On-ramp Prospects for the Information Superhighway Dream

Will the goal of a single, universally available network carrying a wide variety of data types ever be achieved?

and Jim Gemmell

THE Internet provides a vast array of services, information sources, and ways to perform work and engage in commerce. It has an estimated 20–40 million users, and doubles every year. The Internet version 1.0 backbone operated at 56Kbps, and primarily carried email.[1] The current Internet 2.0 backbone operates at 45–155Mbps, which enables the World-Wide Web (WWW). The next stage, Internet 3.0, has been denoted "The Information Superhighway." Internet 3.0 could provide ubiquitous symmetrical, high-bandwidth links that can simultaneously carry telephone, video (television), and data. Ideally, bandwidth would be at the maximum carrying capacity of the copper wires that link central offices with homes, a minimum of 6–25Mbps.

Today's Internet provides a glimpse of an information-rich world enabling commerce, telework, information access and information distribution. Corporations, universities, and government organizations use economies of scale to afford high-bandwidth connection to the Internet—typically 10Mbps and higher to the desktop. However, homes and small organizations are relegated to low bandwidth connections: typically less than 28.8Kbps. This is 300 times slower than the connections offered their corporate cohorts.

It seems extremely unlikely that homes and small organizations will have substantially higher bandwidth within the next five years. The great hope of ISDN gives only four times more bandwidth at substantially higher prices. Even recent IEEE conferences focusing on broadband communications (high-speed data, including video) fail to evoke any short-term optimism. To carry television-quality video such as MPEG-2 requires 4–6Mbps. Even low-quality MPEG-1 video at 1.5Mbps is unlikely to be accessible from the home or small business before the year 2001.

[1]See InternetWorld 1995 Keynote Address: *Internet 1.0, Internet 2.0 and Internet 3.0: It's Bandwidth and Symmetry Stupid!* http://www.research.microsoft.com/research/barc/gbell.

The Last-Mile Problem

In discussing these issues, there are three distinct problems:

- **The LAN:** connecting computers and appliances in the home, office, campus or site. While nontrivial and costly, many solutions are available.
- **The last mile:** connecting the LAN to the Internet backbone via wiring that connects homes or offices to local exchange carrier central offices.
- **The Internet:** connecting all networks together and having server capacity.

The *last-mile* problem is the major barrier to the Information Highway. Fiber-optic bandwidth has been growing at 60% per year for several decades. This allows the backbones to have huge bandwidth inexpensively. It ultimately allows inexpensive bandwidth in the home or small office. Figure 1a shows the evolution of plain old telephone service (POTS), local-area network (LAN), and wide-area network (WAN) service bandwidth since 1975. *It shows that the connection between the home and the backbone is a serious problem:* these connections require huge capital investments by government regulated monopolies. Only recently have a plethora of solutions to carry high-speed data over copper emerged to be tested. Figure 1b shows the evolution of deployed fiber-optic bandwidth and demonstrated in the laboratory. It shows that we have the science but product development has lagged behind that technology. Fiber ignores the last-mile problem.

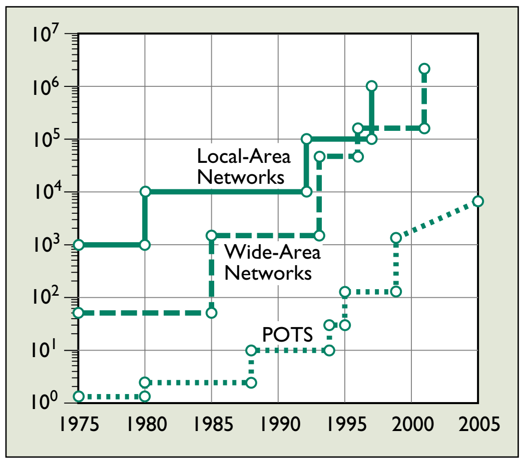

Figure 1a. The evolution of bandwidth, in kilobits per second, versus time for POTS (plain old telephone service), LANs (local-area networks), and WANs (wide-area networks)

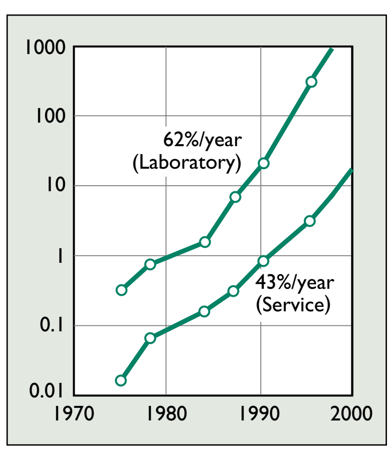

Figure 1b. Fiber-optic bandwidth, in gigabits per second, demonstrated in the laboratory (top) and in service (bottom) versus time

Three industry networks are stumbling forward to address higher bandwidth needs for the last mile: television/cable, telephony, and data-communications (Figure 2). The three have different characteristics, as shown in Table 1, and different core beliefs. It is the beliefs that affect cost and availability.

