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A Year 2003 Conceptual Model for the U.S. Telecommunications Infrastructure

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Abstract

To model the telecommunications infrastructure and its role and robustness to shocks, we must characterize the business and engineering of telecommunications systems in the year 2003 and beyond. By analogy to environmental systems modeling, we seek to develop a "conceptual model" for telecommunications. Here, the conceptual model is a list of high-level assumptions consistent with the economic and engineering architectures of telecommunications suppliers and customers, both today and in the near future. We describe the present engineering architectures of the most popular service offerings, and describe the supplier markets in some detail. We also develop a characterization of the customer base for telecommunications services and project its likely response to disruptions in service, base-lining such conjectures against observed behaviors during 9/11.

Caveat

Telecommunications over the last 20 years has experienced more technology and market change than, say, aviation has in 40 years or the railroads in 100 years. Nuclear technologies over the last 30 years seem positively moribund compared to the rate of change in information technologies. Water resources and many other technologies have never experienced the same absolute amount or rate of change. Only computer technologies have experienced an equivalent rate of change in the last 50 years. Noting that, it is easy to find predictions from computer technology leaders in the 1960s and 1970s that seem quaint or laughable today. This should warn any modeler away from an uncritical reading of this or any other document that purports to accurately characterize future (and even present) states of such a fast-changing technology, much less customer response to these technologies. There are future equilibrium states, e.g., open-spectrum proposals, that may eventually lead to some maturation and relative stability in telecommunications, but how and when we will arrive at such states is more speculation than science. The seersucker hypothesis has not been disproved by this study, that hypothesis being that for every seer, there is a sucker.

Contents

Figures

Nomenclature

A/D	analog-to-digital
AC	alternating current
AOL	America Online
Aspen	(an agent-based simulation model of the U.S. economy)
ATIS	Alliance for Telecommunications Industry Solutions
ATM	asynchronous transfer mode
b	bit
CIR	committed information rate
CLEC	competitive local exchange carrier
CONUS	Continental United States
COTS	commercial off-the-shelf
CPE	customer-premises equipment
CSU	channel service unit
DBS	direct broadcast satellite
DCS	digital cross-connect system
DLN	direct-link-node
DSL	digital subscriber line
DSU	data service unit
DWDM	dense wavelength division multiplexing
EM	electromagnetic
FCC	Federal Communications Commission
FDI	feeder-distribution interface
GDP	gross domestic product
HVAC	heating, ventilation, and air conditioning
IP	Internet Protocol
ISDN	integrated services digital network
ISP	Internet service provider
IT	information technology
k	kilo
kA	kiloampere
LAN	local area network
LATA	Local Access and Transport Area
LDRD	Laboratory Directed Research and Development (a Sandia program)
LEC	local exchange carrier
LSI	large-scale-integration
MIS	management-information-system
MSC	mobile-switching center
NRSC	Network Reliability Steering Committee
NYSE	New York Stock Exchange
OSI	Open Systems Interconnection
OSS	operations support software
POTS	plain old telephone service
PUC	public utility commission

R&D	research and development
RBOC	Regional Bell operating company
ROI	return on investment
ROW	right of way
s	second
Sandia	Sandia National Laboratories
SARS	Severe Acute Respiratory Syndrome
SIAC	Securities Industry Automation Corporation
SLAs	service-level agreements
SoHo	Small office Home office
TCP	Transmission Control Protocol
TIA	Telecommunications Industry Association
UPS	uninterruptible power supply
UWB	ultrawideband
V	volt
VLSI	very-large-scale-integration
VPN	virtual private network
VRLA	valve-regulated lead acid
W	watt
WLAN	wireless local-area network

A Year 2003 Conceptual Model for the U.S. Telecommunications Infrastructure

Introduction

In the early stages of developing CommAspen, a new economics model of infrastructure interdependency that focuses on communications, we sought to gain a greater understanding of the key aspects of the telecommunications industry. We looked at the structure of the industry, how it is regulated, who its major equipment suppliers are, what pricing models it employs, what architectures are in use or anticipated, and how telecommunications is interdependent with other infrastructures. Based on this research, we then proposed a set of categories of telecommunications agents for the model and identified characteristics of the services these types of agents could provide. As disruption of telecommunications services is of prime importance in developing a realistic model of infrastructure interdependency, we also postulated the kinds of behaviors that might be expected during and after a telecommunications outage by both consumers of telecommunications services and providers of these services.

We note that it is easier to develop conceptual models in telecommunications over environmental systems in the sense that most telecommunications engineering processes are man-made and thus theoretically known, although often company-proprietary. Also, customers explicitly opt into many telecommunications services, and the consequences of telecommunications failures do not involve projecting the health affects of low-level contamination.

Our work on defining the behavioral characteristics of telecommunications agents for CommAspen was interrupted by the events of September 11, 2001. However, through press accounts post-9/11, we were able to collect evidence about actual responses to telecommunications outages by both consumers and providers of telecommunications services. We compared these actual responses to those predicted pre-9/11, as a means of validating our initial preconceptions of agent behaviors.

This report describes the research and analysis we performed in the development of the CommAspen model. For the initial version of CommAspen, we implemented a few of the agent behaviors, but by no means all. This report serves as a guide for the further development of the telecommunications infrastructure in CommAspen.

Overview of the Telecommunications Industry

This section of the report was initially a Power Point presentation. We have used many of the viewgraphs from that presentation and have also added textual descriptions to give a more comprehensive picture of the industry than would be available in the viewgraphs alone. Please note that much of the data in this section covers the late 1990s and very early 2000s and may thus be somewhat outdated in the year that this report is being published, 2003.

Structure of the Industry and Revenues

The telecommunications industry consists mainly of six types of service providers: local exchange carriers (LECs), long distance/international carriers, cellular carriers, cable providers, Internet service providers (ISPs), and satellite broadcast and paging providers. A brief description of these provider types follows.

- LECs – Providers of local wireline telecommunications service, e.g., Qwest. More formally, LECs were providers of intraLATA services, where LATA (local access and transport area) is a delineation of a local area, sort of like a county.

- Long distance/international carriers – Long-distance refers to domestic (intraUS) carriers of voice and data services outside of a LATA area, e.g., AT&T, MCI, Sprint. International carriers provide services outside the United States—the incumbent long-distance carriers normally provide these services. A long-distance phone call may use two LEC networks and one long-distance (or IXC IntereXchange Carrier) network.

- Cellular carriers – Providers of (primarily voice) cellular service, which is a wireless telephony scheme using fixed antennae covering a relatively small area, and a scheme for tracking a call as it moves across regions/cells serviced by differing antennae, e.g., Sprint, AT&T, Nextel, T-Mobile, Cingular, Verizon.

- Cable providers – Providers of broadcast cable services in a metropolitan area and increasingly broadband access to the Internet backbone, e.g., Comcast.

- ISPs – Providers of Internet services that supply a bridge between the LEC and the Internet backbone, e.g., America Online (AOL), Earthlink.

- Satellite broadcast and paging providers – Providers of satellite broadcast and paging services. The distinction between these providers and any of the ones above are that the transmissions are broadcast in nature, i.e., one-way, except for a tiny amount of satellite telephone traffic.

From 1999–2000, the annual revenues from telecommunications in the United States was approximately $333 billon dollars. Of this amount, the largest revenues were by LECs, accounting for $111 billion, and the smallest were by direct broadcast satellite (DBS), accounting for $8 billion. Figure 1 shows the distribution of revenues by provider types during this period. This figure was compiled from a variety of sources, mainly Reference 1.

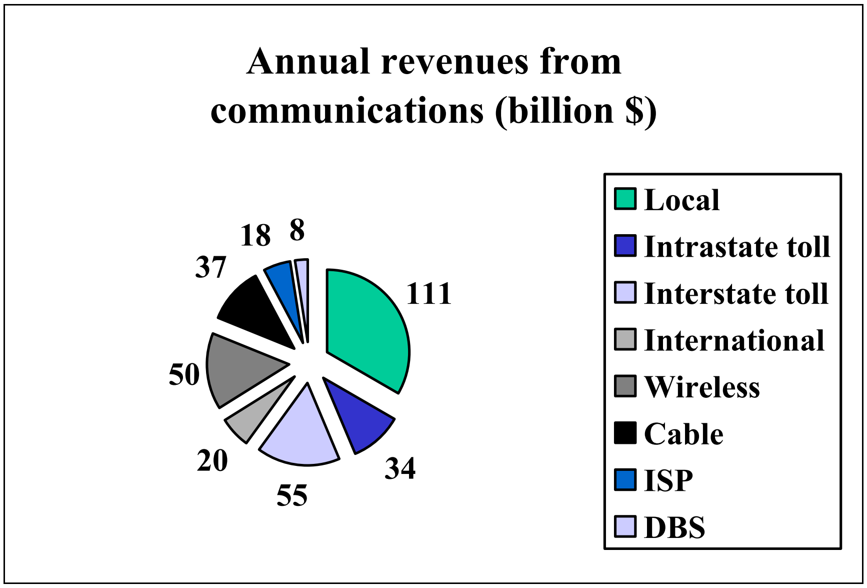


Figure 1. Annual revenues in the telecommunications industry in the United States 1999–2000.

According to Reference 2, the Telecommunications Industry Association (TIA), the telecommunications industry accounted for 5.6% of the gross domestic product (GDP) in the United States in 1999. Looking back over the 1990s, in fact, more than 40% of the economic growth in the United States from 1995 through 1996 was attributed to the information technology (IT) sector, as shown in Figure 2.

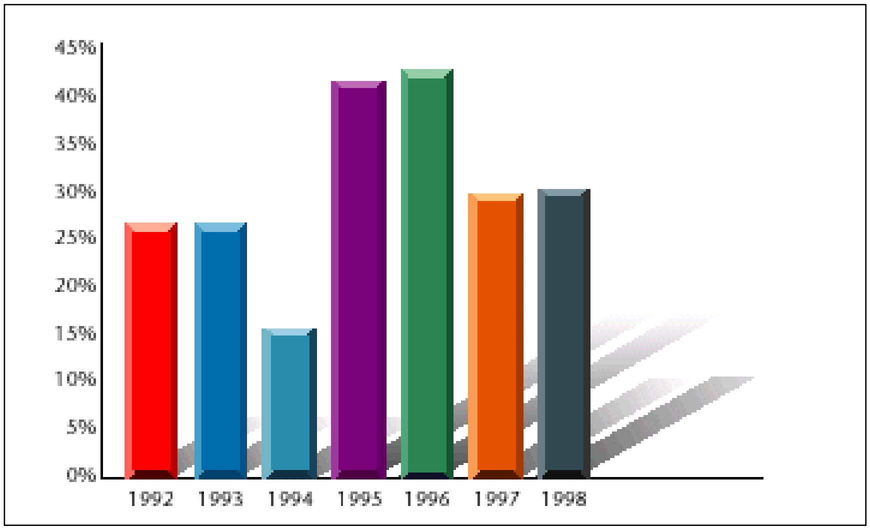


Figure 2. U.S. economic growth in IT, 1992–1998. *Source:* Telecommunications Industry Association [2].

