Chapter 1

Technology for a New Era

The next era of world communications will be created by several complementary technologies and corporate leaders who the Economist s Frances Cairncross has called the best educated group of entrepreneurs ever to blitz a business. [1] This chapter (Table 1-1) reviews the technologies: the digital revolution and continuing improvements in microprocessors; the new fiber optic and satellite technologies that introduce a new economics of global communication; and the remaining last mile connections that will enable individuals and institutions to bring these global capabilities together under their control.

[1] Frances Cairncross, *The Death of Distance: How the Communications Revolution Will Change Our Lives* (Boston, MA: Harvard Business School Press, 1997) 118. Other causes include the unique and relatively peaceful post-Cold War period, globalization of markets and global thinking of corporate leaders, de-regulation of the communications industry, and an extraordinary abundance of venture capital for domestic and global projects. For an overview of the international players and the politics of privatization and deregulation, see: Wilson Dizard Jr., *Meganet: How the Global Communications Network Will Connect Everyone on Earth* (Boulder, CO: Westview Press, 1997).
Heather E. Hudson, *Global Connections; International Telecommunications Infrastructure and Policy* (New York: Van Nostrand Reinhold, 1997).

Chapter 1

Table 1-1

Technology for a New Era

The Digital Revolution
- Moore s Law
- Packages of technologies and bottlenecks

Internet Basics

The New Global Internet
- Fiber technology
- Satellite capacity

The Final Mile
- Thresholds and applications
- Business costs and the last mile
- Physical costs and the last mile

The initial sections of this chapter review the digital revolution and the basic design of the Internet. Readers who are already familiar with this background may wish to skip to the later sections that review the global Internet and the pending last mile upgrade.

I. The Digital Revolution

A digital revolution underlies the new technologies of the new era. It is a simple idea, the translation of all communication - audio, video, text, and data - into a digital alphabet of only 0's and 1's. It abandons the 10 Arabic numerals, the 26 letters of the alphabet, the varying of electromagnetic waves that create radio and television broadcasts. The digital revolution changes everything to a super-speed telegraph and a vocabulary even simpler than the old telegraph code of Samuel Morse - only dits and silences.[2]

For example, one early step was an arbitrary convention to assign to each upper- and lower-case letter, number, punctuation mark, and common command a unique sequence of 0's and 1's. A sequence of eight binary digits can have 256 values (from 00000000 to 11111111; the American Standard Code for Information Exchange (ASCII) assigned a sequence of eight 0's and 1's to each. Thus, the uppercase K on a keyboard is represented in ASCII binary as 01001011; a Delete command is 01111111; a blank space is 00100000; and the end of a transmission is indicated by 00000100.[3] A string of eight binary digits (bits), interpreted together, was called a byte, [4] which has become (kilobyte,

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[2] For early discussions: Bill Gates, Nathan Myhrvold, and Peter Rinearson, *The Road Ahead*, Revised ed. (New York: Penguin, 1996). Nicholas Negroponte, *Being Digital* (Hodder & Stoughton, 1995).

[3] ASCII tables are widely available, e.g. William L. Schweber, *Data Communications* (New York: McGraw-Hill Inc., 1988). The 7-bit ASCII sequence is an American invention and the use of 8-bit sequences permits special characters for European and other alphabets. For the development of Unicode that uses a double-length (double-byte) sequence to include Asian and other languages, see: Julian Perkin, "New Codes Open Doors for Non-Roman Alphabet Users," *Financial Times* 2001.

[4] A kilobyte (KB) is 1024 bytes or 8192 bits. A megabyte (MB) is 1024 kilobytes or 1,048,576 bytes or 8,388,608 bits. The scale proceeds upwards to billions (gigabytes), trillions (terabytes),

megabyte, etc.) a standard measurement unit of the digital revolution.

The digital revolution is winning because of microprocessor economics. It has become increasingly cheaper to construct fast electronic circuits to process tidal waves of 0's and 1's. The 0's and 1's can be represented by simple on/off flows of current, or by a flash of light or darkness along a fiber optic filament. Because only two - very different - values are used, they can be recognized quickly, inexpensively, and (of special importance to reduce the costs) with very low rates of error.[5] (Compare the microscopic tolerances and sensitivities required for a stylus and LP record; or the complex and subtle modulations of a radio wave that must be created and detected, static-free, by electronic circuits to broadcast a symphony by radio.)

The digital revolution has advanced, application by application, as the speed of microprocessor chips and other technologies required for each new application has passed the critical threshold necessary to be competitive with the old media. Music CD s arrived when low-cost processors (and the new storage/playback medium) could handle 16-bit samples and 44,100 samples/second (706 Kbps); Cellular telephones started to become small and more powerful as a package of related technologies were improved.[6] For

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quadrillions (petabytes), and beyond. In most later discussions I will use the basic unit (bits), represented by the lower-case b, i.e., 64Kbps = 64,000 bits per second.

[5] For additional advantages of digital systems, see: Schweber, *Data Communications* 122-27.

[6] Ian Austen, "Shrinking the Cellular Phone One Component at a

DVD s (e.g., movie- and television- quality digital video) the greater requirements to retrieve and process millions of 0's and 1's per second were achieved more recently.[7]

For some applications, old technologies are still better, and the digital revolution may never be superior for all uses. Digital still cameras are not yet economically competitive with earlier (35mm slide) technology for most users.[8] E-books have failed to catch-on, at

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Time," *The New York Times*, E7 2002.

[7] The challenge of desktop video was that, if a computer monitor uses a resolution of 1024-by-768 pixels (micro-dots), refreshes the screen 30 times/second, and the instruction for each pixel requires 3 colors and an instruction code of 8 bits per color the task required processing at least 566,000,000 bits/second. See Edmund X. DeJesus, "How the Internet Will Replace Broadcasting," *Byte* 1996.. High-Definition Television (HDTV) will have more pixels and sharper resolution (1920 x 1080) and a different screen shape (a 16/9 ratio, similar to movie theater screens, rather than the standard home television s 4/3) and (uncompressed) would require pipelines and processing capacity in the gigabit range (1920 x 1080 x 24 x 30 bits/second = 1,492,992,000 bits/second). In practice, these requirements are now reduced by compression techniques: George Abe, *Residential Broadband* (Indianapolis, IN: Cisco Press, 2000).
National Science and Telecommunications Board, *Broadband: Bringing Home the Bits* (Washington, DC: National Research Council, 2002) 288-94.