The telephony industry is old, well-established, and has a track record of being market-blind. Its members are the local exchange carriers (LECs), and long-distance carriers (LDCs). They provide POTS, which carries data at a maximum of 28.8Kbps today, with smatterings of equally inadequate ISDN lines at 128Kbps.[2] The core belief of telephony service guarantees bandwidth on maximum demand. Service can only be guaranteed using circuit switches and pre-allocating time-slots on high-capacity channels. This approach does not benefit from statistical sharing of resources.

The television industry is mature, and focused on broadcast services. Its content distributors use cable, UHF and VHF broadcast, as well as direct satellite broadcast channels. Its core belief is one-way communication broadcast from central sources to widely distributed customers.

The decades-old data-communications industry supports LANs, WANs, and the Internet using IP (Internet Protocol) packet switching. The group of private intranets for corporations and other large organizations is built from a data-communications equipment industry and telephony lines using Internet-compatible technology, tools, and training. While the datacom world has the technological capability to bring us the Information Superhighway, it does not have the ubiquitous presence of television or telephony to solve the last-mile problem, nor does it "own" any wiring, but relies on public carriers. The core belief of the data-comm industry is packet switching. By having adequate bandwidth and evolving the IP protocol, it believes it can provide a single network for data, voice (e.g., the Internet Phone), video telephony, and even broadcast television (e.g., Mbone).

The Internet connects thousands of private and public networks using a high-speed backbone operating above 55Mbps. Large organizations have private data-communication networks, consisting of WANs and LANs, operating at 1.5–55Mbps and 10–100Mbps respectively. Large organizations can purchase a wide array of WAN services and speeds from telephony carriers. When users

[2]ISDN, operating at 112 or 128Kbps, is a slight (4.4x) improvement over POTS, but doesn't take us anywhere near the 1.5Mbps that would be needed to make a really significant difference. ISDN remains a very expensive way of getting a 10th to a 30th of what we really need. This has led many to suggest that ISDN means It Still Does Nothing.

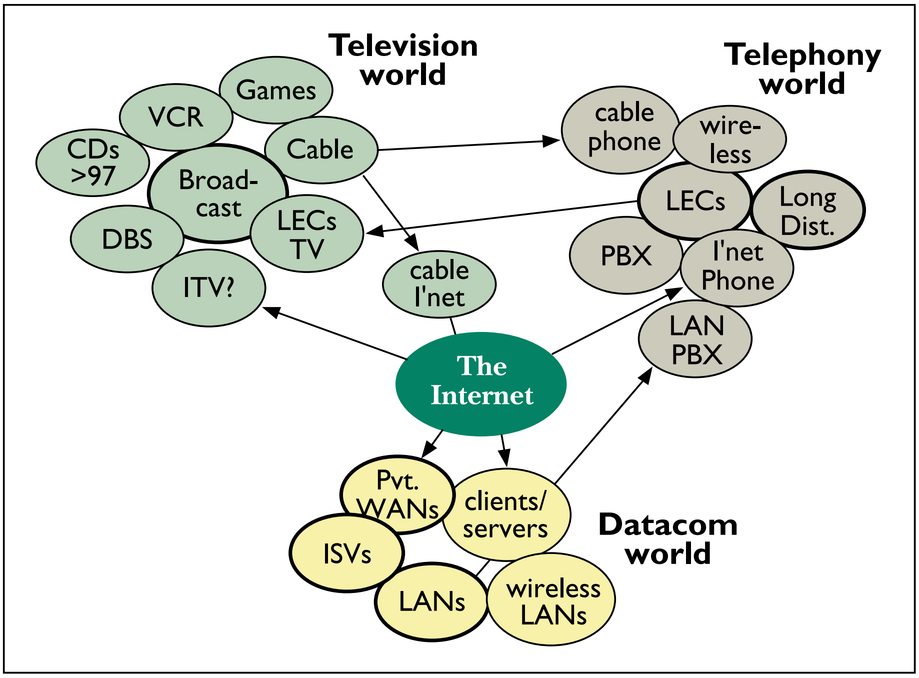

Figure 2.
Colliding worlds of telephony, television, and data communications (a.k.a. Internet/intranets)

operate from a home or small business, network access is via POTS with its associated low bandwidth. Thus response time and ability to carry data at high speed for simultaneous audio, video, and computer applications is non-existent for home workers and small businesses.