Expenditures on telecommunications equipment showed steady and large increases annually from 1995 to 1999 [2], as shown in Figure 3. These expenditures covered, for example, purchases of hardware and/or software for items like switches, multiplexers, fiber-optic cables, and operations support systems software. The expenditures did not include personal computers (PCs), noncarrier routers, or local area network (LAN) equipment, which would fall under data communications. The line between telecom equipment and data communications equipment is becoming increasingly blurred.

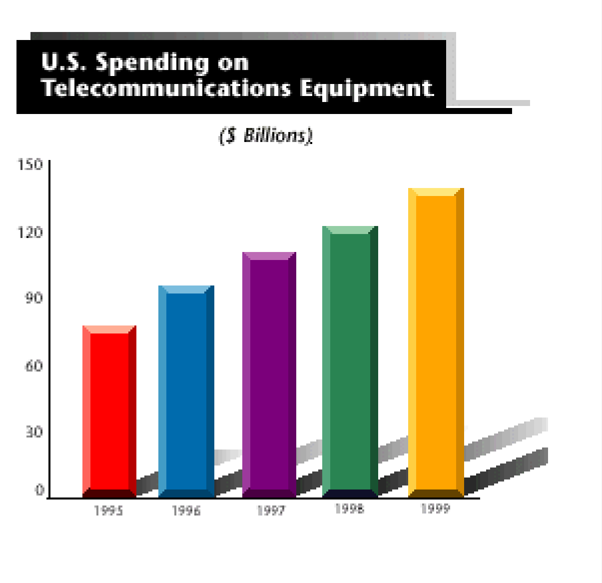


Figure 3. U.S. spending on telecommunications equipment, 1995–1999. *Source:* Telecommunications Industry Association [2].

Local Exchange Carriers

LECs provide local telephone service to subscribers. There are two types of LECS: the Regional Bell operating companies (RBOCs), also called incumbent LECs, and the competitive LECS, called CLECS. In mid-2000, there were approximately 192 million local telephone phone lines in the United States. The distribution across carriers, however, was dominated by the Baby Bells. Within their respective regions, the Baby Bells controlled 93.3% of the local phone lines. The remaining penetration by the CLECs (6.7%) varied considerably by state. Figure 4 shows the number of telephone lines, or local loops, provided by the major RBOC carriers (Verizon, SBC, Bell South, and Qwest) and the CLECS at the end of 1999 [1].

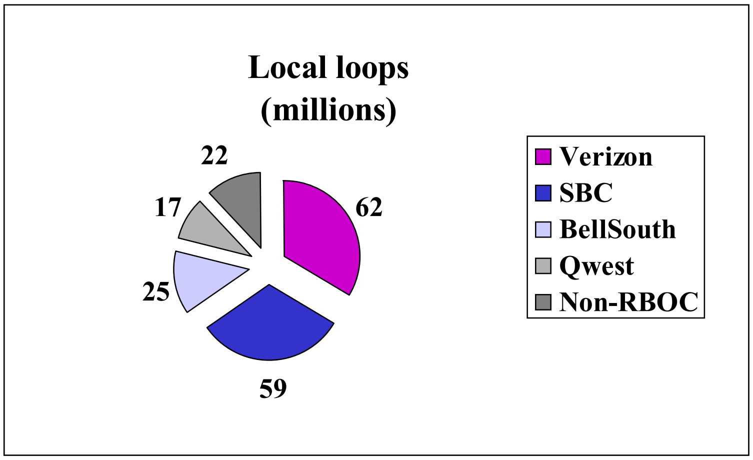


Figure 4. Local telephone lines by major RBOCs and CLECs as of December 31, 1999. Compiled from Table 8.3 [1].

Long-Distance/International Carriers

In the long-distance market, the transition to competition has been a slow process. According to the Federal Communications Commission [1], AT&T had a virtual monopoly on long-distance service in the United States until the 1970s. But by 2000, more than 700 companies offered long-distance service. As shown in Figure 5, three of these companies (AT&T, MCI/Worldcom, and Sprint) generated more than 70% of the toll revenues. Thirty percent of the revenues were thus generated by smaller carriers, none of which had more than 2% market share.

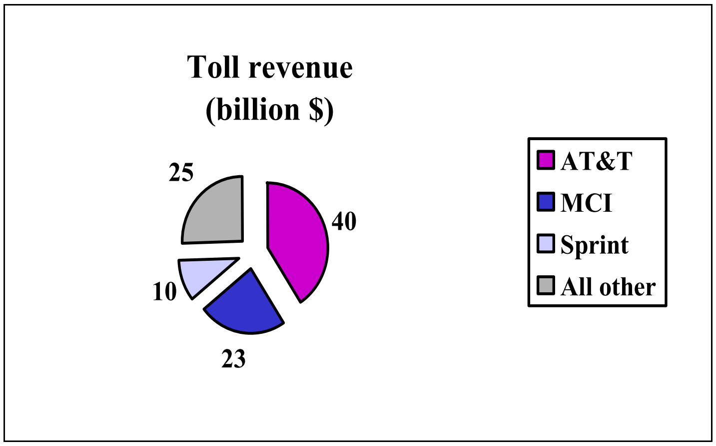


Figure 5. Toll revenues by U.S. long-distance carriers in 1999. Compiled from Table 10.1 [1].

Cellular Carriers

From the early 1980s through 2000, the growth in wireless communications (generally synonymous with cellular during this period) was dramatic. In 1984, there were 92,000 wireless subscribers in the United States. By June 2000, there were over 97 million U.S. wireless subscribers [1], representing approximately 30% market penetration. Compiled from a number of annual reports by one of the authors of this report during the 1999–2000 time frame, Figure 6 shows the numbers of subscribers for the major cellular carriers. As in the long-distance market, a few carriers dominated.

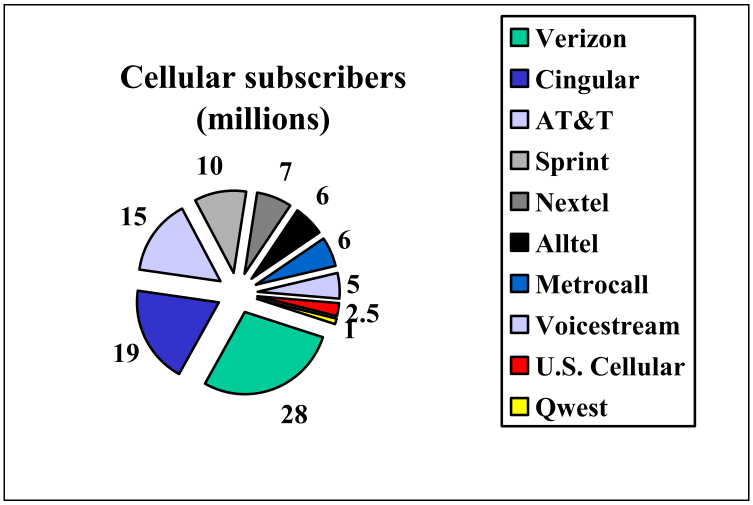
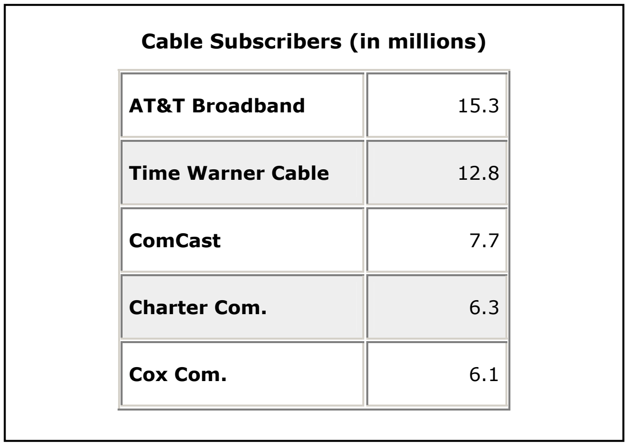


Figure 6. Number of cellular subscribers during the 1999-2000 time frame.

Cable Providers

The cable industry is a significant player in the overall telecommunications industry. According to the National Cable and Telecommunications Association, in 2001 there were approximately 10,000 cable systems in the United States, carrying the programming of more than 200 different cable networks. The employee base for the industry (130,000 employees) [3] was a significant fraction of the overall telecommunications industry (roughly 180,000 for cellular services and 900,000 for regular wireline services [1 – Table 5.1]. Further, there were approximately 69.5 million basic cable subscribers out of approximately 102 million TV households [3]. As shown in Figure 7, five major companies that have 60% of the market share dominated the industry in mid-2001 [4]; however, this consolidation is much less than what is found in either the IXC market or the LEC market.



Cable Subscribers (in millions)

AT&T Broadband	15.3
Time Warner Cable	12.8
ComCast	7.7
Charter Com.	6.3
Cox Com.	6.1

Figure 7. Cable subscribers for top providers in mid-2001. *Source:* Multichannel News, extracted from Reference 4.

Internet Service Providers

The ISP market is less than 10 years old and has not undergone the same degree of contraction and consolidation as cable, nor has it inherited market share after the divestiture of AT&T. It is not under any federal regulatory requirements, so there is no equivalent to the Common Carrier bureau to compile regular statistics on ISPs. The rapid growth and early sign of market consolidation, combined with the lack of an authority with a mission to collect such data, make even a survey of existing ISPs problematic. The ISP market is unstable because it requires little actual physical plant to be an ISP, as compared to being a telecommunications carrier.

In 2000, there were an estimated 8,100 worldwide ISPs [5]. Figure 8 shows the top ISPs in the United States with their associated on-line accounts as of early 2001 [6]. Note that all ISP subscriber data should be taken with a grain of salt since there is no federal reporting requirement, and every motivation for corporate sources to inflate numbers.