[8] For many users, a hybrid system using current 35mm cameras, with digitized prints created by a developer, is more cost effective.

the current level of technology and price. And, although the Federal Communications Commission has been aggressively lobbied to push a national upgrade from old-fashioned analog television to new digital television broadcasting (which would include high-definition television (HDTV) options), so far the public has shown minimal interest to buy several hundred million conversion boxes (there are 2-3 televison sets in most US households) or the new and expensive digital television sets.[9]

A.) Moore s Law

In the early years of microchip technology Gordon Moore, a founder of Intel, observed that their engineers were shrinking the size of chip components and the space between them by about 0.7 every 18 months, thus putting the same computing capacity in about half the area (0.7 x 0.7 = 0.49), or doubling the computing capacity of a chip about every 18 months without increasing the cost. He proposed that microprocessor capacity would continue to double every 18-months to 2-years: He has been right (Table 1-2) and the process is called Moore s Law.[10] (For consumers, a new generation of computer chips (386, 486, Pentium, etc.) is introduced about every three years, with about four times the computing capacity.[11] [12]

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[9] Frank Ahrens, "Agency Pushes Digital TV Shift," *Washington Post*, April 5 2002.

[10] Gordon E. Moore, "Cramming More Components onto Integrated Circuits," *Electronics* 38, no. 8 (1965).
Gordon E. Moore, "An Update on Moore's Law," in *Intel Developer Forum* (San Francisco, CA: 1997).

[11] Another advantage of smaller size is that each generation of chip requires less power - for example, the battery requirements for

Table 1-2
Thirty Years of Moore s Law[13]

Chip	Year of Introduction	Transistors
4004	1971	2,250
8008	1972	2,500
8080	1974	5,000
8086	1978	29,000
286	1982	120,000
386	1985	275,000
486	1989	1,180,000
Pentium	1993	3,100,000
Pentium II	1997	7,500,000
Pentium III	1999	24,000,000
Pentium 4	2000	42,000,000
Itanium (est.)	2002	100,000,000

Intel s 8080 chip, introduced in 1974 and used for the first personal computer (Altair) operated at 2 MHz (cycles/second). Today, after almost forty years of doubling and related improvements, we are moving into a realm when hundreds of millions of transistors can be miniaturized on a single chip, and operating speeds are moving beyond 2 gigahertz (an ability to

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portable applications are smaller - and runs more quickly.

[12] The rate of progress may be accelerating. See: John Markoff, "The Increase in Chip Speed Is Accelerating, Not Slowing," *The New York Times*, February 4 2002.

[13] Source: www.intel.com.

switch on and off two billion times/second).[14] The industry seems confident that its rate of improvement can continue until about 2016 and perhaps, by shifting to a molecular level, several decades.[15] Today, Moore s Law is a foundation for forecasting: entrepreneurs and venture capitalists assume increasingly miniaturized, more powerful, faster, and less expensive technology to support new applications.

B. Packages and Bottlenecks

The growth of microchip capacity has stimulated complementary technologies and more advanced applications. For example, Table 1-3 shows the components that Consumer Reports recommended to its readers across a five year interval, as a decent computer system in 1994 and at the end of 1999.

Table 1 - 3

Decent System Computer Components, 1994 - 1999[16] [17]

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[14]Chris Gaither, "Intel Introduces Chips for Servers Using Pentium 4 Technology," *The New York Times*, February 25 2002. John Markoff, "IBM Circuits Are Now Faster and Reduce Use of Power," *The New York Times*, February 25 2002.

[15] Mark A. Reed and James M. Tour, "Computing with Molecules," *Scientific American*, June 2000. Chip design has used two dimensions, with minute layers along the third dimension, and it can expand along the third dimension. See: Ray Kurzweil, "Fine Living in Virtual Reality," in *The Invisible Future: The Seamless Integration of Technology into Everyday Life*, ed. Peter J. Denning (New York: McGraw Hill, 2002), 201.

[16] Prices in 1999 dollars: Consumer Reports, "Frontlines -

Component		1994		1999
Monitor	14-in. VGA	$327	17-in. XVGA	220
Processor/ Motherboard	Intel 486DX-33	202	AMD K6-2 400	130
RAM	4 MB	327	128 MB	120
Floppy drive		54		20
Hard disk	200 MB	436	13 GB	140
CD-ROM drive	1x	381	40x	70
Keyboard		33		15
Mouse		44		20
Modem	14.4k	272	56k	60
Video card 1 MB		191	16 MB graphics	99
Sound card	SB-Pro	218	32-bit PCI	40
Case, power supply		93		50
Total System		2,932		1,184

Technology: Computers Then and Now," *Consumer Reports*, May 2000, 50.

[17] Consumer Reports, "Make over or Buy New?," *Consumer Reports*, September 2001.

By late 2001 the recommended home system, for a wider range of current applications, added speakers, a home networking connection, a second bay for a second hard drive, a (doubled) 900 MHz - 1GHz processor, DVD and CD-RW drives, and a (doubled) 20-30 GB hard drive.[18]

Between 1994 and 1999 the capacity of each key component grew and prices dropped steeply. However, the rate of improvement was uneven. Thus, by 2001 the microprocessor and other components inside the desktop PC, were already good enough to support global Internet television channels and all other traditional media. However, the bottleneck for this application is the limited 56Kbps modem connection (over old-fashioned telephone lines designed for voice communications) to the Internet. Modems are not a Moore s Law technology. This has restricted video links with the outside world to jerky and murky pictures in 3" windows, and even audio connections can be ragged.[19] It is the so-called broadband upgrade of the 56K pipeline, even more than faster microprocessors, that will move the Internet quickly to a new level.

- A new and important threshold was achieved with the ability to place the basic Internet protocols and the electronic circuits for wireless communications onto small chips. Thus we are about to see

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[18] See also: Bill Howard, "Life with a $500 PC," *PC Magazine*, April 9 2002.

[19] Bell s original modem (1962) provided 300 baud. The increase to 56Kbps was dramatic but an upper limit for twisted-pair copper wire until the invention of DSL (discussed later).

a world with millions of devices and sensors, each with unique Internet addresses, and able to self-initiate communication with each other.[20] There will be many other applications of the new wireless technology (e.g., upgraded cellular telephones with Internet and video capabilities). Palm Pilots and other personal data assistants (PDAs) will join the desktop PC to become part of the Internet.

II. Internet Basics

The Internet is a set of standard protocols to group and transmit sequences of 0's and 1's between computers and networks. In the early days of computing, engineers at the Department of Defense invented it as a convenience to support their own work and links with university researchers and contractors. In these early days, IBM and other mainframe computer manufacturers each used incompatible protocols for email, and they wanted to keep their incompatible, closed architectures to expand sales of their own equipment. The new invention was justified and expanded on national security grounds, as a way to maximize the survival of a national communications net in case of a nuclear war. However, the practical origin was that scientists wanted to get work done.[21]

Two standard protocols (called TCP/IP) define the Internet. The basic IP (Internet Protocol) divides anything to be communicated (i.e., the strings of 0's and 1's) into digital packets of standard

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[20] Across short distances other protocols, e.g., bluetooth, also will be used.

[21] Stewart Brand, "Wire Legends: Founding Father [Paul Baran]," *Wired* 2001.

length, each with a header with information about the destination of the packet, its sequence in the message, etc.

- A higher-order protocol, TCP (Transmission Control Protocol), establishes a standard way to communicate about the message itself: that all of the packets were received, or that packet xxx never arrived and should be retransmitted, and so forth.[22] The protocols do not care what is transmitted, or what machines create the messages or will receive them. Anything can be divided into equal size chunks and sent-off. Many applications (e.g., the World Wide Web, email) can use the Internet.