The telephone and cable industries are only now prototyping ways to increase network speed to enable telephony, video applications, and Internet (or intranet) access. These efforts demonstrate what a single, high-bandwidth network will provide and give a glimpse of the future.

Bits Are Bits: It Could Be All One Network

Bits are bits: a single network could provide fungible bandwidth that could be used for *any* service—the distinction between voice, video, and data is artificial. The Internet is a crude prototype of such a multipurpose single network, with mail, Web traffic, telephony, videotelephony, and Mbone narrowcast video conferences all coexisting on the same communications links. However, low-endpoint bandwidth prevents the current Internet from being more than a prototype. A recent survey showed that 20% of the users turned off graphics when surfing the net and that single-page retrievals average four minutes for many users. And if viewing Web graphics frustrates you, try videoconferencing.

In the distant future, a single network is essential to allow users to "communicate about content."[3] A unified, high-speed, low-cost network will allow users to simultaneously videoconference, view video presentations, access data sources, and run shared computer applications.

Table 1.
Network characteristics for POTs, TV, and data communications

	POTS	Television	Datacom
Transmission and "core belief"	Circuit switched. Must install; Capacity for the worst case.	Multichannel broadcast. Everyone gets the same pictures to choose from.	Packet switched; Channel capacity can be shared.
Media	Twisted pair analog to the home; High-speed time division multiplexed digitally sampled trunk lines.	UHF, VHF, cable (analog), satellite (analog or digital).	Wide range of media.
Bandwidth	28.8Kbps (maximum on trunk 64, ISDN 128). Many new options.	6MHz per channel. (1.5–6Mbps when channel is used for digital data).	Up to Gbps.
End-to-end delay	Short.	Can be arbitrarily long.	Short for RPC, voice and 2-way video.
Sensitivity to delay variations	Variation must be very small.	Buffering for variations.	Data comm. can tolerate delay. RPC, voice and 2-way video require low delay.
Nature of connection	3–5 min. calls.	Hours of broadcast connection.	Wide range, including permanent connections.

[3] A phrase coined by Robb Wilmot, former CEO of ICL and director of Cable and Wireless Ventures.

ATM (Asynchronous Transfer Mode) is the best candidate technology to provide this high bandwidth. But ATM is rooted in the telephony culture of requiring guaranteed capacity before a "call" is accepted, otherwise users get a "busy signal." ATM is starting to be deployed for LAN backbones, WAN service and by some carriers because it provides more flexible and higher bandwidth at lower costs, and is compatible with WAN service. ATM is a significantly cheaper switching method than traditional telephony protocols because it has adopted a form of packet switching. However, ATM continues to be several years away from significant deployment to aid the home user.

It is critical that all of us (users, product developers, planners, and new startups) understand the networking alternatives, impediments, and what is likely to be the slow path to a fast network, in order to encourage and support a future vision.

Telco-Cable Competition

The Information Superhighway requires a single ubiquitous network capable of carrying all electronic media. There is little evidence that today's three independent networks that carry the three forms of information will be combined in any meaningful way in the next few decades. The datacom industry lacks the infrastructure to give us a ubiquitous network. The telephony and television industries are Internet-ignorant, non-entrepreneurial, and seem to only visualize getting each other's business. Neither has been able to visualize or create a new industry or service based on new technology. The recently passed Telecom bill[4] will increase the competition over *traditional* telephony and television services.