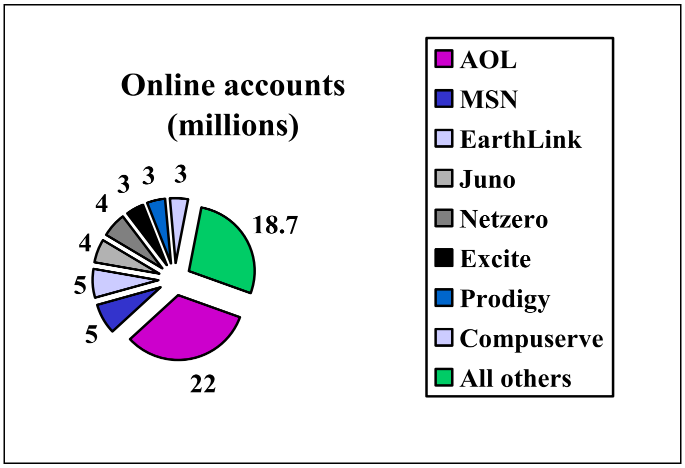


Figure 8. ISP On-line accounts in late 2000/early 2001. Compiled from data available on ISP Planet [6].

About wireless local-area-network (WLAN) technologies. The rapid availability of public WLAN technologies has led to an informal development of a network of free or pay-by-the-hour wireless ISPs. WLAN technologies, often called Wi-Fi today, generally cover anything that falls under the IEEE 802.11 standards for wireless broadcasting of data in the 2.4 or 5 GHz band over the public spectrum. These technologies are referred to as 802.11x, since the standards are indexed that way (802.11a, 802.11b, 802.11g, etc.). There is a single "access point" and one or several basic service sets, like PCs, that home off that point. The access point is also connected to the wireline network in some way, usually a broadband connection to the Internet via an ISP. While there are other wireless data options, these options are generally special-purpose and more limited in deployment [7]. Although it is unknown at this time what ultimate impact WLAN technologies will have, their exponential growth makes it important that we note them here

Because the spectrum is free, anyone with a PC and a few hundred dollars can be a Wi-Fi service provider. In 2001, as reported in Reference 8, approximately $1.5 billion was spent on equipment for Wi-Fi technologies. In the two basic categories of the Wi-Fi market (home and enterprise) in 2001, important vendors with their market share were as follows:

- SOHO/home: LinkSys (22.1%), Buffalo (10.2%), D-Link (10%)
- Enterprise: Cisco (35.4%), Agere (18.4%), Symbol (13%)

Importantly, WiFi is inherently more vulnerable than other kinds of telecommunications services because there is no physical requirement for a connection, and anyone can "sniff" the transmitted data to detect whatever security scheme is in place [9]. A comparison of WiFi and other mobile technologies can be found in Reference 10.

Satellite and Paging

In 2001, there were 15.5 million subscribers of DBS (direct broadcast satellite) TV in the United States [3]. Direct TV and EchoStar were the two competing satellite broadcasters [11]. Compared to broadcast customers, however, the number of telecommunications customers of satellite is very small. As reported in Reference 12, Globalstar, the most widely used satellite phone service, had 77,000 subscribers worldwide in late 2002.

At year-end 2000, an estimated 42 million customers subscribed to basic numeric and alphanumeric paging services [13]. The two leading paging companies were Arch Wireless, with nearly 12 million messaging units, and Metrocall, with approximately 8.2 million units. Both companies had recently acquired other paging companies, which boosted their customer bases [13,14]. Other major pager suppliers included Verizon Wireless, Bell South Wireless Data, Skytel (a division of MCI/Worldcom), and Motien [13].

You can do more with cellular, and for lower cost, than satellite for almost all paging applications, especially now that nationwide deployment of cellular data technologies is being aggressively pursued. And a nationwide WiFi may eventually displace both technologies. The satellite paging market is in significant decline [13,15,16].

Industry Regulation of Service Providers

Five basic principles, or requirements, inform the way the telecommunications industry is regulated, as listed in Figure 9 and briefly discussed below.

- “Lifeline” service
- Vision of “universal service”
- Wireline and cellular viewed as a natural monopoly
- Right-of-way (ROW) and spectrum concerns
- National security, law enforcement and privacy concerns

Figure 9. Basic principles of industry regulation.

First, LECs must provide lifeline service for low-income customers to support public health and safety.

Second, there is a vision of “universal service” that ensures that rural and poor people have equitable access to even nonlifeline services. This vision has been extended to accessing the Internet [17] but has not been a dominant requirement for cellular services, or value-added services such as availability of ultrahigh reliability. For a historical context of universal service, see Reference 17.

Third, both wireline and cellular are viewed as a natural monopoly. Because it is so hard to build a new wireline network, or acquire scarce spectrum for wireless, there is a natural monopoly created by these barriers to entry, allowing incumbent carriers to extract monopoly rents beyond a “fair rate of return.” As a result, the federal government, as well as the states, has regulated rates of return for services that have this monopoly flavor and has also required incumbents to provide access to their network to competitors at a fair price [18,19,20].

Fourth, principles related to ROW and the spectrum are also embedded in regulation of the telecommunications industry. Regarding ROW, which is the real estate portion of the telecommunications network for wireline, there should be no local burdening of interstate commerce. This means that a state cannot charge a toll for traffic that goes through the state and cannot put unreasonable restrictions on networks that carry interstate traffic. The federal government can preempt the states based upon this constitutional requirement. In addition, by the law of eminent domain the government can claim land for such things as landlines and antennae if the land is for the public good and the owner is fairly compensated. The public good is a finite common resource that must be shared among competing interests. Similarly, the electromagnetic spectrum is treated as a public good, with equitable auctions conducted of the spectrum. There is an issue of whether and how property rights can be bestowed on such a shared resource [21]. The auctioning of such spectrum is one approach to spectrum management, but it has been problematic and controversial. Issues such as fairness, financial solvency, and the purchase of spectrum to prevent competitive offerings instead of fostering them must be dealt with.

And fifth, concerns of national security, law enforcement, and privacy are intertwined with regulation of the telecommunications industry. Such concerns are tangential to any modeling concerns the CommAspen group would have in its study of the telecommunications infrastructure.

Equipment Suppliers in Telecommunications

Equipment companies in the telecommunications industry sell a variety of equipment including, for example, switches and associated software, cell towers and antennae, transmission cabling, line-terminating equipment, multiplexers, routers and associated software, various outside plant equipment, operations support software (OSS), and customer-premises equipment (CPE) like telephone sets but not the computers. Some companies sell support services for their equipment as well. The largest suppliers of telecommunications equipment in 2001 are listed in Figure 10. The companies are listed vaguely in order of declining sales revenue, as compiled by one of the authors mainly from Reference 22; where information was not available on that Web site, it was obtained from other corporate Web sites. Those companies shown in italics are not located in the United States.

- Motorola
- HP
- Lucent
- *Seimens*
- *Alcatel*
- *Ericsson*
- *Nokia*
- *Nortel*
- Cisco
- Sun
- 3Com
- Cabletron
- *Fujitsu*
- Tellabs
- ADC Communications
- Qualcomm
- Harris
- Siebel Systems

Figure 10. Largest telecommunications equipment suppliers in 2001.

Figure 11 shows a distribution of equipment expenditures in 1999 [2]. This figure gives some sense of the relative percentages spent on various types of equipment. In 1999, during the dot-com boom, ISPs and Internet-related expenses made up roughly 20% of all equipment purchases—a category that was almost nonexistent 5–10 years earlier. We were still heavily in the long-haul fiber-optics buildout, so fiber equipment was still 10% of equipment purchases.

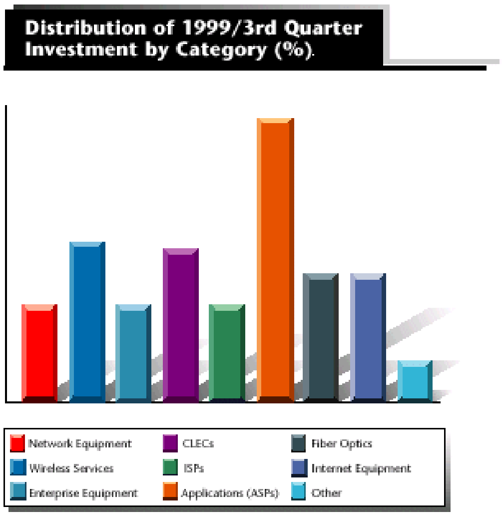


Figure 11. Investment in equipment in third quarter 1999.
Source: Telecommunications Industry Association [2].

The "largest" equipment supplier is not necessarily the most critical. Relatively small (from a revenue standpoint) providers can provide critical components to telecommunications systems and are just as important from a reliability and robustness standpoint as the larger vendors. For example, in 1998, a telephone outage occurred on the East Coast, throwing businesses in East Cost cities in turmoil. The source of the outage was a breakdown in equipment by Illuminet, a small carrier that provided services to phone company networks [23,24]. Verizon purchased Illuminet in 2001.

In addition, though none of the wholesale fiber shops made the list of largest equipment suppliers presented in Figure 11, these businesses are obviously critical. Small companies can also provide OSSs, power gear (the electrical equipment providing power to telecommunications equipment), leased data-center space (office space that meets certain power, fiber access, alternating current [AC], and other requirements to allow telecommunications equipment to be placed there and to service customers in a cost-effective and reliable fashion.

The notion of largest equipment supplier can also extend to the very smallest of companies, which is no company at all. An example is Apache, which is open-source freeware that runs on most Web servers.

Market Structure and Pricing

The telecommunications industry is evolving into wholesale and retail markets. The wholesale market consists of sales of (1) raw bandwidth to retail service resellers who use this bandwidth to develop retail value-added services, (2) other “unbundled” network components to competitors necessary to develop retail services (the offering of which is mandated by the federal government) and (3) network components sold directly to large end-users to build their own networks. The retail market consists of the retail selling of value-added services built with wholesale components.

A number of models are discussed below related to the pricing of telecommunications services. The structure of pricing is important for addressing the kinds of economic models for telecommunications that the CommAspen program should consider in their overall models of the U.S. economy. More specifically, of interest is the difference between economic impacts due to failure of components versus impacts due to pricing fluctuations. Or alternatively, the sort of shocks caused by economic failures of critical small players will result in shocks to the economic system that will be observed and modeled in CommAspen through changes in the prices of services.

Pricing Models

A rich set of pricing models have been successfully employed in telecommunications:

- **flat monthly rate for unlimited use of fixed bandwidth.** An example of this model is “rental” of a T1 line.

- **subsidies, tariffs, but no business/residential X-subsidies.** The reason the business community was so strongly in favor of the AT&T breakup was the policy of subsidizing low residential rates with higher business rates. This cross-subsidization policy has been eroded over the years, but nowhere more strongly or significantly than in these flat-rate services.

- **bandwidth-sensitive (per kb/s).** This model covers usage-based pricing for frame relay services (also called frame relay SVCs) and for long-distance plain old telephone service (POTS) and cellular in the sense that if one is not using the service, 0 kb/s is being used and one is therefore not charged. Frame relay rates are still sensitive to the committed information rate (CIR), which is the minimum bandwidth the carrier guarantees will be available to the user, so it is something like a fixed bandwidth charge as well.