An economic benefit of TCP/IP was that, by using digital packets, the Internet can abandon the requirement of the telephone that users (e.g., on the East Coast and the West Coast, or New York to London) secure an exclusive wireline circuit for the duration of their call. Once digitized, packets of email messages, for example, could be moved so rapidly that many users could share the same wireline circuit, the packets being interspersed and routed to different

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[22] The Federal Networking Council defines Internet as the global information system that: is logically linked together by a globally unique address space based on the Internet Protocol (IP) or its subsequent extensions/follow-ons; ii) is able to support communications using the Transmission Control Protocol/Internet Protocol (TCP/IP) suite or its subsequent extensions/follow-ons, and/or other IP-compatible protocols, and iii) provides users or makes accessible, either publicly or privately, high level services layered on the communications and related infrastructure described herein. Robert E. Kahn and Vinton G. Cerf, "What Is the Internet (and What Makes It Work),", (Washington, DC: Internet Policy Institute, 1999), 14.

destinations in the (to a computer) long pauses between key strokes. (Packets representing the microseconds of telephone conversations can be interspersed the same way.) Today, packets arriving at 56K are interspersed, like individual cars entering an Interstate highway, and travel along commercial public Autobahns (backbones) that can handle (now) 2.4 - 9.6 billions (giga-) bits/second, although by the spring of 2002 Bell Labs was demonstrating 2.56 terabits/second over a distance of 2,500 miles.[23]

Routing computers, along the Internet backbones, read the addresses of packets and can alter the primary and secondary routes of individual packets, microsecond by microsecond, depending upon traffic conditions between the sender and the destination. The use of packet technology and sharing can produce these traffic slowdowns and the Internet operates at best effort speed. Recently, higher-order options have been added to give passing-lane rights for certain types of material (e.g., streaming, for Internet audio and television) to help them flow smoothly.[24] New private Internet backbones are evolving for users who want faster, delay-free links (e.g., for business videoconferencing) and/or extra

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[23] Reuters, *Bell Labs Says It Shatters Data Delivery Record* (March 22) (Yahoo! news, 2002 [cited March 22 2002]). The demonstration used a fiber optic cable with 64, 40 gigabit/second channels and a DWDM coding scheme called differential phase key shifting developed by Bell Labs.

[24] Currently, for retrieving Web pages, final mile connections above 1 Mbps will not improve the performance of the Internet: National Science and Telecommunications Board, *Broadband: Bringing Home the Bits* 79.

security.

The capacity of Internet backbones is determined by the properties of fiber optic cables and a package of related technologies. These cables are made-up of filaments that carry beams of laser-generated light along their length, and the beams can be switched on-and-off quickly to represent sequences of 0's and 1's. The speed of light along each filament is about equal to the speed of light in a vacuum but the actual capacity of fiber optic connections remains far below any theoretical potential that might be achieved by subdivisions as small as individual photons. The speed is limited by the speed at which lasers can be switched on or off; the rate at which receiving equipment can detect high-speed flashing reliably; and the speed of the Internet s routers; and other elements that are being continually improved.[25]

III. The New Global Internet

> Until a few years ago, telecommunications bandwidth was one of the simplest products in the world, and its supply, effectively, a monopoly. If you needed two megabits per second of capacity between Paris and Frankfurt, you ordered a 2 Mbps half circuit from France

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[25] Among the new technologies for switching are optical switches, which permit all-photon links rather than requiring intermediate translations into electrons for computer processing en route. The performance of the Internet also is affected by design decisions. For example: mirror sites and forward caching (for video-on-demand applications and high-use Web sites.) Global caching centers already are under development for sites and applications with strong international demand.

> Télécom and a 2 Mbps matching half circuit from Deutsche Telekom. Several months later, you were connected. Much the same was true if you ordered a circuit from Milan to Zurich or London to Tokyo - only the names of the suppliers changed. . .
>
> In this environment, bandwidth buyers needed the kinds of skills usually found among experienced foreign embassy officials: infinite patience, subtle negotiating powers, and good personal contacts. . . . Negotiations rarely focused on price, since the price - generally far above underlying cost - was fixed by the monopoly owners.
>
> Government action changed the model forever. . .
>
> - Telegeography, International Bandwidth 2000[26]

The global Internet has emerged with unexpected speed because of two world-changing developments in the late 1990s: the continuing deregulation of the communications industry that, traditionally, was a government- or government-regulated monopoly in most countries.[27] And the breakthrough in fiber optic technology -

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[26] Telegeography Inc., *International Bandwidth 2000* (Washington, DC: Telegeography Inc., 2000) 13.

[27] Robert W. Crandall and Kenneth Flamm, eds., *Changing the Rules: Technological Change, International Competititon, and Regulation in Communications* (Washington, DC: Brookings Institution, 1989).
Harvey Sapolsky and et al., *The Telecomunications Revolution: Past,*

the invention of DWDM (Dense Wavelength Division Multiplexing) discussed in the introduction - which permits (today) up to 160 colors of light to use each fiber optic filament at the same time.[28]

There are two basic transmitting technologies in the growing global Internet: a.) fiber optic cables; and b.) satellites:

A. Fiber Technology

With deregulation and DWDM technology, venture capitalists jumped-in and quickly flooded the market. The super-efficient economics of the new technology promised to wipe-out the unlucky dinosaur telecoms who owned old-generation technology. By moving fast and building abundant extra capacity the new companies (e.g., Global Crossing, Qwest, Level 3) hoped to become the dominant wholesalers, and so far ahead that they would discourage competition from later rivals.[29] There was a sudden Golden Age for the fiber optic industry. By the middle of 2001, about 40 million miles of new fiber optic cable was laid in the United States.[30] And, worldwide, almost 100 million miles. Today all

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Present, and Future (New York, NY: Routledge, 1992).

[28] Current capacity of 160: Richard Waters, Sarah Parkes, and Andrew Baxter, "Switch-Off Prompts Search for Light Relief," *Financial Times*, September 19 2001.

[29] The principal cost of installing fiber optic cable on land is the cost of digging trenches. This was another reason to install extra capacity now. Companies also laid empty plastic pipes, through which future generations of fiber optic cable can be threaded without requiring the expense of digging.

[30] Rebecca Blumenstein, "How the Fiber Barons Plunged the

of the principal cities on the world s oceans are connected by a growing number of fiber optic cables. Every major trading city has two or three, and sometimes more, companies laying rings of fiber optic cable in the business districts to facilitate direct high-capacity linkups over private Internet links.[31]

(We are accustomed, based on old technology, to believe that international connections are expensive, and logically more expensive, than domestic communications. However, it can cost less to lay fiber optic cables along an ocean floor than to dig trenches in urban areas.)

