead" in broadband deployment, broadband is not a horse race between technologies, with an eventual winner. The long-term outcome will be diversity in technology options, for several reasons:

- *Location matters.* The United States is very heterogeneous in many dimensions—density and dispersion of population, demographics, topography, and condition and age of infrastructure—and it is not reasonable to expect "one size to fit all." Technology diversity promotes greater ubiquity of service, as cable systems fill in where DSL cannot reach today, for example.
- *Incremental investment in existing infrastructure will continue.* Because of investor expectations for short-term return on investment, incumbents will continue to make use of existing equipment and plant and their deployment will be based on incremental upgrades.
- *Continued exploitation of technology skills.* Companies possessing particular expertise will exploit opportunities where these skills give them an advantage. For example, designing, launching, and operating a satellite system requires know-how very different from that required to upgrade a cable or telephone system.
- *Varying levels of technology maturity.* Before wide-scale deployment, technologies must undergo an extensive development process to reduce the costs of components, installation,

and management. More mature technologies will see wider deployment at the same time that less mature technologies are being developed in test markets.

Looking forward, the following trends are apparent for the various technology options:

Cable and DSL Incremental investment building on existing technology bases will continue, together with some investment in new facilities when the right conditions exist. Particularly in denser urban and suburban areas, wireline broadband—HFC and DSL—is being utilized successfully, albeit with some growing pains. The incumbents (both ILECs and cable system operators) have considerable advantage, because wireline technologies have in common that the labor of installing the line is a significant cost component. Since there is no obvious way to decrease these costs dramatically, options that require investment in new wireline infrastructure are at a disadvantage. Also favoring the incumbents are their existing customer base and other revenue sources. There have, nonetheless, been efforts in more attractive markets to overbuild the incumbents to permit new players to enter the broadband (and associated cable TV or telephone) markets.

Fiber-to-the-Home Given its potentially enormous capacity, format versatility, and long lifetime, FTTH is a logical technology end point (complemented by wireless where mobility is desired). Already, fiber is being driven closer to user premises as part of routine improvements to the public telephone network, cable systems, and wireless base-station feeds, and the technology evolution paths for both DSL and HFC rely on fiber optic links that reach closer and closer to the premises. For new installations, the total life-cycle costs of a fiber-based infrastructure are, generally speaking, lower than those for other wireline alternatives because of fiber's long life and because it lends itself to architectures that have no intermediate electronics (which would require periodic maintenance and/or upgrade) in the path between premises and point of presence. The advantages of FTTH are offset by two cost penalties: (1) instead of leveraging existing wireline plant, a provider incurs the cost of installing new fiber optic cables (and, depending on the architecture, splicing the cable) and (2) at present, the terminating equipment is more expensive, reflecting the cost of the optoelectronics and today's lower product volumes. Terminating equipment costs can be expected to drop as the technology is engineered for mass deployment and production volumes increase. Because they ultimately are tied to the cost of labor, fiber installation costs are less susceptible to cost reduction, but there have been advances in splicing equipment, and a variety of techniques have been proposed to reduce fiber installation costs in particular situations (including creative ways of exploiting existing rights of way).

Meanwhile, there is considerable scope for incremental gain from all access technologies and a great deal of inherent capacity in HFC (because of coaxial cable's very large theoretical bandwidth). Also, a gap currently exists between the capacity of FTTH links and the capacity of typical links to the Internet core, which means that with FTTH deployment, the capacity bottleneck is simply pushed upstream (except for applications that rely only on local bandwidth). Pervasive fiber deployment to the premises thus awaits investor belief that the necessary demand exists, a leap of faith that the demand will emerge once very bandwidth-intensive applications take hold, or a long-term investment horizon. FTTH will be more attractive where there is either no existing infrastructure or where a provider opts to compete with the incumbents by providing a very-high-capacity alternative. FTTH is being used in green-field developments, in some community-based initiatives, and by a few overbuilders in small-scale deployments. As a general rule, FTTH will be deployed when a combination of economics, demand, and capabilities (compared to alternatives, including the infrastructure already in place) justifies the investment.

Wireless Wireless technology offers mobility and the most flexible deployment scenarios. In the shorter term, satellite and fixed wireless are being used to support market entry by providers that lack wireline assets. Fixed wireless may also offer a longer-term residential broadband option, especially in less densely populated areas or areas able to support a larger number of facilities-based competitors, and satellite has an obvious niche in reaching remote areas. To reach the most remote few percent of U.S. households, the high fixed cost of building and launching satellites is offset by low per-passing costs. While so-called third generation (3G) wireless will provide more capabilities than present systems do, the throughput per user falls short of a reasonable definition of broadband. Wireless local area networking technology using the IEEE 802.11b standard is beginning to emerge as an alternative model for untethered broadband access in public places (using both commercial and noncommercial models). Looking forward, advances such as robust multicarrier modulation and space-time processing with antenna arrays will benefit wireless across the board—not only higher-performance fixed wireless, but also enhanced mobile cellular systems, which offer ubiquity and mobility, and wireless local area networks (LANs), which provide complementary "last meters" access. Wireless is expected to continue to lag wireline in bandwidth, but its greater flexibility, anticipated performance improvements that would make it "good enough" for many applications, and the equipment cost reductions that come from reaching mass-market volumes, can make it a long-term competitor.

Finding 6.4. There will be substantial geographical variation in the nature of competition.