- **distance-sensitive (per mile, calling area).** Rates in this pricing model are based on per-mile and calling-area criteria. An example of the per-mile criterion is the charge for T3 lines. Examples of differential charges based on geographical area are intraLATA-versus-interLATA POTS (e.g., a call within Albuquerque versus a call from Albuquerque to Los Alamos), and domestic-versus-international POTS (e.g., a call from Albuquerque to somewhere in the United States versus a call from Albuquerque to Paris).

- **time-sensitive.** The long-distance bill per call is an example of this usage-based pricing model, where there is a per-minute change.

- **enhanced value-added services.** An example of a value-added service is Caller ID, where there is a monthly charge. Custom-contracted telecommunications services can include financial penalties for missing some target performance level. This approach is the opposite of enhanced value-added costing more in that degraded services cost less after financial penalties are assessed.

Performance-Based Pricing Model

What is more interesting in terms of the efficiency of the telecommunications industry in meeting national economic and security needs than the pricing models currently in place is a pricing model based on performance. Historically, performance guarantees have had no financial meaning, though regulators might get into the act when service degraded too much. In the main, telecommunications services have been based on a "best effort" criterion, and customers have had very limited options, if any, for financial recovery. If the telecommunications company exercised its best effort in meeting your needs, the company is not legally liable to compensate you for lost revenue—only for not billing you for the hours of service not provided. For example, if you were using your ISP to sell something, and the ISP service went out for some reason, you cannot sue your ISP for your lost revenues. You can only sue for any billing for the period your service was out, but you cannot sue your ISP for the transition costs to your business.

Now, there are competitive options in many cases. For example, in the situation described above, you could go to another vendor for your Internet service. So there **is** a financial meaning to missing performance targets in terms of long-term revenues, but only if there are competitive options available. There may not be competitive options for services provided by RBOCs like Qwest. Despite having more competitive options, financial incentives are still too weak to improve performance.

To address performance issues, some sort of instrument is needed that would allow, or even force, the incumbents to offer such performance guarantees, with a reinsurance market for incumbent and new carriers to distribute such risks and perhaps a prearranged arbitration board between carriers and customers to address issues of implementation while avoiding the courts.

Related Pricing Issues

In developing economic models for the telecommunications industry, the CommAspen program should consider the distinction between business and residential customers. While in 2000 there were twice as many residential loops (phone lines) as commercial loops, there were also 50% more toll revenues (for long distance and local) from commercial loops than residential loops [1 – Tables 8.4 and 10.3].

The telecommunications marketplace is a vital, robust, and dynamic system. Despite the financial downturn of the telecommunications industry during the late 1990s and early 2000s, companies were still making money. The return on investment (ROI) for RBOCs and other "price cap" companies varied between 10% and 20% [1 – Table 4.1]. Consumers were spending 2.3% of their income on telecommunications, up from 1.9% in 1980 [1 – Table 3.1].

Furthermore, from 1980 to 2000, the costs of the capital components that constitute a modern telecommunications infrastructure (fiber optics and processors/computers) declined exponentially, and the number of employees declined roughly linearly [1 – Chart 5.1,25,26]. This suggests that costs declined faster than the prices actually did, as reported in Section 3 of Reference 1 (see also Reference 27). The point being made here is that there have been strong inefficiencies in the telecommunications industry due to rapid regulatory and technology changes that have slowed the acceleration of price reductions to the residential market. Nothing is being said here, however, about the commercial market, which has the technological expertise and financial clout to gain more significant reductions, especially after the removal of the existing cross-subsidies. The bottom line is that the telecommunications market is not such a pure market to model.

Architectures

To make intelligent modeling decisions regarding the telecommunications market and the ability of consumers to make intelligent choices in the model, especially regarding the reliability and robustness of services, we need to understand something about the equipment architecture for telecommunications services. The infrastructures for the architecture of the present are built. Every telecommunications infrastructure is a network composed of links (transmission media and systems) and nodes (cross-connect equipment between various transmission links), as discussed below.

The transmission media are of two types: wireline and wireless. Wireline transmission media are mainly fiber, with transmission components such as conduit media, regeneration sites, multiplexers, analog-to-digital (A/D) converters, and distribution nodes. Wireless transmission media are cellular, satellite, and microwave. The associated physical plants with these media are cell towers, earth stations, and microwave horns, respectively.

Examples of cross-connect equipment are switches/routers, multiplexers, and electrical/optical converters to get from transmission speed/media to switching speed/media. Physical structures, like central offices for the telephony infrastructure, contain almost all the cross-connect equipment and some of the transmission equipment. As such, central offices are the nodes of the network—but not all of the nodes of a telecommunications network, depending upon the level of detail one is considering.

If we were to summarize the major points of telecommunications developments in the 1990s, we might say the following: Migration to digital equipment is almost complete throughout the United States. Most traffic is serviced with fiber lines, with POTS traffic serviced by SS7 networks, with concomitant declines in domestic microwave and satellite. Widespread deployment of SONET ring technologies has led to fiber networks that are more robust to cuts by backhoes and the like. The migration of traffic through leased data centers ("carrier hotels") exploded during the late 1990s, and cellular traffic has continued to grow rapidly. However, the promise of a vital fiber wholesale market has collapsed along with most of the new entrants in that market. Competition in the local market was enhanced with the passage of the Telecommunications Act of 1996, which required that the unbundling of service components be offered to competitors at a fair price. Yet that has not led to a significant erosion of the RBOC market share. With the explosive growth of demand for cheap Internet connectivity by residential and commercial customers, ISPs have grown to become an entrenched part of the data communications landscape, while other data communications offerings such as frame relay and asynchronous transfer mode (ATM) have eroded the demand for conventional private-line offerings. Broadband data offerings via cable and wireless, and voice over IP, are the new burgeoning areas of communications services.

How Architecture Is Used

The logic of how a network operates in the architectures of the present is implemented via software. The most complex real-time software is used in switches and routers. Software in combination with hardware controls the switches and maintains the control data. The roles of people in the architectures of the present are to maintain the physical and logical plant and OSS software and processes, including billing, and to manually provision services.

Hardware and software in the architectures of the present digitize and format information content at or near the source. Information is converted from analog to digital, and formatted for transmission. Either there is already a pre-established connection, a connection is established through a switched network in real time, or the network routes the packets of information in a dynamic fashion without a formal single connection being established [28].

Architecture Examples

There are a vast number of architecture diagrams when you consider a given private commercial network or a large carrier's entire infrastructure. Where, applicable, the subsections below give examples of architectures for switched services, private-line/wholesale services, wireless services, IP/internet services, cable services, application services, and satellite broadcast services.

Plain Old Telephone Service POTS Wireline Service

Figure 12 illustrates an architecture for the regular phone service with which we are all familiar.

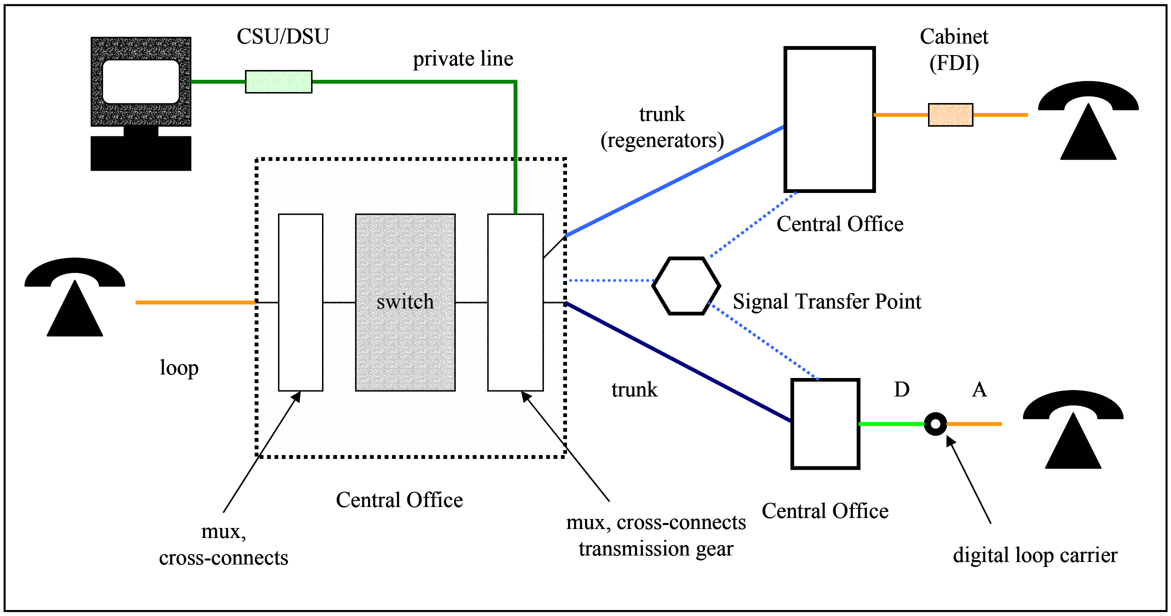


Figure 12. Example of architecture of POTS. *Source:* Developed from information in Reference 29, as well as common knowledge about the industry.

For a regular phone call, lifting the handset from the phone creates an off-hook condition that is detected at the central office. The switch at the central office is now expecting to receive dialed digits associated with the phone call. Upon receipt of the digits, the SS7 network is queried (represented here by a signal transfer point), and if the receiving station is not off-hook or busy, the choice and assignment of trunks is made through switches (as represented in the diagram), establishing a route through the network. This route may pass through three or more central offices. When the route is established, a signal is sent to start the receiving station ringing. Upon the completion of the call, one station goes on-hook, and the SS7 frees up the capacity for that call.

For a private line connection, the connection is permanent, and the customer generally handles signaling. The interface to the private line network is made through a channel service unit (CSU)/data service unit (DSU), as represented in the diagram.

In both cases, the signals are multiplexed up to line rates (generally 1–10 Gb/s for fiber systems) with multiplex equipment represented in the diagram at the central office, and also at the point identified as the digital loop carrier in the diagram. Also when the signal is being transmitted at higher bit rates, or when it is still on a metallic carrier near the home, the signal can be cross-connected onto other paths via cross-connect equipment that is either as simple as a distributing frame or feeder-distribution interface (FDI) along the side of a road, or as advanced as a digital cross-connect system (DCS) in a central office, as represented in the diagram.

Plain Old Fiber Transport

Figure 13 illustrates an architecture for plain old fiber transport.