In the introduction, Table 1 [~ pp. xx, above] showed the growth of international submarine cable (DWDM) capacity between 2000

Nation into a Telecom Glut," *Wall Street Journal*, June 18 2001. Blumenstein estimates $90 billion of domestic investment from 1997 - 2001, and cites an estimate by Merrill Lynch that 2.6% of domestic capacity is used. (For example, of the 96 filaments in Level 3's first conduit, only two were lit by the middle of 2001.) Much of this initial construction was long-haul capacity, laid along the rights of way of railroads and pipelines, where digging was less expensive than in urban areas. The last mile connections to consumers were not part of the business plans of these companies, who hoped to be long-distance wholesalers. The original venture capitalists under-estimated how quickly other venture capitalists would jump-in. One result of competition was that the wholesale cost of a dedicated fiber on the Qwest network fell from $5,000/mile in 1997 to $1,200/mile by mid-2001.

[31] Telegeography Inc., *Mans 2003 [Municipal Areas Networks]*, in press ed. (Washington, DC: Telegeography Inc., 2002).

and 2003. The growth of new capacity can be seen from the (pre-DWDM) 1997 baseline: on the competitive US-Europe route, total capacity was 23 gigabits/second in 1997. It grew to nearly 550 gigabits/second by the end of 2000, where Table 1begins.[32]

It provides a useful perspective to observe the impact of DWDM at the wholesale level of international communications, where prices have fallen at 50% - 60% in each of the past three years.[33] The annual lease of an E-1 (2 Mbps) circuit between New York and London fell from about $125,000 at the end of 1998 to less than 10% of this price in early 2002.[34] (The changes are in wholesale prices; the reductions are not yet available to most organizations and individual consumers.)

Another example: In 2000 it cost $500,000 for an annual lease of a 155 Mbps trans-Atlantic circuit. Using digital technology, a telephone call requires about 5Kbps: thus, the circuit s capacity is about 30,000 simultaneous calls/minute. At ten cents/minute, that is $3,000/minute. If you can sell the full capacity, in just three hours (180 minutes x $3,000) you have paid for the annual lease and have

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[32] Telegeography Inc., *International Bandwidth 2000* 12-13.

[33] Telegeography Inc., *Submarine Bandwidth 2002: International Bandwidth Supply and Demand* (Washington, DC: Telegeography, Inc., 2002) iii.

[34] Ibid. See also www.telegeography.com. The E-1 (European) line for digital transmission is similar to the North American T-1 line. An E-1 circuit carries 2Mbps (32 channels of 64Kbps); the T-1 carries signals at 1.54 Mbps (24 channels of 64Kbps).

started to make a profit.[35] It may seem astonishing that companies have overbuilt and are using only 2% of capacity. However, at current international prices and costs, selling 2% of the capacity still is highly profitable, although the companies can have short-term problems to pay interest on the debt they incurred.

- Another implication of these numbers is worth keeping in mind: Since photons are free, the other 98% of capacity could be given away, free, and the companies would still make a profit. The new era of global Internet video applications is not inherently more expensive than today s prices. It may be less expensive, although it will require more competition, and/or nonprofit purchasing intermediaries, to secure the lowest prices for retail users.

At this point, competition at the wholesale level of international communications is growing and prices should continue to fall. In July 1997 less than 600 companies were authorized to build international telephone services; by the end of 2001 there were 4,000. The market share of new competitors, which was less than 1% in 1990 and 5% in 1995, became 31% in 2000 - and in 2001 one of the challengers, WorldCom, became the largest provider in the world (surpassing AT&T). All international communication markets (except Eastern Europe and Africa) show a steady double-digit annual growth in demand (e.g., up 21% to 132.7 billion minutes in 2000. Business is booming, although the prices and profit rates are down (and a shake-out phase is underway as this book goes to press): International traffic volume quadrupled in the 1990s, from a base of 33.5 billion minutes in 1990; revenue doubled during the

[35] Cost is for an STM-1 trans-Atlantic annual cable lease (155 Mbps): Telegeography Inc., *International Bandwidth 2000* 14.

same period from $37 billion in 1990 to $70 billion in 2000).[36] [For a historical perspective: the first transatlantic telephone cable (from Scotland to Newfoundland) began operation on September 25, 1956 and provided 36 telephone circuits. The first trans-Pacific telephone cable began operation from Hawaii to Japan in 1964 and provided 128 voice circuits.)

One result of the new economics, and changing patterns of demand for international links, is that Internet service companies, who once provided slow service and traffic jams on international routes, have vastly expanded their capacity. Leases for new transoceanic submarine bandwidth increased 196 percent in 2000 and 212 percent in 2001: the majority of the capacity purchases were for new Internet network capacity, which quadrupled in both

[36] Data are from Telegeography, Inc. Executive summaries of their annual reports are available online at www.telegeography.com. Telegeography Inc., *Packet Geography 2002* (Washington, DC: Telegeography Inc., 2002).
Telegeography Inc., *Telegeography 2001* (Washington, DC: Telegeography Inc., 2000).
Telegeography Inc., *Telegeography 2002* (Washington, DC: Telegeography Inc., 2002).. Traffic flows across private data networks, including Internet traffic flows, are guarded secrets and published data increasingly under-report the growth of international communications, especially within and among large organizations.

For international links, there has been especially strong growth in cellular telephone use and (from a much lower base) Internet telephone (an important, low-cost alternative for connections to underdeveloped countries - e.g., US-Mexico.)

1998 and 1999 and tripled from 2000 to 2001.[37] International Internet links can operate as smoothly as within the US - just as international telephone calls can be clear and noise-free.

B. Satellite Capacity

While we do not yet think of satellites as part of the Internet, all of the elements of communications are becoming linked by the shift to digital translations. All of the new technologies can use Internet protocols and will become part of the new global system.

The first global communication satellite (Early Bird) was launched in 1965, the beginning of a commercial space industry that has grown to $80+ billion/year.[38] Two new kinds of direct-broadcast satellites will provide major components of the Internet s global backbones:

1.) Traditional geosynchronous satellites (GEO), which are in a fixed position 22,300 miles above the equator. These require (since the strength of a signal is reduced by the square of the distance) more expensive satellites and/or larger dish antennas. Depending upon the configuration, three geosynchronous satellites can provide a signal to most of the world. The economic advantage of a satellite is that, once launched, it can provide a common signal to a vast

[37] Telegeography Inc., *Submarine Bandwidth 2002: International Bandwidth Supply and Demand* iv.

[38] Statistics concerning commercial satellites are the responsibility of the Associate Administrator for Commercial Space Transportation of the Federal Aviation Administration. See their annual series of Commercial Space Transportation Forecasts, available at http://ast.faa.gov.

geographic area and population within the footprint of its beams. Unlike the telephone system, the cost of added distance and added users within the satellite s geographic area is zero. After the signal is received from the ground, the satellite does not care how far away a message has to travel, or how many recipients access the beam.