Diversity in technology will be accompanied by diversity in the competitive landscape, with different degrees of "natural" competition—competition that is facilities-based or that occurs through voluntary business arrangements with facilities owners. With broadband, local conditions are very important, and the distribution of broadband availability will be quite uneven, especially in the earlier stages. No matter what regulatory approaches are applied (short of policy embracing a single monopoly provider), all of the following outcomes are likely to occur in one or another region of the United States:

- *Type 0—no terrestrial providers of broadband.* This is not uncommon today despite significant deployment, but it can be expected to become less common as the near-ubiquitous public telephone and cable networks are upgraded to support broadband. There is no region of the lower 48 states that entirely lacks service today, because some form of satellite-based broadband is possible wherever the user is able to install an antenna dish with line-of-sight view of the satellite (albeit with cost and performance inferior to what would be possible with access through alternative technologies if they were to be available).
- *Type 1—one terrestrial facilities-based provider in the area (e.g., cable but not DSL, or vice versa).* This common circumstance will diminish to the extent that the incumbent telephone companies and cable operators both expand their broadband coverage. It will persist where the market is perceived to be large enough to support the first entrant but not large enough to attract a second incumbent provider.
- *Type 2—two terrestrial facilities-based providers.* This will be a common long-term outcome. The incumbent telephone and cable provider will both upgrade to support broadband, but no other provider will enter the market. One or both may choose to support multiple higher-level service providers such as Internet service providers. Alternatively, one of the incumbents and an overbuilder (using wireline or wireless technology) could provide broadband service.
- *Type 3—one or more facilities-based providers install new infrastructure to compete with the incumbents.* This has occurred in limited fashion so far, with companies such as RCN overbuilding with HFC, and Sprint and WorldCom overbuilding with terrestrial wireless in selected markets. The financial viability of type 3 competition—and prospects for competition beyond that offered by the incumbent telephone and cable companies—will be tested over the next few years.

Finding 6.5. The vitality of the CLEC industry is in doubt, but the source of apparent troubles is uncertain.

In 2001, the vitality of the data CLEC industry, which has provided broadband retail competition in a number of markets, came into doubt. Charges and countercharges were made as to whether the CLECs or incumbents were responsible for reported difficulties and delays in establishing service, a number of Federal Communications Commission (FCC) proceedings were held on the matter, and fines were assessed against ILECs. The possibility that incumbent-deployed technology (such as fiber-fed remote terminals) might complicate or preclude copper loop unbundling added an element of uncertainty. A wave of CLEC bankruptcies and outright shutdowns disrupted service and left some consumers without any broadband alternative. It is unclear whether the CLECs' apparent woes were due to the better engineering and operational practices of the incumbents, to unrealistic undercapitalization, intrinsically flawed business models, poor management, anticompetitive practices, failures of their business partners, or insufficient added value relative to the incumbent, or to some combination of these factors. Where this alternative no longer exists, there is less price pressure on ILECs offering broadband and one less option for access to alternative ISPs.

Finding 6.6. Unlike the underlying communications technologies, the capabilities of deployed broadband are not on a Moore's law-like curve.

Unfavorable comparisons are sometimes made between sustained improvements in the performance-to-price ratio of computing and lagging improvements in the capacity of broadband local access links. From this perspective, and consistent with broadband definition 1 above, local access links are a bottleneck. The communications technologies themselves—most notably, ongoing improvements in fiber optic transmission speeds—have in fact kept pace with or surpassed improvements in computing. The gap that exists is between *deployed* access technology and computing technology, reflecting economic considerations rather than an inherent mismatch.

Finding 7. The Relationship Between Broadband and Content and Applications Businesses Is Critical and Is in Flux.

Today's debate over ISP access to cable broadband systems puts a spotlight on a more general possibility that is motivated by a range of factors—that increased ties between communications technologies and the content and applications that run over them could result in an Internet that is balkanized (even as the industry consolidates), is less open in character, or is less supportive of application and service innovation. Past experience with content-conduit relationships suggests a range of possible long-term outcomes for broadband. Telephony has long followed a common carrier model in which content and conduit have been cleanly separated. Cable operators today have considerable control over the content carried by their systems. Such content-conduit ties have been a source of financial strength; cable-unique services helped fuel the industry's growth beyond its community antenna television roots. These ties are also associated with business and regulatory complications.

With dial-up Internet access, the ISP and phone carrier were separate entities; customers were free to select from among a wide array of ISPs. Internet connectivity was often understood to mean access to the full range of content and applications available via the Internet, though there were ISPs offering services ranging from full connectivity to delivery of comprehensive, proprietary content and services. The availability of services offering full connectivity, together with ISP diversity, has been an enabler of experimentation with new applications and services. Going forward, broadband Internet service providers have a choice of offering full, unrestricted connections to the Internet or evolving toward a more defined package of services (using Internet technology). In the early days, when the business side was still developing and the user base was smaller and generally more sophisticated, users expected to be able to do anything with their Internet connection, services were geared more toward these users, and with a few exceptions, the ISPs were not strongly differentiated in terms of the content or services they provided. When cable operators started offering broadband, they opted to do so through exclusive ISPs, more recently evolving to offer a set of ISP choices.

Today, the provider industry is more mature (and more consolidated, especially in broadband), users are not all technology-savvy, and providers are becoming more sophisticated about consumer behavior and about how to make money. ISPs are seeking opportunities for additional revenue streams by bundling additional services, establishing preferred content and services (even restricting access to particular content and services), and defining tiered services. These factors all suggest the rise of alternatives to traditional Internet access that offer a more limited, defined set of content and services that could change the fundamental nature of the Internet as experienced by consumers. While consumers may differ in their preference for one type of service or another, it would represent a significant shift in the communications landscape if they were to lose the option of full, open Internet broadband connectivity. Voluntary measures—and those adopted in order to obtain permission for mergers—have given cable broadband customers some choice of ISP and thus decreased restrictions on access to Internet content. These responses to critics may address concerns about the potential market power of facilities owners, but their effectiveness remains unproven.