Telephony Eyes Television

A typical telephony strategy is to compete for the $30 subscribers pay for cable TV each month. Today, many LECs are working to install specialized systems that completely replicate television distribution systems shown in Figure 3, an arrangement that competes with the cable industry. In January 1996, AT&T invested in Direct TV (and eventually Direct PC), a satellite broadcasting system. Meanwhile, Pactel has a four-prong effort to deliver television: (1) MMDS, a wireless broadcast service that can deliver television to a large area such as the Los Angeles basin (where 7 million viewers reside); (2) LMDS, a more narrowcast wireless service that can supply television to a smaller area and number of users (with LMDS limited two-way and point-to-point service can be delivered); (3) experiments using existing copper wiring to carry high-speed data; (4) limited deployment of hybrid fiber and coaxial cables that resembles cable TV, yet also carries POTS. This last service is being installed because it is supposedly cheaper to maintain than traditional POTS lines using copper wires that go from a central office to homes.

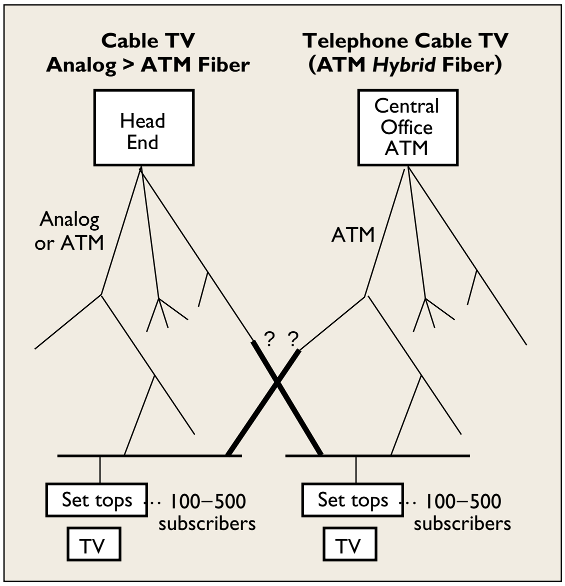

Figure 3. Hybrid fiber and coaxial data distribution in telephony and cable television networks. We predict that ultimately these two networks will merge into one solution for the last mile problem.

Cable TV Pursues Telephony

Simultaneously, the cable industry is attempting to provide POTS telephony on its cables to increase revenue. However, cable companies face significant barriers to becoming large-scale telephony providers. The current voice telephone companies have an installed, working, and paid-for system with a rich feature set and unrivaled reliability. To provide POTS, the cable companies must develop the equivalent of central offices. Cable companies are unlikely to succeed in telephony because of their inability to raise capital, understand user and operation requirements, and profitably compete. This suggests or even demands collaboration or more likely, mergers between the two industries.

Competition: Solution or Root of the Problem?

Both the telephony and television industries are considering utilizing hybrid fiber and coax (HFC). Fiber optic cables are run from the head end/central office to neighborhood nodes. At these nodes, the signal is converted and sent over the neighborhood's coaxial network.[5] This scheme is called Fiber To The Neighborhood (FTTN). Pacific Bell and Southern New England Telephone have plans to build FTTN networks. Therefore, telephony and television are converging on a single (FTTN) distribution structure —only their regulation, size, and capital-raising abilities differ. Figure 3 shows a comparison of the two

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[4]By the U.S. Congress, Feb. 1, 1996. This bill allows all information carriers to compete with one another.

[5]Cable television is currently configured as a branching tree of coaxial cable that carries broadcast data. Because the signal content is the same in all branches of the tree, it functions as a bus. With fiber replacing the portion of the tree near the head-end (root), only the coax portion need be a logical bus.

hybrid-fiber plants that would provide telephony, television, and higher speed data. They ultimately could be combined to form a single network. Both these plants could help solve the last-mile problem.

The battle to provide television and telephony services in the short term will offer lower prices based on many suppliers. In the long term, LECs with their larger assets will probably buy out cable companies to gain access to their information sources and customers, and because LECs have access to capital. Overall higher prices for telephony and television will follow as LECs pay for their television forays and return to the good old days of monopolistic positions with state and federal regulators. It is unclear whether the new environment that legislators envision with the Telecom bill will create competing services to many homes. One indication, however, is that approximately 100 competitors have registered to provide telephony service in California.

Installing fiber to the home is extraordinarily expensive outside urban centers. To connect even 100 million sites, using existing copper wires, would cost at least $100 billion—roughly half the annual revenue of the U.S. telcos.