For consumers, a new type of GEO satellite is the direct-broadcast (DBS) satellite system of DirecTV and its principal competitor DishNetwork.[39] These satellites beam hundreds of television channels (and some broadband Internet transmissions controlled by individual users) to small dish antennas at individual homes.[40]

With a recent launch, DirecTV, the leading direct-broadcast satellite company, will have a North American broadcasting capacity (across six satellites) of about 750 national channels and spot beams with different programming to dozens of different local markets.[41] Because GEO systems are in a fixed orbit above the equator, these satellites require unobstructed views of the Southern horizon for a direct link. Subscribers grew nearly three million households in 2001 to a current total of about 10.7 million for DirecTV and 6.8 million for its competitor Echostar.[42]

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[39] DishNetwork, at this writing, is seeking to buy DirecTV,

[40] DBS technology requires a clear window to the Southern sky (see www.directv.com); LEO and MEO systems will not have this restriction.

[41] Theresa Foley, "DirecTV Proceeds with a Local-Market Plan," *The New York Times*, August 13 2001.

[42] See www.directv.com/DTVAPP/aboutus/Investor.jsp; Alicia

GEO (DBS-direct broadcast) satellites are economical solutions to the traditional (scheduled) television channel component of the evolving Internet. They are good for mass communications: hundreds of channels can be provided to hundreds of millions of subscribers within the satellite s beams for only the small added cost (perhaps $150) of a modestly-sized satellite dish. As they do not have to wire, and rewire, the nation, their fixed cost is inherently much lower than the (older technology) cable television companies. A range of technical options could permit DBS service even to homes and businesses that lack a clear window toward the satellites orbits above Southern horizon: for example, tall towers (or antenna at the top of tall buildings) to the north of users might acquire the DBS signal and rebroadcast it, reusing the satellites frequencies (without interference, because the dish antenna would be pointed northward).

The small dish antennas (Very Small Aperture - VSAT) used by DirecTV also provide a breakthrough for underdeveloped countries, as they can offer two-way capacity (e.g., with 8Mbps down and 150Kps uplink) that is good enough for small villages to be served by micro-enterprise equivalents of Mailboxes, Etc. with public cellular telephones, email accounts for villagers, fax, and other services): India, for example, has contracted with DirecTV for 50,000 local kiosks with two-way links and expects to have 200,000 villages online by 2002.[43]

Mundy, "Charlie's Angel," *Cableworld*, April 1 2002, 15.

[43] Priscilla Awde, "Satellite Market," *Financial Times (online)*, December 6 2000. Peter Benjamin, "African Experience with Telecenters," *e-OTI: OnTheInternet*, October 2000.

2.) Low- and Mid- earth orbit (LEO and MEO) satellites. These satellites operate at low (e.g., 480 miles) or middle - e.g., 10,930 km. orbits. Their advantages are that they are much closer and they require less power, can be less expensive, and accessed with a smaller antenna. They also have the potential advantage - because a large rotating shell of such satellites is used - that their markets are not restricted just to users with clear windows toward the sky above the equator. An early example of a LEO system was Iridium, which used 66 satellites to provide cellular telephone service worldwide but with (at the time) brick-sized cellular telephones and rates that were too high for a commercial success.

The most promising new satellite system in this category is Teledesic (Bill Gates et al.). It has been announced in several configurations, beginning as a LEO design with 840 satellites. The current design for its new Internet-in-the-Sky system is 30 middle-earth-orbit (MEO) satellites at 10,930 km to begin service in 2005. Teledesic has announced that it will sell wireless broadband, at competitive prices worldwide.[44] Teledesic has been secretive about the details of its technology. Speculation has ranged from a system that will wipe-out all competitors to the possibility of a complete commercial failure.

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[44] The original design of 840 LEO satellites, announced in 1994, was scaled back to 288, and then redesigned to 30 MEO satellites: Barnaby J. Feder, "Teledesic Avoids Loss of Licenses for Spectrum," *The New York Times*, February 4 2002. Teledesic s new altitude: Roger Nyhus (personal communication). The current plan is for an initial group of 12 satellites, followed by another 18: Inc. Teledesic, *Teledesic Reaches Satellite Construction Agreement for Broadband Internet-in-the-Sky Network* (Online) (www.teledesic.com, 2002 [cited March 3 2002]).

Rapid growth is underway in private satellite capacity. Much of the capacity is sold at wholesale - for example to companies for internal communications. A base of about 350 operational communication satellites in late 2001 is scheduled to expand with about 75 additional launches in 2002.[45] (As we will see in chapter five, satellite capacity above the Third World also is becoming plentiful - India for example now is served by 150 commercial channels from 18 satellites, including many channels that are available to American cable subscribers.) Satellite technology continues to improve; it runs in two-year cycles, from design to construction and launch: corporate plans beyond two years are difficult to determine, but past forecasting models predict about 30 additional GEO satellites/year through 2010 and a robust market scenario of 252 LEO and MEO satellites in same period.[46]

For large international organizations or corporations in the densely populated areas of large inner cities, links to these new capacities are easy because they can readily lease satellite links or contract directly for fiber optic links. For individual users, especially in the suburbs, there is a final mile connection to be negotiated with

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[45] See www.satnews.com

[46] Federal Aviation Administration, *2001 Commercial Space Transportation Forecasts* (Washington, DC: Federal Aviation Administration (AST), 2001) 1. Federal Aviation Administration, *2001 Commercial Space Transportation Projections for Non-Geosynchronous Orbits (NGSO)* (Washington, DC: Federal Aviation Administration (AST), 2001). Teledesic is secretive about its plans. Speculation ranges from the hypothesis that it is in serious trouble and may never launch; to concern that it has hired the best brains on the planet and may blow-away all competition.

local providers.

IV. The Final Mile

> Major cities in the U.S., for example, are routinely traversed by a thousand (or more) pairs of optical fiber while pan-European networks have laid hundreds of pairs through population centers. Only a small portion of those fibers are actually lit: on average, 10 percent of potential wavelengths on 10 percent of available fiber pairs. As a result, only one to two percent of potential bandwidth is active. However minor that proportion might seem the amount of lit capacity it represents is staggering. New York, for example, has 23.5 Tbps (terabits-per-second) running through it on domestic and international networks; London has 6.5 Tbps on international networks alone. Such tremendous bandwidth isn t the exclusive domain of international commercial centers, as second-tier cities (e.g., Cleveland and Basel) along important routes also boast terabits per second of capacity. The potential capacity is even more astonishing, reaching petabits per second in the U.S. (on domestic and international networks) and hundreds of terabits in Europe (on international networks alone.) . . . Even Harrisburg, Pennsylvania, one of the most bandwidth-starved U. S. cities studied in this report, has access to capacity equivalent to over one STM-1 circuit [155 Mbps] per capita.
>
> - Telegeography Inc. (2002)[47]

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[47] Telegeography Inc., *Terrestrial Bandwidth 2002: Long-Haul Bandwidth Supply and Demand* (Washington, DC: Telegeography

In central cities, a linkup to as much bandwidth as an institution needs is a straightforward commercial transaction, with at least modest competition among several vendors. Fiber-to-the-Office-Building private channels already may be available (or will arrive soon), or the nodes will be within several hundred feet; and fast and inexpensive Ethernet cables or other technology can distribute capacity within a building. Direct broadcast satellite and other wireless technologies also are available.