RECOMMENDATIONS

The present policy framework for broadband, which revolves around the Telecommunications Act of 1996, is problematic and is unsuited in several respects to the new era of broadband services. The significance of broadband data communications was appreciated in general terms by some of the key players that shaped the act (and is reflected in multiple sections of the act dealing with advanced services), but the central role of the Internet (and the rapid rise in popularity of applications running over the Internet, such as the World Wide Web) in the communications landscape was not fully anticipated. Framed before the Internet was fully commercial, the Telecommunications Act of 1996 devotes much of its attention to the voice telephony market and maintains distinct rules for the various communications networks (telephone, cable, cellular, broadcasting, and so on). To stimulate competition, the act employs both facilities-based competition, in which providers compete head-to-head using their own facilities, and unbundling, in which incumbent telephone companies are required to provide network elements—most notably, the copper lines that run from the central office to each subscriber—to competitors at regulated prices.

While implementing some of the recommendations below would require changes to the Telecommunications Act of 1996, many would not. Viewing the act's provisions as only one of a number of factors shaping broadband deployment, the committee believes that revision of the act or associated regulation is not critical at present, but that changes in light of the realities of broadband will become increasingly important over time. At the same time, the committee has not shied away from making recommendations simply because they would be inconsistent with the provisions of the present act. Further, the committee anticipates that in view of the public spotlight enjoyed by broadband, there will be multiple efforts to change the act itself as well as to undertake more evolutionary changes within the act's framework. Rather than comment on the merits of any particular pending legislation (the committee is explicitly not doing this), the committee offers the recommendations below as guidelines, as broadband policy evolves over the next several years.

Recommendation 1. Prioritize Widespread Deployment and Defer New Regulation in the Early Stages.

The committee is mindful that there is a tension between permitting private sector deployment of broadband to proceed without any hindrance from government intervention and society's desire to guide the outcome. Decision makers will have to balance the inevitable calls to shape broadband toward some particular end against the "natural" trajectory defined by user preferences, private sector investment, and the market. The committee's specific, pragmatic strategic preference is to promote broad deployment relatively quickly and to foster facilities-based competition.

Recommendation 1.1. Avoid present-day policy making that is based on presumptions about the final form of broadband markets.

Some forms of intervention to expand access could deter investment from taking place at all, which suggests prioritizing widespread though not universal deployment over addressing access gaps early on. Because government intervention may affect private sector investment decisions, it should be undertaken with great care in this nascent area in order to avoid unintended consequences. Also, resolving the chicken-and-egg dilemma depends on broadband reaching some critical level of penetration if new content and applications are to take off. Once a mass market is achieved—which brings with it prospects of new applications and business opportunities—there is a likelihood that demand and willingness to pay will increase, which in turn may attract new players to provide competition, and decrease the need for regulation. Also, learning more about the nature of consumer desires and the shape that the technology and associated markets "naturally" take will help inform the policy debate. It is, for example, premature to conclude that facilities-based competition is or is not feasible in many locations. As the shape of broadband deployment starts to become clearer, a firmer basis for broadband policy will be in place.

Recommendation 1.2. Complementary to favoring policies facilitating rapid deployment over intervention, develop and implement enhanced monitoring of deployment, investment, and market outcomes and develop metrics to permit independent evaluation and rating of performance.

The committee acknowledges that the approach reflected in Recommendation 1.1 is different from that of others who advocate increased early attention to ensuring access to all or who argue that it is essential to shape the behavior of incumbents (telephone or cable) or to otherwise regulate the competitive environment early on. There is, indeed, some risk that if facilities-based competition does not materialize, the committee's recommendations could lead to a stagnant scenario in which incumbents face little competition and deploy and upgrade broadband services slowly. Thus, attention should be paid to distribution and performance variations as well as to overall rates of deployment. It is also essential for regulators to watch for undesirable outcomes that would have long-term consequences—most notably, abuse of market power. Monitoring would provide a basis for distinguishing between unrealized concerns and actual provider behavior, and would help inform public debate about the need for possible regulatory intervention.

Detailed data on market penetration are hard to gather, inconsistently described, and often proprietary. Likewise, it is difficult to acquire solid data or assess commercial claims about costs and markets. To monitor the shape of broadband deployment and refine policy responses, government at all levels needs a consistent picture of data on total market penetration, the extent of competition, and other key indicators of future trajectories. Since national averages tell very little about variation in levels of local competition, these data must be gathered at a fine grain—even community by community—and they must be updated on a regular basis.

At this point in the deployment of broadband, when the mature form of the market has not emerged, it is more important to watch for signs that the market is not serving important policy goals than to predict the final outcome now. These concerns suggest the following as key indicators to track:

- What percent of the population is situated in what sorts of competitive context—regions of type 0 through 3? Which of these regions are expanding and contracting over time?
- For different applications, is the performance perceived by the consumer improving or deteriorating? This is a measure of whether, by broadband definition 1, services available are actually broadband. Sound metrics of performance and means of monitoring their trends would have to be developed and agreed to.
- Are new applications that depend on high bandwidth emerging? If they do not, it would be an indication that by broadband definition 2, the services being deployed are not broadband.
- How effective are emerging alternatives to formal regulation? Open access policies aim to limit the market power of incumbents (both local exchange carriers and cable operators) in providing broadband services, reflecting concerns that facilities-based competition may not provide a robust alternative in all circumstances and that incumbents' ability to leverage past monopoly status should be bounded. Existing unbundling and resale rules require incumbent local exchange carriers to provide would-be competitors with access to the local loop, so public attention to open access has focused mainly on cable system operators. The year 2001 saw the development of a potential template for the industry as a whole: conditions on the AOL-Time Warner merger, which were agreed to by the Federal Trade Commission, were developed in the face of significant pressures to block the merger. Ongoing scrutiny of that industry, such as that to be carried out by the appointed monitor of the AOL-Time Warner merger, is needed, to determine if emerging alternatives to formal regulation will prove adequate.
- Is subscriber access to certain Internet content or services being blocked or impaired (as compared with other content)? The open access issue is one manifestation of a broader question of the extent to which nondiscriminatory access to Internet content and services will continue with a shift to broadband. Impairment of subscriber access in any industry segment would be an indication of undesirable consequences arising from vertical integration of content and broadband communications businesses.