Why Telcos Haven't Started to Give Us Internet 3.0

The telephony industry has been wrong too often in its business, product, and market judgment[6] to be thought of as a solution. They have access to cash and many technology alternatives—but are unwilling to offer high-bandwidth to the last mile. Just to support low-quality MPEG-1 video requires 1.5Mbps—the equivalent of their T1 line. Although the wiring into most homes and small businesses could support T1 data rates, the telcos cannot offer low-cost T1 to home users at reasonable prices because it would foul the lucrative corporate market that uses T1 for data and voice multiplexing.

Pactel's experience with ISDN illustrates one telco's naïveté for data communications. Pactel initially priced its ISDN service to be nearly equivalent to two POTS lines. Aggressive pricing and Internet demand has resulted in a doubling of the number of lines to a few tens of thousands in 1995. Recently Pactel filed for rate increases because, due to software problems in the telco switches and long call-holding times, ISDN turned out to be more expensive to deliver than expected. Since ISDN falls far short of being adequate for video, these rate increases may squelch the newly created ISDN market.

Unfortunately, ISDN is the only last-mile service improvement widely available over the next few years to homes and small businesses. Pactel and other telcos have no efforts to provide inexpensive Internet service to the home adequate to carry MPEG encoded video requiring 1.5 to 4 megabits per second.

The many connection alternatives exacerbate the problem because telephony managers have a high downside risk of adopting the wrong technology. As in every new technology, pioneers are likely to succumb to lethal arrows. The cost of deployment depends on whether an entirely new network with links and switches has to be installed, or whether existing connections can be used. Telephony, somewhat rightfully, blames federal and state regulators for their inability to offer innovative services. In the very long term (2020), telephone networks must be digital, using some form of packet switching if they carry data traffic. Data communications requires packet switching to be cost-effective—it multiplexes many users over a few physical circuits.[7]

Switch Cost Matters—More Switches Must be Added

Old-fashioned telephony switches are expensive because they are based on circuit switching, must support the legacy feature set that LECs offer, and the switches are proprietary to a company with negligible portability among vendors. The obvious solution is packet switching based on general-purpose computers—doing to the classic private branch exchanges (PBXs) and central-office switches what minicomputers and PCs did to mainframes.

These new switches are likely to migrate features to the periphery, including a subscriber's computer. Switches will turn out to be built from high volume computers and software supplied by a data-communications industry. Restructuring the switch equipment industry as a horizontally integrated industry, like the computer industry will have a profound effect on our ability to get to a single, all-digital, packet-switched network.

Short-Term (by 2001) Solutions for the Last Mile

Providing a new network utilizing fiber to the home is ideal. Indeed, Japan is planning to install fiber to

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[6]For example, public packet networking, ISDN, Video-on-Demand, acquisition of computer, content, and cable companies, and investing in closed information architectures to supply proprietary services, etc.

[7]While data transmission has the circuit-switched telcos perplexed, the flip side of this is that traditionally circuit-switched data like audio and video is now finding its way into the packet-switched data communications world and causing just as many headaches.

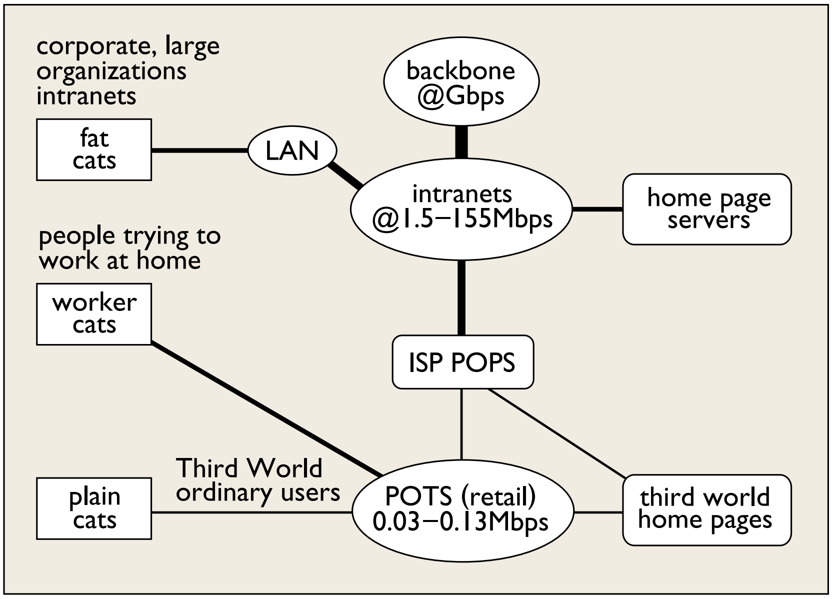

Figure 4.
Three worlds of medium- and high-speed networks for large organizations, and third world of home and small organization users accessing Internet via POTS and ISDN lines