For home use in the suburbs, the definition of broadband, and the decision of how much to acquire, depends upon applications. Typically, a high capacity fiber optic node ends at a distance (e.g., within one mile) from the average home, and the capacity is divided by using less expensive coaxial cable (for cable companies) or telephone lines (for telephone companies that use DSL, digital subscriber line technology) for the last step. The capacity to users can be increased by bringing the fiber nodes steadily closer, and dividing among fewer households. Table 1-4 shows new uses that can be acquired, at current levels of compression, by securing a broadband upgrade:

Table 1 - 4
Final Mile Broadband and Selected Applications
(with current compression technology)

5 Kbps	human speech
20K bps	audio + slide presentations
*56K bps	painful, 3" window, jerky & murky television

Inc., 2002) i.

	* (This is where most users are, today.)
126 Kbps	Mini-screen 3G cellular videophones (MPEG-4 compression); CD-quality sound[48]
384 Kbps	Internet television for lectures, full-screen video telephone
500 Kbps	VCR-quality video for many old (slower) movies.
1 Mbps	Fast action video games, simple graphics If you just want Web pages to download very quickly, this is fastest Internet connection that it makes sense to buy. Faster last mile connections will not improve the current Internet s overall response, given the way Web pages are stored and retrieved from around the Net.)
1.5 - 2 Mbps	SDTV (standard definition television). But requirements vary by content: basketball and commercials (e.g., new scenes every 2 seconds) need higher capacity, perhaps 5-6 Mbps. Video-on-demand for normal television programs and movies.
19.3 Mbps+	High Definition television; telepresence

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[48] National Science and Telecommunications Board, *Broadband: Bringing Home the Bits* 92.. MP3 compression at 64Kbps is roughly analogous to FM-quality audio.

realism (?)

At this point, Web pages will download more quickly, and a basic academic lecture via Internet television can be delivered with acceptable quality (i.e., good enough not to be distracting) at about 350K - 400K/second.[49]

Old movies, without much action and fewer frames/second, require at least 500kbps. Given limitations in the current public Internet in North America, the speed of retrieving and downloading standard Webpages will not improve beyond what can be obtained with a final mile connection of 1Mbps.[50]

Today, a good definition of true broadband is probably the capacity to receive or send 2 to 6+ megabits/second. This is enough to watch standard television (SDTV) in digital form. Higher speeds (e.g., 5-6Mbps) would permit fast sports, the ability to download movies and video files quickly (for storage or later viewing), and high quality videoconferencing and telecommuting. The ability to operate at equally high speeds, downstream and upstream, will be especially important to give authoring capabilities for desktop television stations, videoconferencing, and telecommuting to users.

Moving upward on the scale, the new high definition digital television (HDTV) can be compressed and delivered smoothly

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[49] Abe, *Residential Broadband*. The number 384K is sometimes cited, reflecting six, 64K connections.

[50] National Science and Telecommunications Board, *Broadband: Bringing Home the Bits* 78-79.

through a pipeline that supports about 19 megabits/second. This level may also be enough to create a sense of reality, or telepresence, that is especially desirable for music (including music collaboration via the Internet), virtual-reality games, and live sports.

Beyond, lies the ultraband range of hundreds of megabits, or gigabits/second. Nobody has yet devised home applications (e.g., holography) that would use such capacity, which could be easily supplied by connecting fiber optic cables directly to the home.

The last mile pipeline goals should be increased for multiple-user homes. If there are two HDTV television sets downloading two different channels, a teenager playing a superfast action game over a computer linkup and another family member using an Internet-linked telephone, 45 megabits/second would be sufficient.

As more applications become available, the standard for decent broadband connections are likely to move upward, just as Consumer Reports (~pp. xx - xx, above) has steadily increased its recommendations for home computing.

In the future, there may be a dozen or more kinds of companies that will compete to use different wireline and wireless technologies to provide these broadband and ultraband upgrades to consumers. For ease of exposition, I will discuss these details in chapter eight. They include cable and telephone companies, the GEO and LEO satellite companies, and others.[51]

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[51] At least a dozen technologies are emerging: Lloyd S. Etheredge, "Consumer-Oriented Broadcasting and Video Archives for Health,", (Washington, DC: Health Insurance Reform Project - Robert Wood Johnson Foundation, 2001).. See also: John Markoff, "2

For most consumers the build-out of options is at the point that the industry calls Fiber-to-the-Neighborhood, an architecture used by cable and telephone companies to bring their fiber nodes to within about 3,000 feet for division among 250 - 500 homes (only a fraction of whom, right now, will subscribe to the upgrade package.) (For businesses, the analogy is Fiber-to-the-Office Building.) A future step will be Fiber-to-the-Curb, which may place a node at street corners, with capacity for 20-30 homes within 1,000 feet. Finally, there will be Fiber-to-the-Home. [Telephone companies offer a similar link to fiber optic nodes with a technology called DSL - digital subscriber line - that uses the twisted-pair copper wire for home telephone systems for the last mile. The capacity of DSL, while it uses a different technology, has the same logic as cable television technology - the deliverable capacity can increase by bringing fiber junctions closer to each household. Advanced DSL systems can deliver 21 Mbps to a distance of 4,200 feet. Because of the similarity, I will defer discussion of DSL and ADSL to chapter eight.)[52]

Tinkerers Say They've Found a Cheap Way to Broadband," *The New York Times*, June 10 2002. Amy Harmon, "Good (and Unwitting) Neighbors Make for Good Internet Access," *The New York Times*, March 4 2002.
John Markoff, "The Corner Internet Network Vs.The Cellular Giants," *The New York Times*, March 4 2002. For a European perspective on options: Priscilla Awde, "Many Ways to Ease Last Mile Bottleneck," *Financial Times*, January 17 2001.

[52] Aaron Donovan, "Faster Data Connection Waits Impatiently in Line," *The New York Times*, March 22 2001. Across a distance of 1,000 meters, ADSL probably can deliver 25 Mbps, enough for High Definition television. To secure such capacity in both directions, the optimum distance for a fiber junction is within 200 meters of a

The speed of these final-mile build-outs reflects two costs: a.) the business cost to the cable company; and b.) the cost of the physical connection. In a technological sense, there is no last mile problem: rather, suburban consumers have a monopoly s business plan problem.

A. <u>Business Costs and the Last Mile</u>

Currently, cable companies are regulated monopolies. They use most of the capacity from fiber nodes to provide, for monthly subscription fees, hundreds of cable television channels. Then a residual capacity is called broadband and divided among subscribers to permit faster downloads of Web pages and (more limited) upload speeds. While the advertised (Up to . . .) speed ratings can be impressive, less than half the broadband purchasers in the US can count on sustaining even 500 Kbps downstream.[53]

The existing networks <u>can</u> be reconfigured to provide 2+ Mbps (or much higher) two-way capacity to users. However, the cable company would prefer to use the capacity on its coaxial cables to sell hundreds of channels, in monthly subscription packages, to its users - and it probably can make more money than by using the same capacity for the Internet.