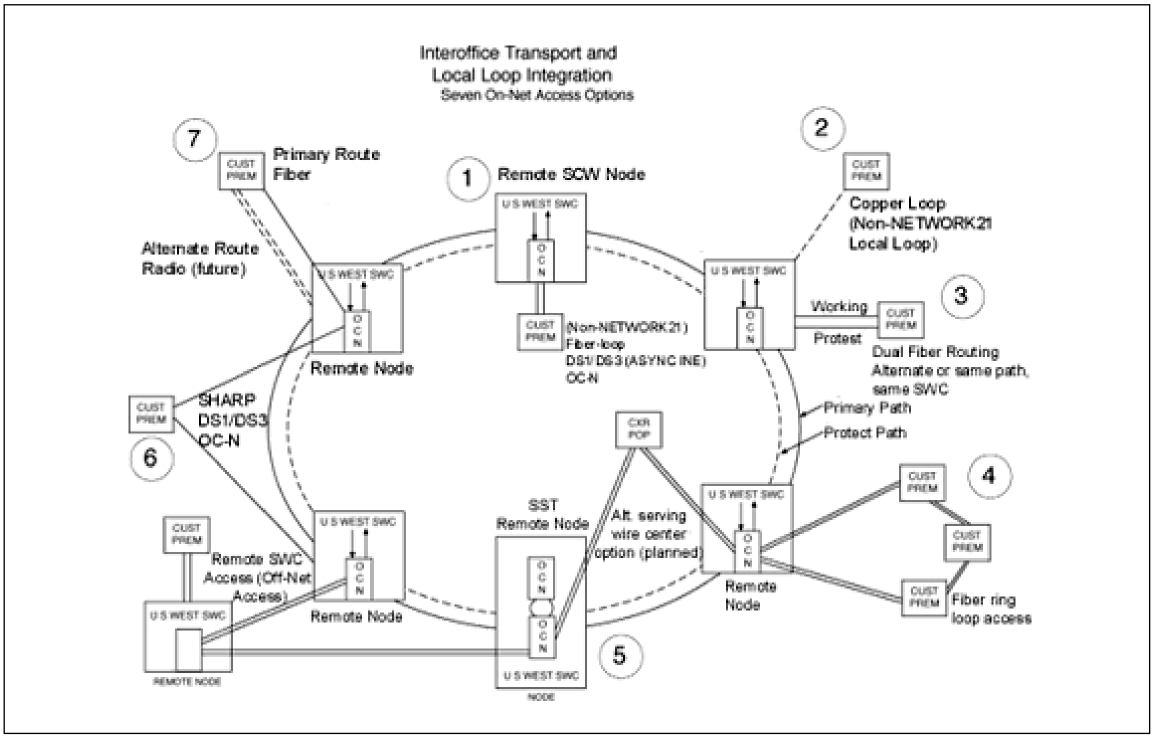


Figure 13. Example of architecture of plain old fiber transport. *Source:* US West [30].

As shown in Figure 13, traffic often must travel from one central office to another when the two callers or stations are some distance from one another. Rather than simply establishing a single link, which could fail and leave nodes/stations isolated, a “SONET ring” architecture like that shown in Figure 14 has been generally deployed, where failure of a link on a working path (represented by the red path in this figure) results in an immediate switchover of traffic onto a countercyclic backup path (represented by the blue path).

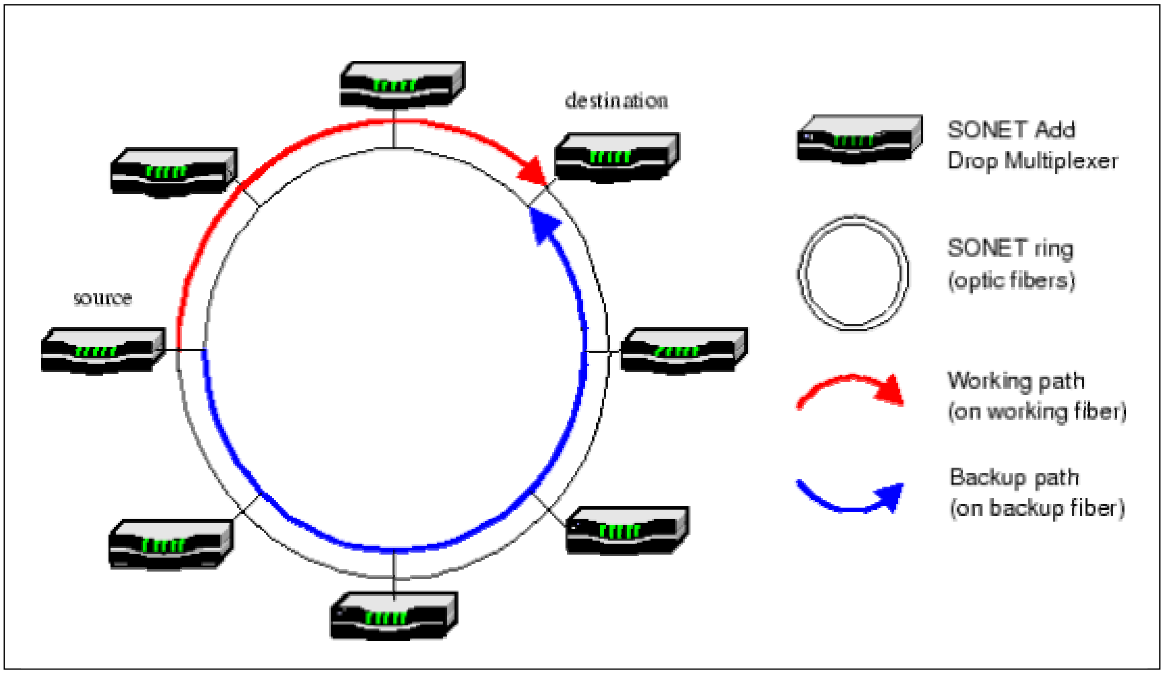


Figure 14. Example of SONET ring architecture. *Source:* University of Virginia Computer Science [31].

Plain Old Cellular Network

A cellular network is little different from a wireline network, where the wireline “loop” media is replaced by a wireless signal. The only difference between the two systems is the fact that the wireless loop must be built for each call, in the sense that an antenna must be chosen to initiate the call, and that loop must be re-established with a new antenna when the caller moves out of range of the original antenna. These call ranges are presented by the hexagonal cells in the figure. After the antenna receives the signal, it is then generally passed off to the regular wireline network at the mobile switching center (MSC) which then transports the call to the receiving wireline station or the antenna closest to the receiving wireless station via another MSC. Figure 15 shows the architecture of a plain old cellular network.

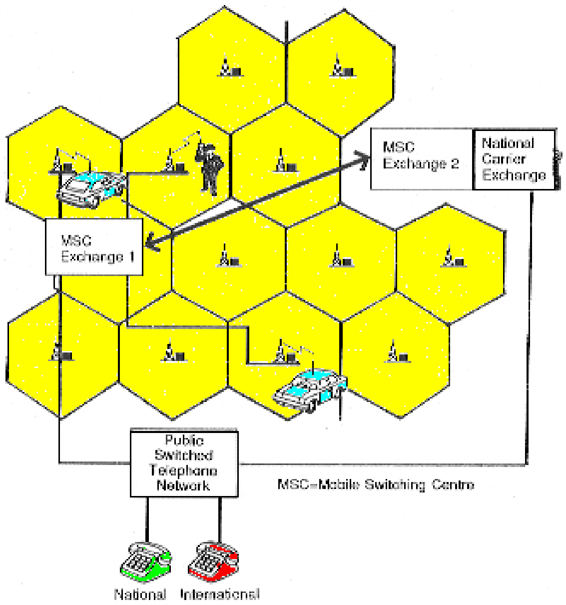


Figure 15. Example of architecture for plain old cellular network. *Source:* Periannan and Fahham [32].

Plain Old IP/Internet

The Internet is an amorphous, evolving, rapidly growing network tenuously held together by a few data transmission protocols (i.e., TCP/IP) that govern the formation of packets and their transport through a data network via routers. Figure 16 is the closest thing to a representation of the dynamic beast known as the Internet that one can get. Because of the lack of obvious hierarchy and structure, graphical maps of the Internet are hard to develop and interpret, as witnessed by this graphic.

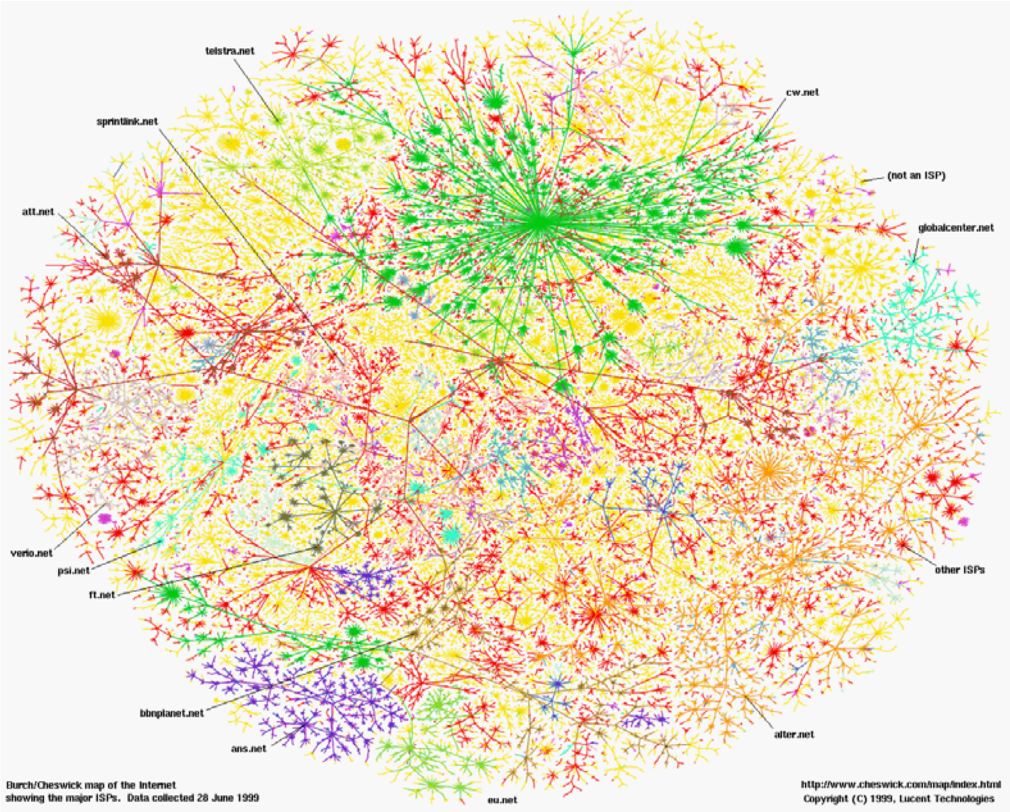


Figure 16. Representation of the Internet. *Source:* Cheswick and Burch [33].