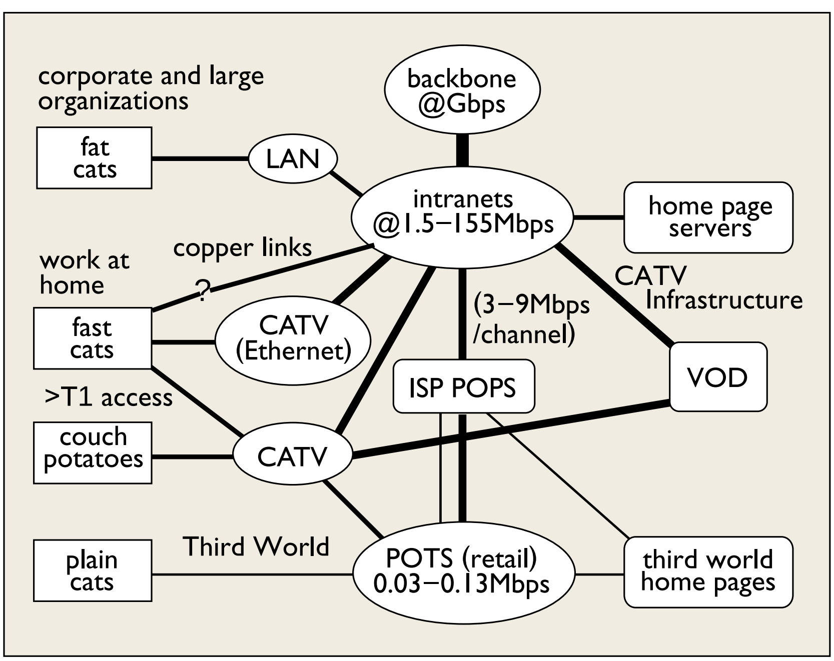

Figure 5.
High-speed access is supplied to small users via Internet service provider (ISP) supplied channels that connect to cable TV systems and LECs that use existing copper wiring

everyone's home. However, installing fiber to the home is extraordinarily expensive outside urban centers. To connect even 100 million sites, using existing copper wires, would cost at least $100 billion—roughly half the annual revenue of the U.S. telcos. Choosing an alternative will not help much—no matter what new wiring scheme is chosen, the cost of new wire, fiber, or cable installation and modem[8] are all roughly the same. Existing wiring owned by LECs (multiple twisted pairs that carry analog voice) or cable operators (coaxial cable carries multiple 6MHz, analog TV channels) must be used in the short term (i.e., the next decade).

Cables can carry high-speed data in lieu of television channels in a broadcast fashion. Cable modems have been tested and are becoming available that use a 6MHz TV channel to carry from 2 to 40Mbps. Users would rent or buy the modems as they do now. Point-of-Presence computers (POPs) placed at the cable head ends could be supplied by a variety of Internet service providers (ISPs) including long-distance carriers. By using independent ISPs, cable providers would not have to "learn" about data-communications or the Internet.

A significant problem with using cable is the lack of symmetrical communications caused by limited upstream or back channel bandwidth. For mostly one-way cable systems, the data-rate from homes or small businesses back to cable TV switching centers or head-end is either nonexistent or limited to a POTS line. With no upstream bandwidth, telephony is used for carrying the "mouse clicks." Two-way cable systems provide several-hundred-Kbps upstream for the teleworker, and one scheme provides Ethernet in a channel. A Silicon Valley startup company, @home, hopes to address the Web access or client market using cable.

The simplest and best solution seems to be for LECs to use existing wiring from the central offices that serve homes and businesses and offer T1 service (1.5 Mbps) at reasonable prices. Unfortunately, offering T1 to home users at low prices would most likely destroy the LEC's high-priced, high-profit business with corporations. This could be ameliorated by offering hard-wired, private service IP links to ISPs with only Information High-

[8]High-speed fiber modems cost will be $250–$500 initially and then will decline with volume.

way services—thereby assuring that customers do not start their own phone systems.