Thus, there is a conflict of interest between cable companies and their customers. The second business consideration is that, once

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residence and 300 meters of the television set or desktop: Abe, *Residential Broadband* 194-95.

[53] Sue Zeidler, *Experts: Broadband Not Ready for Hollywood* [On-line] (Reuters, February 3, 2002; 9:08 AM 2002 [cited February 3 2002]).

Internet capacity expands to a reliable 2Mbps to 6+ Mbps per consumer, the consumer suddenly becomes a free agent and the cable company loses control. Technically, a consumer does not need hundreds of television channels arriving at a set-top box. Each consumer only needs one 2Mbps-6Mbps channel that can be switched quickly, via the Internet, to whatever content he wants to view. He could get the television programs from his cable company - or anybody. I.e., at 2Mbps - 6Mbps the middle man (the cable company) can be cut out and a consumer could build an individual subscription package to just the 6-10 channels he wants (Discovery, Disney, etc.) instead of all the channels that the cable company wants to sell in its packages. (In the long-run, the local cable company could probably compete to be the middleman and handle the logistics of subscriptions. However, it would no longer be the monopoly provider and would be required to lower its prices to retain its customers.)

There also is an extra economic advantage to a cable company to be a monopoly middle man. One of the incentives for the rapid consolidation of the cable industry is that, while it can secure billions of dollars of revenue from monthly subscription fees paid by consumers, it also is the only monopoly option for most of the cable channels, who may pay hundreds of millions of dollars for the right to be carried. The cable company collects in both directions (and it can secure money from advertising.) Now that today s large cable companies have consolidated many smaller cable companies, they control access to tens of millions of homes and are in a position to charge for higher fees.

(The technical point I am making is analogous to the design of the telephone system. You do not need hundreds of lines to your home, so that you can connect to hundreds of different people. It is mindlessly inefficient. All you need to each home is one, twisted-pair copper wire, whose use is switched to any telephone in the world at a central office.)

I will return to this issue in chapter two, and in chapter eight: More competition will be needed before high-capacity and low-cost broadband are quickly available from for-profit companies. (While there are options for telephone companies to compete to offer final-mile connections, this may not enough - and only create a cable-telephone duopolcy.)[54]

B. Physical Costs of Last-Mile Linkups

The second economic issue is simply the cost of a fiber optic build-out, and who pays?

At this point, nobody knows how to use gigabit/second capacities to each home. However, the current cost of connecting this immediately is primarily the economics of physical construction, similar to linking-up to water or sewer.

Currently, cable companies use lower-cost and lower-capacity coaxial cable that can be strung on telephone poles, like electric or telephone wires. Coaxial cable is the wire that comes to your house, and from the wall socket to the back of the cable box. This last

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[54] Some cable companies are experimenting with offering dedicated, larger, and secure Internet channels to home users for an additional fee atop the full month charge for an entertainment upgrade package, although using one of the home user s television channels this way does not cost them additional money: Thomas E. Weber, "More Trouble at AOL: Cable Rivals May Push Net Prices Even Lower," *Wall Street Journal*, April 22 2002.

mile technology also is more forgiving: coaxial cable can be blown-around in the wind or bent at angles without affecting performance.[55] It also is more cost-effective because it is older technology and, in part, its cost has been amortized by consumers through past years of cable subscriptions. By contrast, high capacity performance along fiber optic cable typically requires that it be laid straight and level (usually underground, or in ceiling conduits in buildings). Changes of direction involve careful splicing and added equipment, training, and installation time. Digging trenches in large urban areas also can be expensive, including (e.g., in New York City) the costs of permits.

Fiber connections to each home might cost, at a conservative estimate, an average of $1,000 per household (or more, depending upon whether installation is aerial or underground.)[56] The cost/home becomes greater when there is a greater distance between homes and/or only a fraction of the homes passed by the fiber cable actually subscribe. It is less for apartment houses (and college dormitories) where each unit will have an outlet.

However, even at a fixed cost of $1,000, households might save money, if given a choice to substitute their own gigabit/second fiber link: The typical household already spends over $900/year on

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[55] Once to a home, fiber optic capacity can be distributed efficiently by using 100 Mbps Ethernet connections over lower cost (wire) lines. This avoids the physical constraints and costs of installing fiber connections to every final location. Or there can be wireless, or other short-distance networks installed.

[56] National Science and Telecommunications Board, *Broadband: Bringing Home the Bits* 154.

its Internet dial-up ($264), basic cable ($456), and long distance telephone ($216). These costs could, in principle, be steeply reduced by Internet connections that allow competitive purchasing. And as competition increases and cell phones become less expensive (the typical cellular telephone household spends $540/year) additional funds will free-up from current budgets.[57] An added $25/month charge would pay off the investment in just over three years.

Cable companies are regulated monopolies and might be expected to provide these options. But they are unlikely to make any initiative as, given their current monopoly business plans, they believe that they have conflicts of interest.

At this point, too, I want to underscore that the final mile problem only slows the (wireline) home entertainment and home PC Internets. Most organizations in urban areas can move quickly to secure the large capacity pipelines (and even direct fiber links to office buildings) at prices that are more competitive than for residential suburbs and rural areas. Local communities may have to become more active to assure competition to secure the best options.

V. Five Internets

As technologies continue along these pathways, the Internet will divide and begin to grow rapidly at several different levels, each with its own technology and economics:[58]

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[57] Robert J. Samuelson, "Telecom's Disconnect," *The Washington Post*, February 27 2002.

[58] In 2000 the average American household spent $420 for

1.) a new world of miniature devices and machines that can communicate among themselves over the Internet wirelessly, without human involvement;

2.) a new world of a portable, wireless Internet with upgraded (3G+) cellular telephones and upgraded handheld devices such as Palm Pilots, offering a small-screen version of Internet content, digital radio and other entertainment;

3.) a home entertainment Internet including upgraded cable and digital television and options for direct satellite links; new online games, video-on-demand archives, and other interactive services;

4.) a fast (private) business and science Internet, with high-capacity video-conferencing and data networks and using a new generation of national and global fiber optic backbones;[59]

5.) the familiar desktop PC Internet, expanded to offer

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local telephone service; $216 for long-distance; $540 for cellular telephone; $456 for cable television; and $264 for Internet dial-up: Ibid..

[59] Re Internet2 (which began operation in 1999) for scientists and academic institutions see: Scott Thurm, "High-Speed Networks: New and Improved," *The Wall Street Journal*, February 11 2002.. Examples of companies offering private networks are EDS (www.eds.com) and Global Crossing (www.globalcrossing.com) - now being restructured as a result of bankruptcy but likely to continue.

telephone service; and with growing broadband capability that improves performance from a 3" jerky and murky window to provide fast and affordable video connections worldwide.

Abe, George. *Residential Broadband*. Indianapolis, IN: Cisco Press, 2000.