Computers establish connections to ISPs or to gateway points within company Intranets, represented by the green and blue nodes at the periphery of Figure 17. These ISPs have leased-line access to the nodes of the Internet itself. The Internet is composed of a set of backbone data networks owned by various telecommunications companies that exchange packet traffic at exchange points or through private peering arrangements. So a given packet will leave a computer and pass over a regular phone line, cable link, satellite link, cellular link, or leased line to an ISP, which will then pass the traffic over a wireline leased line to an Internet backbone network, which may then need to transfer to another, or several, backbone networks to get closer to the destination, where the process is reversed, passing traffic to another ISP on its way to the destination computer. Some organizations can directly terminate their servers on the Internet, bypassing an ISP.

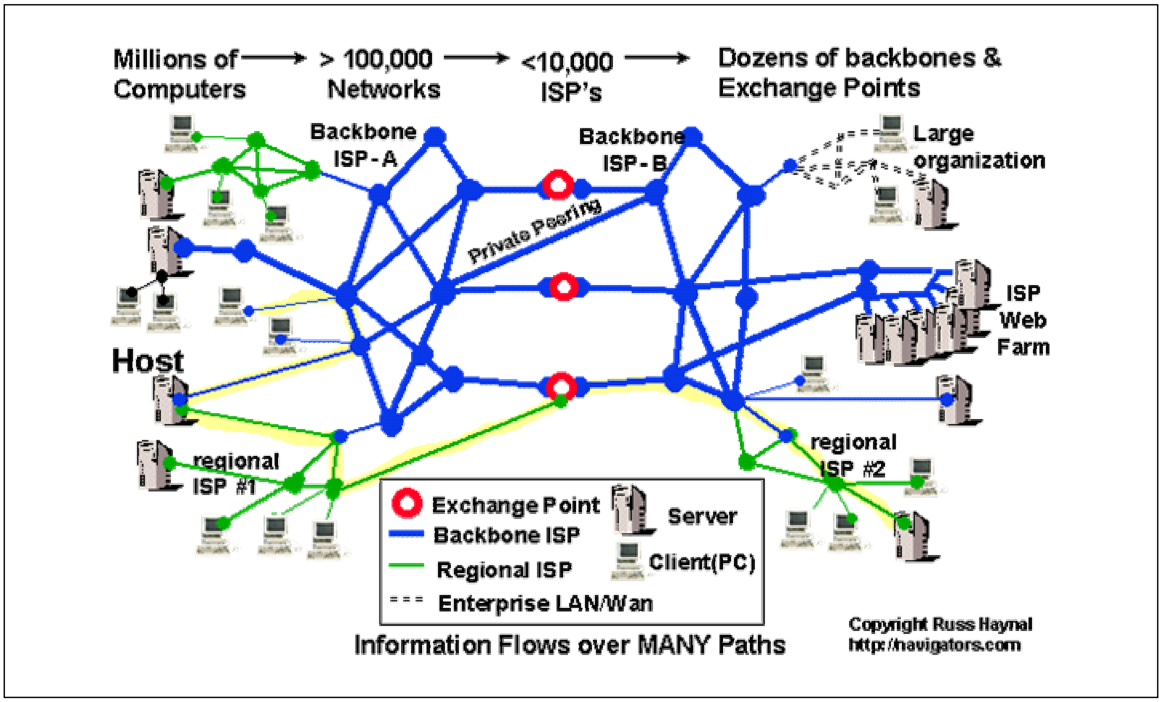


Figure 17. Physical layers of the Internet. *Source:* Russ Haynal [34].

Figure 18 shows the protocols of the plain old IP Internet. The protocols are the glue that permits diverse packet networks to interoperate in a nonhierarchical but structured fashion. The Internet is known as a TCP/IP network, named for the two major protocols that govern the construction of packets, and transport of packets through the network, (Transmission Control Protocol) TCP and Internet Protocol (IP) [35)]. These are seen in the middle layers of the diagram. The lower layers, which correspond to the lower levels of the famous Open Systems Interconnection (OSI) seven-level model, address issues of physical transport (notice the mention of SONET). The levels above the TCP and IP layers correspond to higher levels of the OSI model, addressing application, control and monitoring functions. Both the lower and upper layers are outside the purview of what is considered "the Internet."

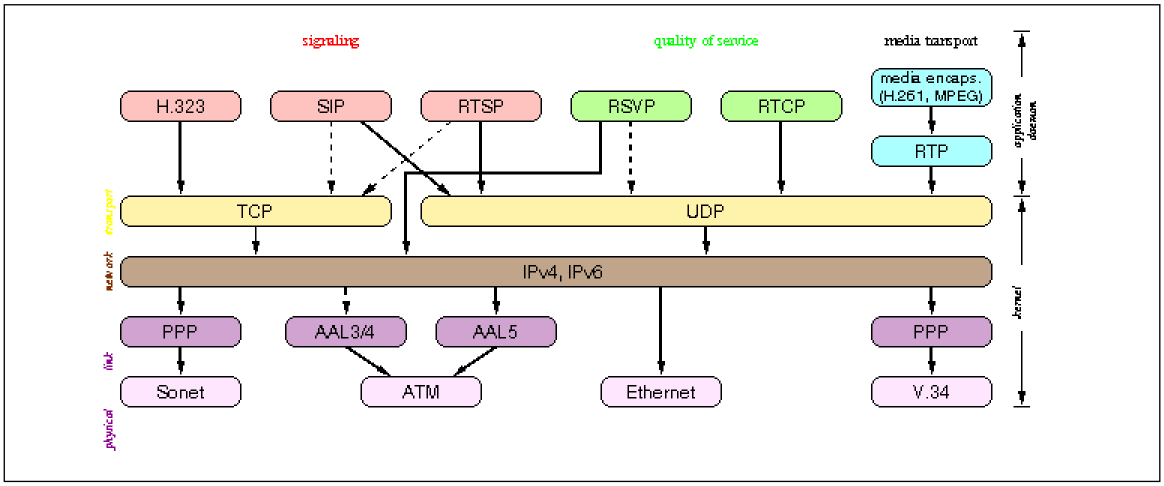


Figure 18. Protocols of the plain old Internet. *Source:* Internet Technical Resources [36].

Plain Old High-Speed Cable

Figure 19 is a representation of the plain old cable service. A signal is received by an earth station or some other head-end facility that is the central point of distribution for a metropolitan-area cable system. The plain old cable service is a pure one-way broadband broadcast network, laid out as a tree network. Major trunks feed the signal to a set of smaller feeder lines each of which feeds a set of drop cables, one per household. This is generally a pure analog network.

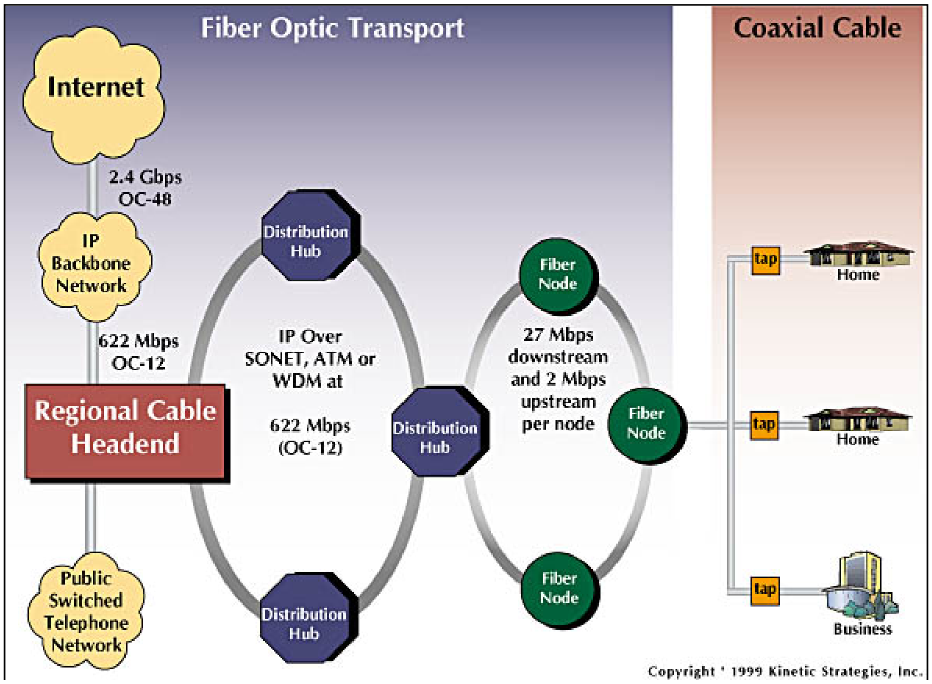


Figure 19. Representation of plain old cable service. *Source:* Cable Datacom News [37].

Figure 20 represents the two-way enhancement of the cable network, allowing digital services such as the Internet and regular phone service to be provisioned over the existing cable infrastructure. This generally involves upgrading the trunks and feeder plant to digital fiber technology.

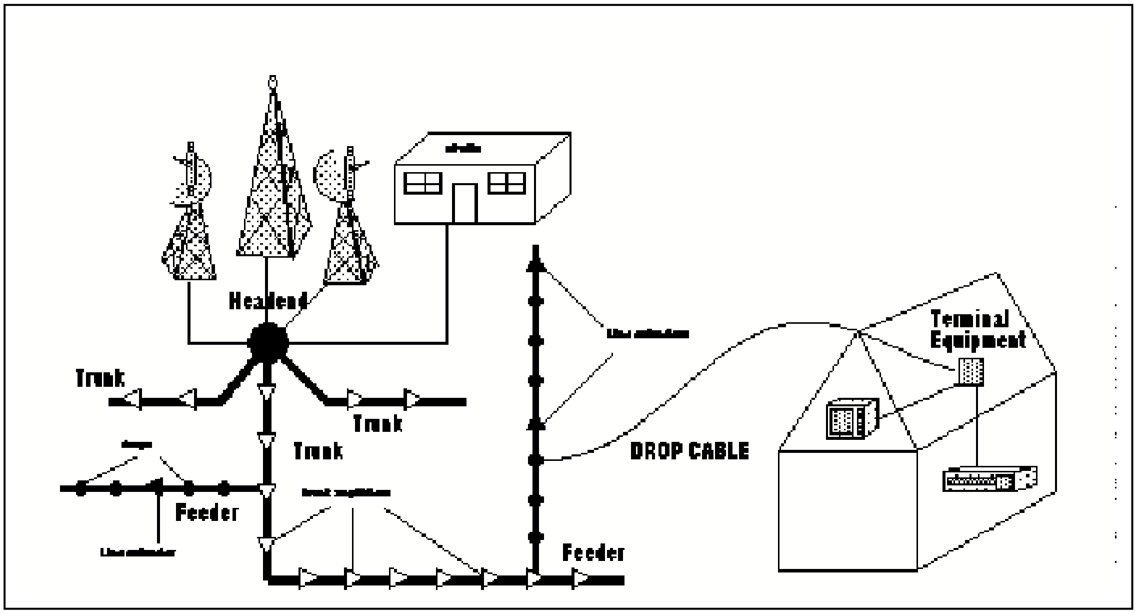


Figure 20. Two-way enhancement of cable network. *Source:* JavaWorld [38].