Even higher bandwidths are possible over the existing telephone wiring in most neighborhoods. Modern signaling methods allow bandwidths to increase to 5, 10, and even 25Mbps, depending on the age, loop distance, and condition of the wiring. These faster signaling technologies are not yet standards. More importantly, equipment suppliers still have not yet actually delivered the required semiconductors and modems. Assuming the equipment does arrive and tests are successful, it may be technically possible to offer 25Mbps to the home over existing wiring by the end of the decade. Building a tariffed service is a hopeless process entangling LECs, long-distance carriers, and state and federal regulators. Whether the Telecom bill will solve this problem is unclear.

A second problem is that LECs have no operational knowledge or ability to deliver data-communications. Thus, any solution must include the ability for various ISPs to access the lines in the central offices that LECs own. This could be accomplished by installing minimum multiplexing equipment that would take the copper lines from subscribers that terminate in the central office and relay them to ISPs over high-speed fiber lines carrying multiples of one optical channel of 55Mbps. Various capacities are available: OC-3, OC-12, OC-48, and most recently OC-192 carry 155-, 655-, 2,560-, and 10,240Mbps, respectively. By building a network using fiber to deliver multiplexed subscriber traffic, LECs need not worry about or understand data communications in the short term. More importantly, their risk is minimized and placed with the entrepreneurial ISPs. Finally, this structure enables a competitive market for data that is likely to become another telephony monopoly by default because the LECs own the subscriber wiring.

Figure 4 shows the current situation. Figure 5 describes the alternatives. In these scenarios, both industries will provide marginally adequate (1.5Mbps) to good (4–8Mbps) links adequate for most current applications. MPEG-1 encoding at 1.5Mbps is almost certain to be inadequate for television by the time systems get into operation. Direct Broadcast Satellite (DBS) and Digital Video (or Versatile) Disks will both be operating at over 4Mbps, delivering substantially higher-quality pictures.

The Need for Symmetry

Bandwidth asymmetry is a major problem that limits cable solutions: the cable plant provides good downstream bandwidth but limited upstream bandwidth. Some of the technical alternatives are asymmetrical and will limit potential future use. While we do not understand all future applications, we do know that as the Internet progressed from 56Kbps (Internet 1.0) that carried electronic mail to Internet 2.0 operating at 56Mbps, the use changed radically, enabling the WWW to be invented. Symmetry is required if we want all subscribers to be full members of the Internet. Small information providers, teleworkers, and consumers of high-quality video-telephony consumers will all want high upstream bandwidth. We assume the Internet 3 "killer app" will come "bottom-up" from having a fully symmetrical system—just like the Web was invented.

Conclusion

The problem is clear: providing last-mile bandwidth inexpensively to all sites. The answer also seems clear: we must encourage and help structure data network solutions that will first get increased bandwidth for Internet and intranets in order to continue to meet the Internet demand and incrementally expands a base of users that requires audio, video, and data. Evolving in this fashion, using existing facilities and providing service on an incremental basis, will not enable homes or small organizations to all become video-on-demand suppliers or solve the telework problem when high-resolution videotelephony, teleconferencing, and LAN access are required. However, providing symmetrical T1 or better data rates seems adequate to start the telework and Web access for entertainment, commerce, and information. It will also provide a ubiquity and vision that will let us eventually move to the next stage. In this stage, every home is equipped with symmetrical, high data-rate access that can potentially carry voice, video, and data in a unified fashion.

Getting adequate, ubiquitous symmetrical, bandwidth will be based on the slow, evolutionary nature of the communications industry, using the technology it knows best—managing waiting. Eventually (e.g., by 2020), a single high-bandwidth network that carries fungible bits could exist. However, it will take at least five years to demonstrate a need based on the hodgepodge of evolving networking experiments. In this way a vision, backed by demonstrated applications (the market), can cause the investment in a modern network.

Acknowledgments

The authors are especially grateful to Jim Gray of our laboratory for his suggestions and patient editing of the original manuscript for this article.

About the Authors:

GORDON BELL is a staff member at Microsoft Corporation's Bay Area Research Center. email: gbell@microsoft.com

JIM GEMMELL is a staff member at Microsoft Corporation's Bay Area Research Center. email: jgemmell@microsoft.com

Authors' Present Address: Bay Area Research Center, Microsoft Corporation, 301 Howard St., Suite 830, San Francisco, CA 94105-2241.