Ahrens, Frank. "Agency Pushes Digital TV Shift." *Washington Post*, April 5 2002, E1, E4.

Austen, Ian. "Shrinking the Cellular Phone One Component at a Time." *The New York Times*, E7 2002, January 31.

Awde, Priscilla. "Many Ways to Ease Last Mile Bottleneck." *Financial Times*, January 17 2001, XIV.

. "Satellite Market." *Financial Times (online)*, December 6 2000, 1-3.

Benjamin, Peter. "African Experience with Telecenters." *e-OTI: OnTheInternet*, October 2000, 1-4.

Blumenstein, Rebecca. "How the Fiber Barons Plunged the Nation into a Telecom Glut." *Wall Street Journal*, June 18 2001, A1, A8.

Brand, Stewart. "Wire Legends: Founding Father [Paul Baran]." *Wired* 2001, 144-53.

Cairncross, Frances. *The Death of Distance: How the Communications Revolution Will Change Our Lives*. Boston, MA: Harvard Business School Press, 1997.

Consumer Reports. "Frontlines - Technology: Computers Then and Now." *Consumer Reports*, May 2000, 10.

. "Make over or Buy New?" *Consumer Reports*, September 2001, 16-19.

Crandall, Robert W., and Kenneth Flamm, eds. *Changing the Rules: Technological Change, International Competititon, and*

Regulation in Communications. Washington, DC: Brookings Institution, 1989.

DeJesus, Edmund X. "How the Internet Will Replace Broadcasting." *Byte* 1996, 51-54,56,60,62,64.

Dizard Jr., Wilson. *Meganet: How the Global Communications Network Will Connect Everyone on Earth*. Boulder, CO: Westview Press, 1997.

Donovan, Aaron. "Faster Data Connection Waits Impatiently in Line." *The New York Times*, March 22 2001, E3.

Etheredge, Lloyd S. "Consumer-Oriented Broadcasting and Video Archives for Health.". Washington, DC: Health Insurance Reform Project - Robert Wood Johnson Foundation, 2001.

Feder, Barnaby J. "Teledesic Avoids Loss of Licenses for Spectrum." *The New York Times*, February 4 2002, C4.

Federal Aviation Administration. *2001 Commercial Space Transportation Forecasts*. Washington, DC: Federal Aviation Administration (AST), 2001.

. *2001 Commercial Space Transportation Projections for Non-Geosynchronous Orbits (NGSO)*. Washington, DC: Federal Aviation Administration (AST), 2001.

Foley, Theresa. "DirecTV Proceeds with a Local-Market Plan." *The New York Times*, August 13 2001, C4.

Gaither, Chris. "Intel Introduces Chips for Servers Using Pentium 4 Technology." *The New York Times*, February 25 2002, C2.

Gates, Bill, Nathan Myhrvold, and Peter Rinearson. *The Road Ahead*. Revised ed. New York: Penguin, 1996.

Harmon, Amy. "Good (and Unwitting) Neighbors Make for Good Internet Access." *The New York Times*, March 4 2002, C1,C4.

Howard, Bill. "Life with a $500 PC." *PC Magazine*, April 9 2002, 65.

Hudson, Heather E. *Global Connections; International Telecommunications Infrastructure and Policy*. New York: Van Nostrand Reinhold, 1997.

Kahn, Robert E., and Vinton G. Cerf. "What Is the Internet (and What Makes It Work).". Washington, DC: Internet Policy Institute, 1999.

Kurzweil, Ray. "Fine Living in Virtual Reality." In *The Invisible Future: The Seamless Integration of Technology into Everyday Life*, edited by Peter J. Denning. New York: McGraw Hill, 2002.

Markoff, John. "2 Tinkerers Say They've Found a Cheap Way to Broadband." *The New York Times*, June 10 2002, C1, C6.

. "The Corner Internet Network Vs.The Cellular Giants." *The New York Times*, March 4 2002, C1, C4.

. "IBM Circuits Are Now Faster and Reduce Use of Power." *The New York Times*, February 25 2002, C3.

. "The Increase in Chip Speed Is Accelerating, Not Slowing." *The New York Times*, February 4 2002, C1, C5.

Moore, Gordon E. "Cramming More Components onto Integrated Circuits." *Electronics* 38, no. 8 (1965): April 19.

. "An Update on Moore's Law." In *Intel Developer Forum*. San Francisco, CA, 1997.

Mundy, Alicia. "Charlie's Angel." *Cableworld*, April 1 2002, 12-15.

National Science and Telecommunications Board. *Broadband: Bringing Home the Bits*. Washington, DC: National Research Council, 2002.

Negroponte, Nicholas. *Being Digital*: Hodder & Stoughton, 1995.

Perkin, Julian. "New Codes Open Doors for Non-Roman Alphabet Users." *Financial Times* 2001, IT Review 2-3.

Reed, Mark A., and James M. Tour. "Computing with Molecules." *Scientific American*, June 2000, 86-93.

Reuters. *Bell Labs Says It Shatters Data Delivery Record* (March 22) Yahoo! news, 2002 [cited March 22 2002].

Samuelson, Robert J. "Telecom's Disconnect." *The Washington Post*, February 27 2002, A23.

Sapolsky, Harvey, and et al. *The Telecomunications Revolution: Past,*

Present, and Future. New York, NY: Routledge, 1992.
Schweber, William L. *Data Communications*. New York: McGraw-Hill Inc., 1988.
Teledesic, Inc. *Teledesic Reaches Satellite Construction Agreement for Broadband Internet-in-the-Sky Network* (Online) www.teledesic.com, 2002 [cited March 3 2002].
Telegeography Inc. *International Bandwidth 2000*. Washington, DC: Telegeography Inc., 2000.
. *Mans 2003 [Municipal Areas Networks]*. in press ed. Washington, DC: Telegeography Inc., 2002.
. *Packet Geography 2002*. Washington, DC: Telegeography Inc., 2002.
. *Submarine Bandwidth 2002: International Bandwidth Supply and Demand*. Washington, DC: Telegeography, Inc., 2002.
. *Telegeography 2001*. Washington, DC: Telegeography Inc., 2000.
. *Telegeography 2002*. Washington, DC: Telegeography Inc., 2002.
. *Terrestrial Bandwidth 2002: Long-Haul Bandwidth Supply and Demand*. Washington, DC: Telegeography Inc., 2002.
Thurm, Scott. "High-Speed Networks: New and Improved." *The Wall Street Journal*, February 11 2002, R13, R16.
Waters, Richard, Sarah Parkes, and Andrew Baxter. "Switch-Off Prompts Search for Light Relief." *Financial Times*, September 19 2001, I.
Weber, Thomas E. "More Trouble at AOL: Cable Rivals May Push Net Prices Even Lower." *Wall Street Journal*, April 22 2002, B1.
Zeidler, Sue. *Experts: Broadband Not Ready for Hollywood* [On-line]. Reuters, February 3, 2002; 9:08 AM 2002 [cited February 3 2002].