Application Services

There are no representative architectures for a generic application. It would take a lot of effort to develop a categorization of even a small set of applications.

Satellite and Broadcast Services

Figure 21 gives a representation of how satellite services are broadcast [39].

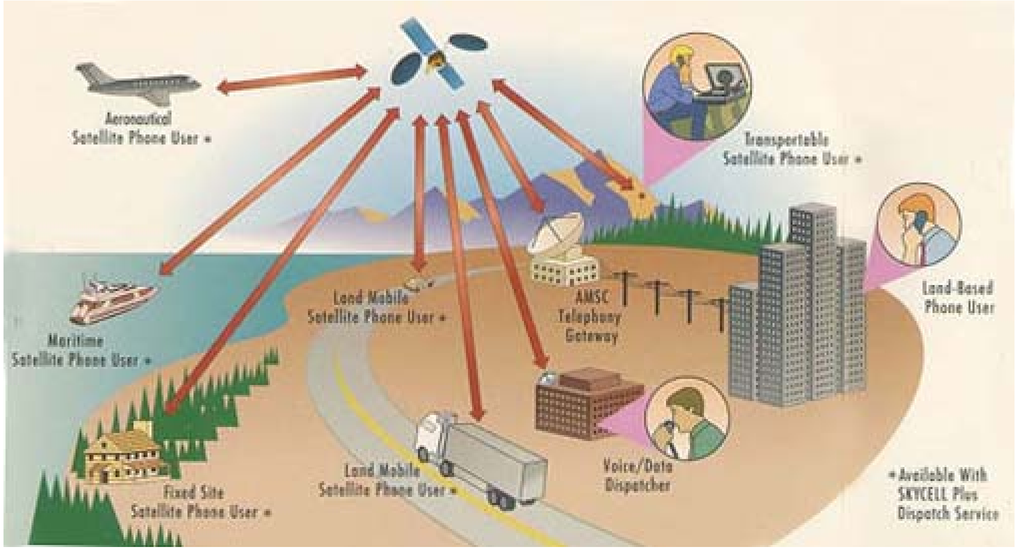


Figure 21. How satellite data is broadcast. *Source:* Remote Satellite Systems International [39].

Architecture of the Near Future

Telecommunications can be viewed as an exercise in the digital representation of information and in the manipulation and transmission of that digital representation. Very-large-scale-integration (VLSI) and fiber technologies have enabled these bits to be created, manipulated, and transmitted with resources whose costs have declined, and whose capabilities have increased, exponentially over the last fifty years. Worse still, for the players in the IT marketplace, a bit is a bit is a bit, i.e., a bit lends itself to being viewed as a commodity. And it is difficult to make much of a profit selling commodities. There are exceptions to commodity transport services, e.g., bits that absolutely positively must get there on time, bits that must stay with other bits in a stream, bits that can be authenticated as coming in an uncorrupted way from a source. But the majority of traffic can be reduced to commodity, low-profit-margin bit transport. As a result, the 1990s were a time of migration to digital technologies and a time of major consolidation of telecommunications companies [40,41,42].

There are a number of future architecture trends, including the following:

- Digital IP convergence
- Rapid growth of wireless point-to-point
- Bridging the “last mile” for residential broadband
- Migration from private lines to ATM, frame relay
- Migration to shared “condo space” for equipment
- Managing the security of IP networks

Each of these trends is discussed below.

Digital IP Convergence

This trend is much like a bit is a bit is a bit. The ubiquity and popularity of the Internet, along with the universal availability of PCs to put data into packets, has led to a situation where "a packet is a packet is a packet." This is not exactly true, however, because Internet packet transport is not well-designed for long-distance streaming content like video broadcasts. Nonetheless, the exponential improvement in digital technologies papers over those few bumps [43].

Rapid Growth of Wireless Point-to-Point

As shown in Figure 22, cellular experienced annual double-digit growth in the late 1990s and is continuing apace, with Wi-Fi technologies in the early stages of its own exponential growth curve [44,45].

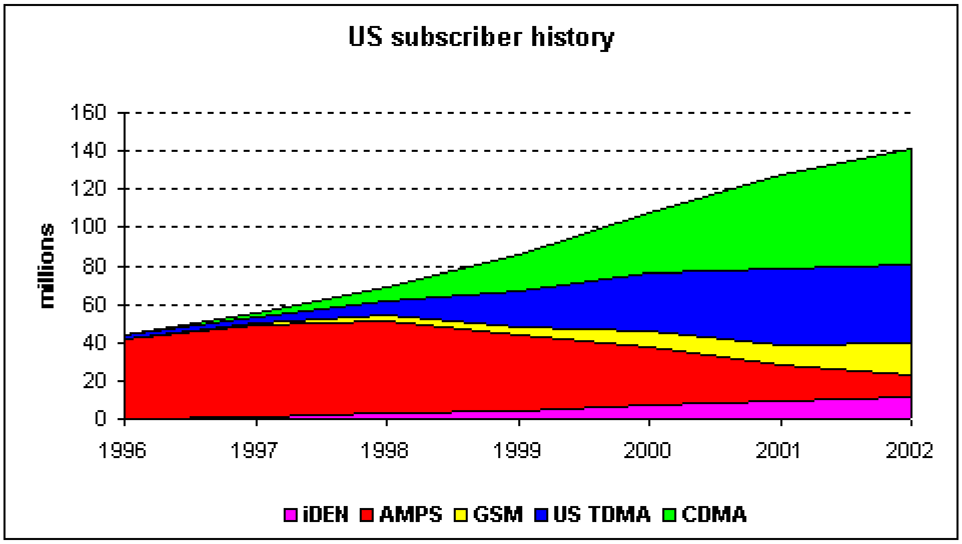
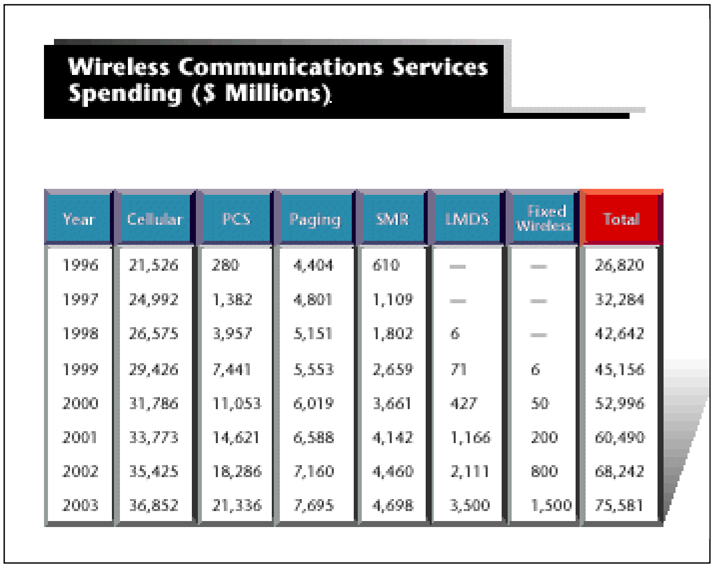


Figure 22. Subscribers in the United States by type of cellular technology, 1996–2002. *Source:* EMC [44].

As shown in Figure 23, all wireless technologies experienced double-digit revenue growth through the late 1990s and into the new millennium [2].



Wireless Communications Services Spending ($ Millions)

Year	Cellular	PCS	Paging	SMR	LMDS	Fixed Wireless	Total
1996	21,526	280	4,404	610	—	—	26,820
1997	24,992	1,382	4,801	1,109	—	—	32,284
1998	26,575	3,957	5,151	1,802	6	—	42,642
1999	29,426	7,441	5,553	2,659	71	6	45,156
2000	31,786	11,053	6,019	3,661	427	50	52,996
2001	33,773	14,621	6,588	4,142	1,166	200	60,490
2002	35,425	18,286	7,160	4,460	2,111	800	68,242
2003	36,852	21,336	7,695	4,698	3,500	1,500	75,581

Figure 23. Projected revenue growth in wireless. *Source:* Telecommunications Industry Association [2].

Bridging the "Last Mile" for Residential (and Commercial) Broadband

Figure 24 shows the relative shares of technologies that provided broadband access to residences in June 2000 [1]. Less than 4 million households had access to broadband data, as of that date.

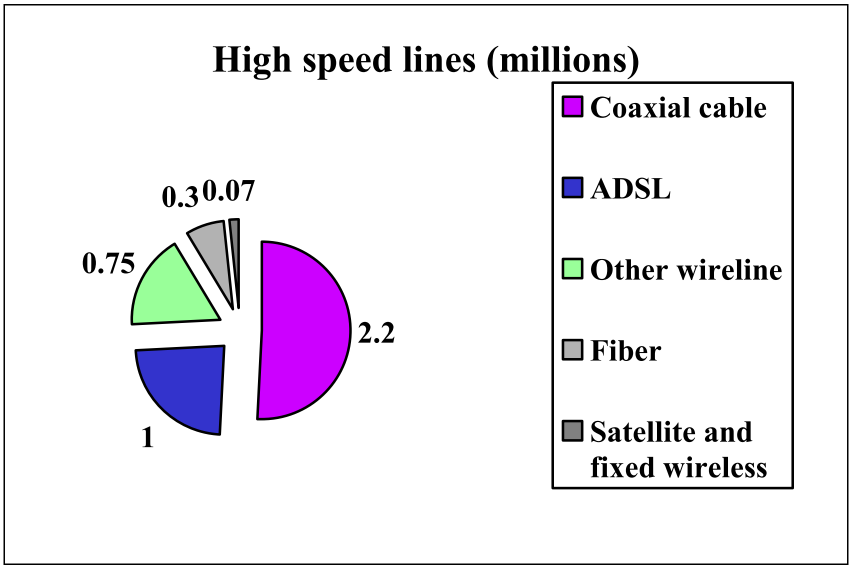


Figure 24. Shares of technologies providing broadband access, June 2001. Compiled from Reference 1, Table 2.1.

Figure 25 shows the estimated growth of broadband access [2]. What is promising is that the number of high-speed data lines grew by over 100% in a single year (2000) and looks to continue to grow at this rate.