Recommendation 2. Structure Regulation to Emphasize Facilities-Based Competition and to Encourage New Entrants.

Recommendation 2.1. In the long term and in the case of investment in new facilities, policies should favor facilities-based competition over mandated unbundling.

Current regulation of the ILECs contemplates three forms of competition—(1) facilities-based competition, (2) competition enabled via unbundling of ILEC network elements, and (3) competition through resale of ILEC services. In facilities-based competition, providers rely substantially on their own local access facilities rather than relying heavily on access to local access facilities owned and operated by other providers (a facilities-based provider might make use of backhaul links from other providers). Unbundling, in which ILEC network elements are made available to would-be competitors at regulated prices, was initiated as part of the 1996 act's attempt to stimulate competition in both the local and long-distance markets and to reflect the advantages of scale and scope enjoyed by ILECs. For cable operators, the only access requirements have arisen in the context of mergers and acquisitions. Current regulation is ambivalent and sometimes ambiguous as to which is the preferred approach.

Per the taxonomy presented in Finding 6.4, the policy goal with respect to competition, simply put, should be to increase the prevalence of type 3 conditions in place of type 2, shift type

1 conditions to type 2, and so on. Increasing the extent of competition through facilities ownership (and voluntary business arrangements to open facilities) rather than relying on regulation that mandates unbundling is important for several reasons:

- *It reduces the need for persistent regulatory intervention.* Until there are effectively competitive facilities-based alternatives to the incumbent monopolist, full deregulation is very unlikely to come about, and there will be a continued need to regulate such things as the terms and conditions of access to incumbent unbundled elements.
- *It permits the natural (i.e., competition-shaped) character of broadband service and industry structure to be discerned.* This helps define an end-point goal for regulation in those regions where competition is less robust. Otherwise, since broadband cannot be precisely defined without learning much more about consumer preferences and the shape of the market where consumers have a real choice, regulators could strive toward the wrong outcomes.
- *It promotes diversity.* Facilities-based competition better supports diversity in both the technology base (which makes broadband more adaptable to changing user needs and circumstances) and more diversity in types of cost structures (which makes broadband more robust in the face of changing business circumstances).
- *It avoids deterring competitors from investing in their own infrastructure.* While unbundling is often offered as a stepping-stone to facilities-based competition by providing a revenue stream to a start-up firm, it can also inhibit facilities-based competition by reducing the incentives for competitors to build new facilities (or upgrade existing ones).
- *It removes a disincentive to new investment by incumbents.* To the extent that the unbundling requirements are extended to new network elements deployed by incumbents to offer advanced services, such as fiber-connected remote terminals, it is a disincentive for investment by the incumbent in such enhanced facilities, because the incumbent cannot capture all of the benefits of its investment. In making this observation, the committee is not necessarily accepting at face value ILECs' assertions that their investment decisions are driven chiefly by unbundling requirements when there are other plausible explanations (such as the benefits of not having to face the threat of CLEC competition or pressures for financial results). Nonetheless, the incentive level is critical, especially if investment is to occur in lower-density or poorer areas where the business case may be less attractive.
- *It avoids costs and organizational complications associated with coordination between incumbents and competitors.* Organizational coordination problems arise because the incumbent's and competitor's interests are not aligned, a difficulty manifested in delays and confusion in provisioning DSL service. The coordination issues give rise to extended regulatory proceedings, with the associated delays and expenditure of resources.
- *It facilitates technical optimization of total bandwidth.* Crosstalk among telephone lines constrains DSL performance. Bit rates and corresponding ranges can be improved when transmissions can be coordinated so as to minimize interference. Logical-layer unbundling (see below) is another way to facilitate this.

In its focus on investment in new facilities and the long term, the committee distinguishes between how to treat the existing telephone copper plant facilities and new facilities. The case for the present unbundling of the copper plant rests on the premise that the public should benefit from past investment made when the telephone companies enjoyed a (regulated) monopoly position. Also, changing present policy would severely disrupt the business plans of today's CLEC industry. Thus, it is reasonable to maintain unbundling rules for the present copper plant.

It is when looking to the future, to investment in new facilities, that reconsideration of unbundling is most important. Because the objective is to minimize disincentives for new investment, existing unbundling rules should be relaxed only where the incumbent makes significant investment to extend service to areas not served by existing infrastructure or to facilities constructed to enable new capabilities. Investment for routine maintenance or minor upgrades should not be sufficient to result in exemption from unbundling requirements. That assessment must also take into account the extent to which an incumbent's control over the existing plant can be leveraged to gain an anticompetitive advantage in offering broadband over new facilities.

At least in more densely populated, more affluent areas, facilities-based competition appears to be possible. That is not to say that sustaining facilities-based competition will be easy, and policy should reflect this reality. If more facilities-based entrants in an area are successful, each provider will have a lower take-rate and increased facilities competition may be accompanied by higher prices. But the policy objective of competition is not simply lower prices; the aim is also to increase quality, stimulate investment in upgrades, and provide meaningful consumer choice—and consumer education about these other factors may be necessary.

Facilities-based competition can be stimulated by reducing barriers to entry. Certain forms of access—such as access to rights-of-way and (possibly incumbent-controlled) poles and conduits—stem from privileges granted or property controlled by governments and are not a direct product of the innovative activities of a competitive firm. Governments should devote increasing attention to this type of access so as to reduce obstacles to new facilities-based entrants.

Recommendation 2.2. Favor alternatives to physical unbundling.

In cases where facilities-based competition is found to be insufficient, the most common regulatory alternative is some form of mandated unbundling. An example is the currently debated opening up of cable systems to unaffiliated ISPs. When policy objectives call for the opening up of incumbents' facilities, this goal can be achieved in several ways, either at a low level, by unbundling the physical links of the provider, or by unbundling some higher-level service. In physical-layer unbundling, a competitor to the incumbent gains direct access to the electronic signals on the wire (or light on a fiber) running from the subscriber to a central office or remote terminal; can adopt whatever transmission scheme it chooses to; and is free to compete on speed, quality, and other transmission characteristics. However, the ultimate performance and reach of the physical links may be impaired by such low-level sharing. Options for enhancing DSL, such as coordinated assignment of copper pairs and coordination of transmitted signals among pairs, cannot be implemented if competitors are free to implement their own technology. Similarly, low-level unbundling of cable, for example, allocation of different frequency bands to different providers, raises the risk of interference among signals and overall loss of quality and operational stability. No individual purchaser of unbundled access has an incentive to internalize the interference problems its traffic causes for others.

Logical-layer unbundling exploits the layered way in which broadband services are implemented. It is the basis of today's cable open access initiatives. Higher-layer services concerned with transmitting bits are implemented on top of protocols concerned with transmitting electrical signals across the wire, which means that they can be implemented independent of the particulars of the physical layer connection. That is, a competitor need not control the actual signals running over the wires if it can implement its service using bit transport capabilities provided by the incumbent. In addition to facilitating measures to address the crosstalk problem, logical-layer unbundling may be a more practical way of providing unbundling as fiber is pushed deeper into the telephone network and the termination point shifts from the central office to remote terminals.

A principal disadvantage of logical-layer unbundling for the competitor is that the performance characteristics of the link implemented by the incumbent may restrict the types of services the competitor may offer and limit the competitor's ability to differentiate itself from the incumbent. Nonetheless, in the long term, particularly with respect to new facilities, logical-layer unbundling would provide a better foundation for technology-neutral broadband regulation, provided that facilities owners are not permitted to exercise market power with respect to transport.

The current situations of the ILECs and the cable providers differ somewhat. The physical links of the ILECs, specifically the local loops and subloops, are currently subject to physical-layer unbundling requirements, which has allowed a number of data CLECs to enter markets. The cable debate about open access has, in contrast, been centered at a higher service level. In the long run, a convergence toward a uniform open access policy based on logical-layer unbundling may be the best outcome. The cable industry claims that it will implement logical-layer unbundling voluntarily. If this outcome does not occur, mandated open access may well be the regulatory response (unless a much more competitive landscape appears). In the case of ILECs, regulators should consider whether the goal of robust competition among different services offered by different providers could be better achieved in the long run through logical-layer unbundling rather than physical-layer unbundling, especially as the telephone plant evolves to make increased use of remote terminals.

Recommendation 2.3. Anticipate that facilities-based competition will not occur in all places, and fashion appropriate policies to address these gaps.

While their boundaries are difficult to forecast and will likely change over time, it is reasonable to anticipate areas where there is a single terrestrial provider. These type 1 areas will generally exist where population density is lowest and the per-passing cost burden is highest, making the business case for entry by a second facility owner unattractive. In these areas, policy makers will face the challenge of how to address a noncompetitive broadband market. Questions that must be addressed in fashioning such policy include whether and how to intervene, how long to wait before assuming that a rough equilibrium situation of only a single facilities-based carrier has been reached, what impact either mandated unbundling or voluntary facilities-sharing have on the competitive landscape, and to what extent satellite-delivered broadband (with less attractive price or performance) provides sufficient competition to the terrestrial facility owner.

Local conditions may also change over time—especially early on—and thus the extent and approach to intervention will have to change. This flexibility will challenge traditional regulatory approaches, which move more slowly. Consider the most complex case: a competitor withdraws (transforming a type 3 region into a type 2 region, for example). A result may be a need to increase regulation of the survivor. This outcome would certainly be characterized by the provider as unfair after-the-fact rule changing, but this sort of eventuality must be anticipated. Thus providers might face a changing and nonuniform set of business conditions—a situation that, while potentially confusing for providers, reflects the realities of their operating environment.

Recommendation 2.4. Ensure appropriate radio spectrum for broadband and associated capabilities.

Wireless is well suited for certain less densely populated regions, offers an additional path for entry by new facilities-based competitors, and, if suitably configured, is unique in its support for mobile use. Both licensed and unlicensed spectrum plays a role in enabling various wireless broadband alternatives as well as local area and mobile capabilities that complement and supplement wireline broadband access. The committee did not examine in detail whether current spectrum allocations are sufficient or appropriate, but notes that spectrum availability is a precondition to any wireless deployment. Nor did the committee evaluate the merits of various allocation schemes or the trade-offs between allocations for fixed versus mobile, licensed versus unlicensed, or unshared versus shared uses. Efforts to examine spectrum policy to support broadband and related services (both current and contemplated), such as those being undertaken by the Federal Communications Commission, should be continued.

Recommendation 3. Reflect the Convergent Nature of Broadband and Target Policy at the Appropriate Layer.

The Telecommunications Act of 1996, which for the most part assumes the continued existence of a number of distinct services that run over distinct communications technologies and separate infrastructure, does not fully reflect the convergent nature of broadband (different communications infrastructures are able to deliver a similar set of services using a common platform, the Internet) nor the evolution toward a common technology end point (deep penetration of fiber, complemented by short runs to the premises).

Recommendation 3.1 Move toward a more coherent, consistent policy framework for broadband.

Failure to move toward a more coherent, consistent policy framework could lead to policy-induced distortions in technology deployment. For example, even as several major cable operators have entered into open access agreements, the industry has considerably greater control over access and content than do the telephone companies, which fall under industrywide common carrier rules. A more coherent policy would also better accommodate technological innovation beyond today's HFC and DSL systems. Progress in rationalizing the overall regulatory framework (which would require revision of the Telecommunications Act of 1996)—to address the mismatch between convergent services and stovepiped regulation—would also help reduce uncertainty and thus could stimulate investment. In the process of reconciling policy across technologies (and associated industries), policy should emphasize broad deployment and facilities-based competition (Recommendations 1 and 2) and not simply apply existing regulations that were designed to deal with circumstances particular to individual technologies (or associated business). Also, technology convergence notwithstanding, policy should be able to accommodate a diversity of business models as incumbents and entrants alike experiment with different business strategies. These realities are generally appreciated by the FCC as well as by the regulated industries themselves; the issue today is how and when the regulatory framework should be reformulated.

Recommendation 3.2. If regulation of a broadband-delivered service is contemplated, it should be done in a service- rather than a technology-centric fashion.

Reflecting political or social interests, various communications services—such as today's broadcasting and telephony—are subject to regulation. It is reasonable to anticipate that services delivered over broadband will be subject to similar scrutiny, and thus it is prudent to identify the most appropriate means of regulating them. In formulating any future regulation, one should focus on the service rather than on the particular transmission technology.

Flexible service-centric approaches that tolerate technology diversity are essential, because broadband-delivered services are subject to faster change and greater variation than conventional services because of the general-purpose nature of the broadband infrastructure over which they run. For example, if broadband were used to provide telephone service intended to substitute for conventional telephone service, regulators should focus on the marketing of the service to ensure that the promised reliability and 911 service were in fact delivered, rather than on the technical means by which the service is provided (whether over the Internet or otherwise). Defining regulated services this way not only encourages convergence by relying on a technology-independent way of describing the service, but it also tolerates service diversity by permitting different types of services to be defined. One might, for the purposes of regulation, define two classes of telephone service: (1) a service intended to substitute for conventional phone service (providing high reliability and 911 service) and (2) a less costly service for more discretionary uses. Another reason to move toward a service-centric approach is that the assumptions underlying regulation of services are frequently tied to the characteristics of particular technologies. For example, regulation of broadcasting has been fashioned in an environment of over-the-air channel scarcity, a condition that need not apply to broadband-delivered services.

Recommendation 4. Take Active Steps to Promote Increased or Accelerated Deployment, Including at the Local Level.

As described above, the economics associated with investment in broadband suggest that, absent some additional impetus, achieving nationwide broadband deployment may be a protracted process. In at least some parts of the country—type 0 and 1 regions—there may be little or no broadband deployment or facilities-based competition, and intervention may be required. Type 2 areas, in which the telephone and cable incumbents constitute a duopoly, are also places for government at all levels to explore intervention that would encourage new entrants where the market appears to be capable of supporting more participants. Many of these incentives should be locally based, because there is considerable local diversity in the conditions for broadband deployment.

Recommendation 4.1. Establish a federal and state policy framework supportive of local initiatives that ease market entry and foster competition.

Current broadband policy is largely federal in scope, and it assumes, at least implicitly, a uniform national approach. But the degree of natural competition and prevalence of technology will vary by region, state, and municipality, and policy at all levels will have to accommodate this diversity. Federal rules should continue to bound the range of outcomes—for example, by preventing local governments from raising unreasonable barriers to entry or from discriminating in providing access to public facilities, and by preventing a proliferation of inconsistent local rules that can complicate and deter investment. But because it is communities themselves that have the most at stake in regard to broadband service, there are appropriate forms of local decision making, based on local conditions and needs. Particularly at the municipal level, various sorts of incentives and local arrangements can encourage and even shape the form of broadband deployment that occurs (e.g., localities may target their communications purchases as a way to encourage an entrant).

Recommendation 4.2. Explore public sector initiatives that foster market entry.

Initiatives involving public sector actors may provide an alternative to imposing unbundling requirements on incumbents in order to provide increased competition in type 0, 1, and 2 circumstances. These initiatives should be articulated, researched, and evaluated with a focus specifically on reducing barriers to entering competitors by building or facilitating enabling infrastructure.

A decision to provide a publicly funded broadband service—which might be done in an attempt to introduce service where there currently is none—can affect the number of broadband providers in a given area. In cases where a market is capable of supporting only one private provider, the introduction of a public network to compete with it could have the effect of driving the private sector network out of operation. Similarly, the creation of a public network could deter future entry into a market capable of supporting only a very limited total number of players. Also, where government bodies enter into exclusive arrangements with a single company, there is the risk of regulatory capture. These factors all argue that local governments should concentrate on taking steps to encourage and facilitate competition among private sector players, rather than creating new quasi-monopolistic entities. Options include these:

- *Fiber condominium arrangements with public participation.* A locality declares its intention to build out fiber along its streets and invites any interested parties to purchase some share of the fibers installed (and possibly installs additional dark fiber for future use).

- *Customer-owned condominium arrangements.* Customers own links to a suitable aggregation point. This option would most likely take the form of a condominium arrangement in which a group of households would coinvest in new wireline infrastructure—probably fiber—that serves a neighborhood or community; this arrangement might be facilitated by local governments.
- *Partnerships with the private sector to install (and possibly maintain) fiber.* The town itself, the schools and municipal departments, businesses and other private sector players in the town, the citizens themselves, and any interested broadband providers can sign up.
- *Municipal investment in wholesale second-mile fiber facilities, or fiber conduit.* Second-mile fiber facilities provide connectivity to neighborhoods that can be shared by competing broadband providers who in turn provide broadband to individual homes and shared conduit that decreases each provider's installation costs. Municipal investment in either would be analogous to the investment in streets as an enabler for local commerce—here enabling the value-added flow of bits instead of the flow of cars and trucks.

In each case, the locality provides motivation, coordination, and resources for joint action. It may share in the cost of the common construction and may also prohibit the digging up of the streets again for some period after the construction. Typically, some provision would also be made to lease colocation space to service providers at the fiber termination points to facilitate Internet interconnection. By avoiding the extra cost of uncoordinated overbuilding—keeping down the per-passing costs—this approach attempts to provide competition at per-passing costs comparable to those of a single provider. Local and regional government or quasi-governmental agencies can also act in effect as anchor tenants that underwrite some of the cost of installing infrastructure, reducing the costs for other government agencies, private sector firms, or even individual customers.

Recommendation 4.3. Relax federal, state, and local rules to ease market entry or to stimulate investment.

Local governments can also relax rules that deter or preclude overbuilders from entering a market, such as by providing access to rights-of-way, forms of relief for opening of facilities to competitive higher-level service providers, and so on. Local policies that tend to protect the incumbents from facilities-based entrants should be strongly discouraged or even preempted at the state or federal level.

Various forms of regulatory relief—such as a relaxation of franchise fees or obligations—could be granted in return for infrastructure build-out or upgrade commitments. One option would be to provide relief from certain forms of regulation, such as mandated access in exchange for specified deployments of new or upgraded facilities. Another option would be to reduce the business risk associated with facilities construction by providing assurances that compensation would be provided for future regulatory imposition of unbundling requirements. Regulators might also provide a "safe harbor" (exceptions from heavy regulation) for providers in a type 1 situation if they behave comparably (in terms of prices and service quality) to providers in a type 3 situation. Finally, in cases where broadband providers fail, governments at all levels can take steps to expedite a transfer of assets to ensure continuity of service for affected customers.

Recommendation 4.4. Provide financial incentives for investment in underserved and high-cost areas.

Examples of financial incentives would include tax credits given for building out infrastructure in underserved areas, or incentives—including tax credits and changes in permitting and zoning rules—given to providers that invest in infrastructure upgrades exceeding specified build-out or performance targets or that make investments in training and support of developers and users. Another option would be to provide government-guaranteed loans for infrastructure upgrades and build-out in high-cost areas.

Recommendation 5. Increase Local Capacity to Promote Broadband Deployment.

The recommendations above point to a number of specific measures that local or regional governments might pursue to promote broadband deployment in their communities. These opportunities also represent a considerable challenge for many communities that lack experience and knowledge in managing the complex legal, regulatory, and economic issues these options encompass. A few communities have already taken significant initiative with respect to broadband, but the majority are just now exploring the options before them. Therefore, mechanisms to enhance local capacity can play a critical role. Because one of the motivators for broadband is demand for work- and business-related applications and associated applications such as continuing education, in some circumstances it will be appropriate to link broadband initiatives with broader economic development efforts.

Recommendation 5.1. Support planning grants for localities to explore options.

Because an exploration of the complex set of issues confronting each community requires expertise, the engagement of various sectors within the community, and input from the public at large, federal and state governments should support planning grants to communities that demonstrate serious interest in taking steps to advance broadband deployment.

Recommendation 5.2. Provide cost sharing for field trials, including local-government sponsored initiatives.

Cost-sharing grants or subsidies for communities that have limited-performance or no broadband would support experimentation with premarket technologies and alternative organizational models. Such trials would permit governments and private sector firms to obtain more realistic experience with the performance of technology alternatives, help industry move up the learning curve of emerging technologies, test alternative organizational approaches and access models (such as municipally owned fiber or conduit available to multiple providers), and test demand stimulation strategies (e.g., locally developed content and applications). While there may be municipalities that have existing public utilities capable of embarking on such a program, a more likely mode is through partnership with private firms.

Recommendation 5.3. Establish a national clearinghouse to raise awareness, provide technical assistance, and disseminate best practices for local and regional efforts to accelerate broadband deployment.

A mechanism for sharing best practices for local and regional policies, regulation, and planning would help communities that are facing complex decisions. For instance, model regulatory frameworks would illustrate the range of possible outcomes, provide regional and local governments a starting point in negotiating with providers, and help overcome the knowledge and experience imbalance that local and regional governments may experience. Efforts by the National Association of Telecommunications Officers and Advisors and the Association for Community Networking are promising first steps. In-depth, authoritative information will be needed if best practices are to be useful to communities across the capability spectrum. A national clearinghouse would permit maximal sharing of best practices but would not necessarily supplant state or regional efforts, which may be better positioned to focus on local circumstances and needs.

Recommendation 6. Defer Development of a Universal Service Policy for Broadband Until the Nature of Broadband Services, Pace of Deployment, Distribution of Access, and Social Significance Become Clearer.

The Telecommunications Act of 1996 devotes considerable attention to measures that continue support for near-universal telephone service. Existing universal access programs such as the high-cost fund support (which, by helping to expand or upgrade rural public telephone networks, can also provide a foundation for DSL deployment, as well as extend or improve dial-up service) and the e-rate program (which funds Internet access in many schools, libraries, and health care institutions) have helped to increase broadband access. The act has instigated efforts to develop policy for expanding broadband access (such as the Federal-State Joint Board on Universal Service).

A number of the committee's recommendations aim to increase the breadth of deployment. While the committee anticipates demands that universal service programs be extended to residential broadband, its view is that it would be premature to embark on a comprehensive new universal service program until the overall shape of residential deployment and the nature of broadband services are better understood. The committee does not believe, at least at present, that a social contract analogous to that developed for telephony would be appropriate for broadband.

It is already apparent that broadband is a desirable and useful service, and it is reasonable to presume that it will take on increasing social importance in the future. But there is a difference between a service's being useful and showing great promise, which has motivated the recommendations in this report aimed at widening deployment, and a service's being critical to meaningful participation in society (as telephone service has come to be understood). In the early stages of deployment and acceptance, policies aimed at fostering rapid, widespread deployment, complemented by broadband access through schools, libraries, and other public centers, are appropriate.

Further, defining an appropriate universal service policy will be complicated. For voice, the shared understanding of what society should expect from the telephone industry, which became the goal of federal and state regulators, has been that a more or less uniform telephone service should be available to residential customers at a roughly uniform price. However, broadband is not a uniform service. Different users have different needs, and different technologies deliver different variants with different features as well as cost and performance characteristics. Also, as the two definitions for broadband advanced by this committee indicate, as technology and use evolve, what is broadband today will not be considered so in the future. One cannot employ a simple universal definition for broadband such as "faster than 200 kilobits per second." The cost could be made uniform only through substantial transfer payments within the system—an approach that was possible in the simple, more static world of telephony but that is very hard to carry out in the less well defined, changing, competitive world of broadband. This suggests that natural cost and service variations must be accepted (which must be distinguished from exercise of market power). For instance, satellite-based service is capable of reaching essentially all parts of the country. As a result, there will be relatively few people who will literally be unable to obtain some form of broadband (assuming these services are marketed to them). Thus, the geographical access divide is much smaller if the requirements for what must be the same across regions are relaxed, and if such trade-offs as lower reliability (e.g., satellites are susceptible to rain fade), higher latency, lower data rates, or higher up-front and monthly costs are permitted.

Recommendation 7. Support Research and Experimentation.

Recommendation 7.1. Support research and development on access technologies, especially targeting the needs of nonincumbent players and other areas that are not targets of stable, private sector funding.

Much of current research has reflected the interests of incumbents. Research that looks at the needs of nonincumbent overbuilders should be specifically encouraged. Such systems will in all likelihood make use of less mature technology alternatives. And as overbuilds, they have lower levels of subscription (lower take-rates) and need to be cost-engineered to anticipate this outcome. Particular research targets include these:

- *Architectural options and other means of cost reduction in fiber access networks*, including new techniques for using coarse wavelength-division multiplexing and low-cost in-home receivers and/or transmitters.
- *Enhanced wireless capabilities*, including capacity and other enhancements for wireless that provide robust, spectrally efficient, and scalable broadband wireless access to homes; architectures for synergistic coexistence of various wireless access technologies (fixed, mobile, in-home, ultrashort-range, and so on); technologies for true mobile broadband wireless services beyond 3G; convergence of fixed and mobile Internet architectures and protocols; and new information-delivery paradigms for broadband mobile Internet services.
- *Technologies that foster the accommodation of multiple competitive service providers over facilities*. Such open access-ready systems might not be a natural research and development target of large incumbent providers but will be the preferred form for a variety of public sector or public-private deployments.
- *Quality of service for homogeneous and heterogeneous access scenarios in the local access link and home*, including for applications that make intensive use of the upstream channel.
- *System robustness and reliability,* reflecting the increasing importance of broadband services to individuals and organizations.

Because the primary objective is to develop technologies that can be practically implemented by a broadband provider, research and development programs should encompass systems and economic perspectives, not just individual technologies or components. Doing this sort of research requires overcoming several institutional problems. Much of the computer science community traditionally has viewed cost reduction as an engineering topic for industry to pursue rather than as a legitimate research topic. Further, few academic research centers devote attention to systems engineering issues, which have generally been addressed by incumbents and their equipment suppliers.

Recommendation 7.2. Support research on economic, social, and regulatory factors.

With broadband a nascent service, now is an especially opportune time to study potential social and economic implications and to develop an understanding of these factors so as to inform government policy making and industry strategies. Areas for further research include these:

- *Social and economic impacts of broadband connectivity and availability*. Such understanding will help localities assess the case for local broadband initiatives and help fashion any future broadband universal access programs.
- *Alternative business models and better understanding of consumer behavior* and its relationship to currently available and prospective applications and services.
- *Economic and regulatory barriers that may hinder the nonincumbent facilities provider*. For example, the cost of the first mile is not the only barrier to deployment. Small neighborhoods

(new construction, pockets of dense development, and so on) may be able to justify the construction of new facilities. But this construction cannot occur unless there is some larger network to connect to that serves to aggregate traffic from these neighborhoods. This is what might be called the "second-mile" problem—aggregation of traffic to the point where it is economically viable to connect to the rest of the broadband world.

- *Improving our understanding of why local access performance has lagged that in other computing and communications sectors* and what strategies might help to close that gap.
- *Comparing U.S. progress with that in other countries*, and evaluating how progress abroad relates to national broadband policies and strategies.

Historically, a substantial fraction of funding for telecommunications economics research has come from industry itself. The increasing politicization of broadband (and telecommunications more broadly) argues for increased support from less directly interested parties, such as the federal government and foundations.

Recommendation 7.3. Support development of alternative broadband content and services.

More diverse content and applications—beyond mass entertainment and more commercially-oriented content—could create new sources of demand and help attract individuals and communities to make further investments in broadband. Examples of such content include information of local interest; enhanced access to government information and services; and materials related to education, health, and culture. Not all such services require broadband (narrowband may be sufficient, and a way of reaching a wider audience in the short term), but broadband supports much richer content. Traditional means of providing such content, such as cable public, educational, and government channels or public radio and television broadcasting, do not obviously translate to broadband, so further consideration about how to achieve such ends will be required.