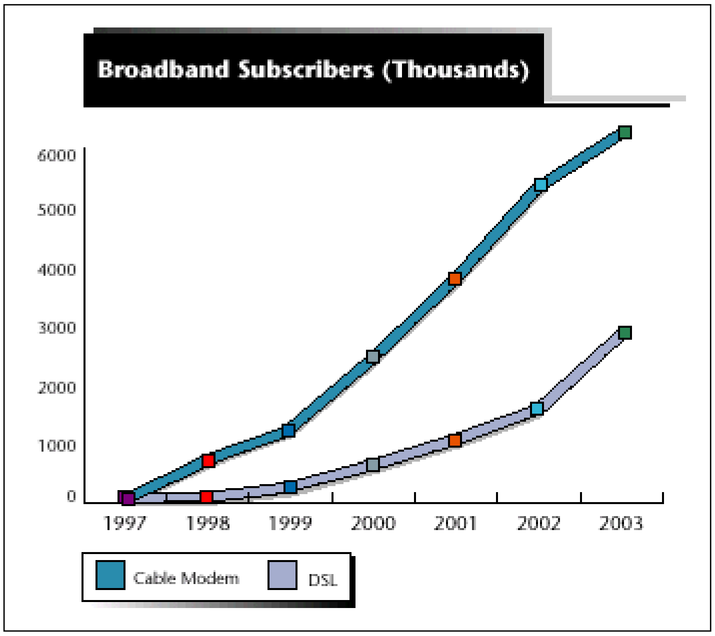


Figure 25. Estimated rate of growth of broadband access. *Source:* Telecommunications Industry Association [2].

Investment in installing fiber in the access or loop has stalled over recent years. The cost of such an undertaking and the technological uncertainties with competing technologies such as cable and wireless have slowed progress in achieving a fiberization of access for both business and residences. In 2003, only 10% of large businesses are connected with fiber [46]**,** while residences are much lower than 1% [47]. Figure 26 shows the current and projected availability of fiber to residences in North America.

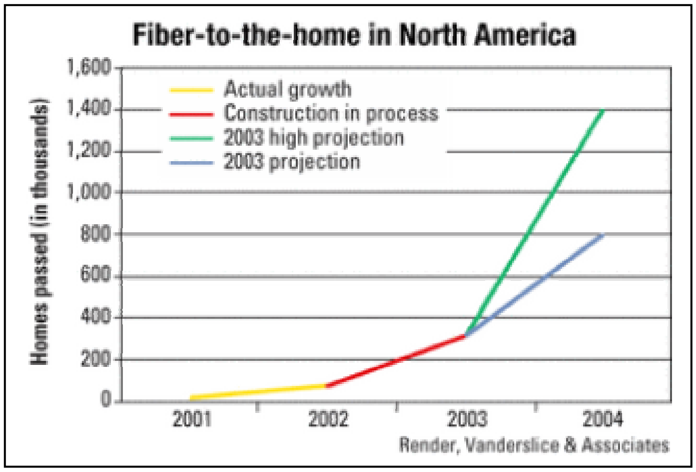


Figure 26. Actual and projected growth of fiber access, 2001–2004. *Source:* Render, Vanderslice & Associates as extracted from Reference 47.

Migration of Private Lines to ATM and Frame Relay

ATM and frame relay are substitutes for leased lines. As the actual late-1990s data show in Figure 27, both ATM and frame relay have grown (as measured by capacity) relative to the leased-line market, which shrank during the same period [2]. And those trends are projected to continue.

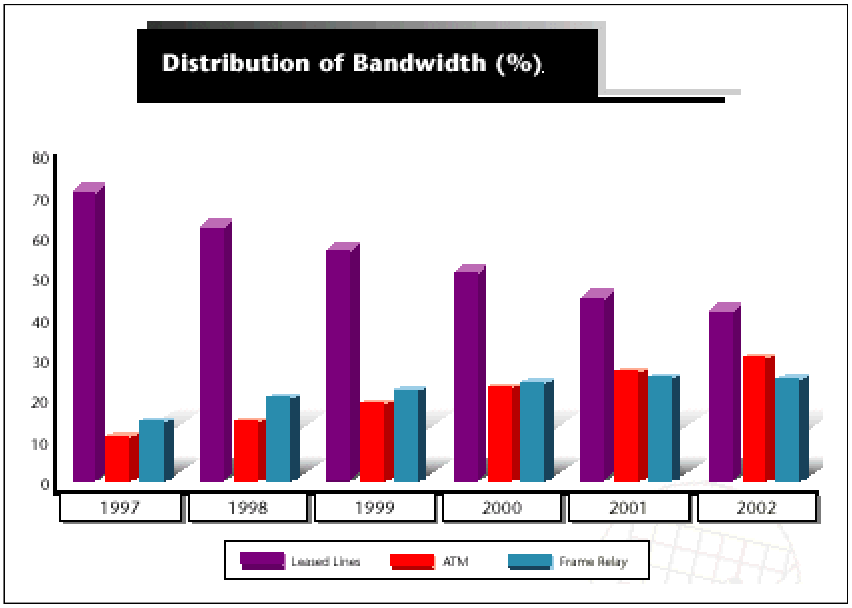


Figure 27. Migration of private lines to ATM and frame relay, 1997–2002. *Source:* Telecommunications Industry Association [2].

Packet transport service offerings like frame relay and ATM will meet the needs for subT1 bit transport that were previously met by private line offerings [48,49].

Migration to Shared "Condo Space" for Equipment

The leasing of data centers to support ISPs and other telecommunications companies burgeoned in the late 1990s with the dot-com boom, and although it has suffered along with the other new entrants in the market in the subsequent bust, there are still many millions of square feet of new data center space that have been deployed and used over the last 10 years. The latest deployments have been driven by disaster recovery concerns following 9/11.

As a result of the Telecommunications Act of 1996, RBOCs are required to lease their central office space to potential competitors. This leasing is referred to as collocation, but collocation can also mean several ISPs and carriers sharing the same leased data center space. The leasing of data center space, or carrier hotels, is viewed as a revenue opportunity for the RBOCs. "Vanilla space" charges can be from $15–20 a square foot, where the service is bare-bones, offering space and power but little else. Full support can cost $200 a square foot [50]. Full support covers the provision of computers, SLAs, and perhaps support for software and maintenance. There were 46 million square feet of rentable data center space in 2001 [51] with a 40–50% vacancy rate, which prompted consideration of managed hosting [51,52,53]. The space, of course, with the additional benefits of managed hosting, would be more expensive.

Managing the Security of IP Networks

Even prior to 9/11, IT security was one of the top concerns of IT professionals, and that has only grown in recent months [54,55]. In 2001, the biggest worries of IT, as reported in Reference 56, were as follows:

- hackers (25%)
- network availability/uptime (20%)
- reliability (12%)
- network availability/enough bandwidth (5%)
- keeping up with technology (5%)

Security was a greater concern than service performance.

Telecommunications Sector in Overall Economic System

The telecommunications sector has been moving over the last 20 years into a market-driven environment, as compared to the quasi-governmental utility role played by the single monolithic AT&T. This competitive model for telecom services will only work if the underlying market for such equipment and services is a sound and efficient one. Unfortunately, the rapid pace of new technologies, combined with the large fixed costs associated with some of the investments, e.g., building a fiber network or data center, has led to major market instabilities.

Two prime examples of such technology-driven instabilities have been the rise and collapse of the dot-com and new economy companies, whose demand was to pay for the dramatic expansion of digital telecommunications networks that occurred in the 1990s, and the collapse of the wholesale fiber market and bankruptcy of most of the major players in that arena. The dot-com collapse was particularly insidious, because it occurred so rapidly that not only did it shrink demand for new equipment, but it also provided a ready source of current and second-hand equipment, the combination of which multiplied the impact on equipment vendors. The dark fiber that was installed involved an expensive capital investment, whose return was contingent on a rapid growth for demand in digital services driven by the very new economy concerns that went belly-up after 2000. When the demand disappeared, and it was discovered that many players had invested in new fiber to meet the same nonexistent demand, the newest of these entrants went bankrupt or were bought out [57,58]. For a dissenting opinion, see Reference 59.

Figure 28 shows the trends in venture capital for telecommunications from the third quarter of 1998 through the third quarter of 1999 [2].

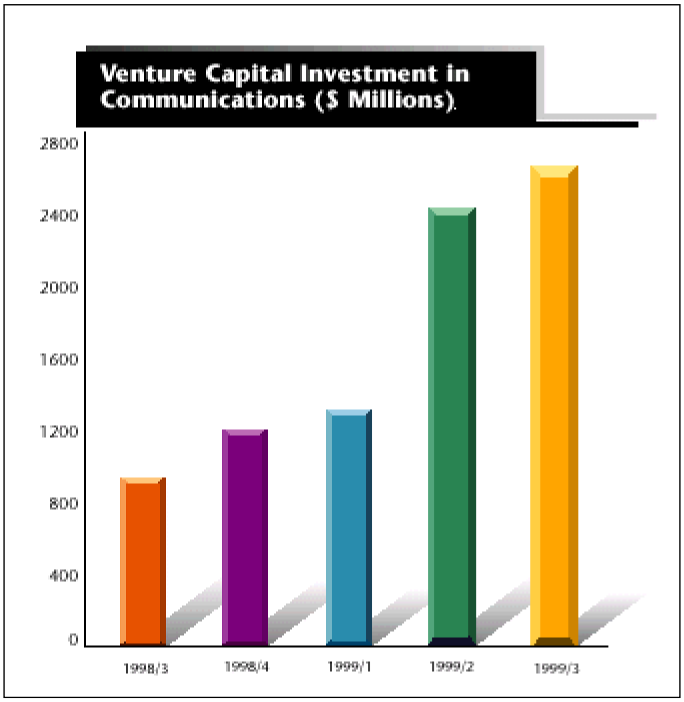


Figure 28. Investment in telecommunications by venture capitalists, 1998–1999. *Source:* Telecommunications Industry Association [2].

Between 2000 and 2002, $2 trillion of market valuation was lost in the telecommunications sector as evidence that something very bad happened in the market [60]. For further reading about the market instabilities that occurred during this period, see Reference 61 (summarizes the justification for the investment and the fiber hangover). The bath the venture capitalists took is discussed in References 62, 63, and 64.

Infrastructure Interdependencies with Communications

To put the size and scope of the domestic telecommunications infrastructure in perspective with the other infrastructures we are concerned with, here are some estimated characteristics of the physical plant for telecommunications in the United States generally in 2000:

- There were about 20,000 central offices (derived from information in Reference 65), with 16,000 RBOC switches [1 – Table 1.1], approximately 1000 switches for long-distance companies [66], and perhaps 300,000 vaults and 2 million cabinets (derived from information in Reference 65).

  Note: There will be roughly as many central offices as there are switches. Mills [67] is cited in References 68 and 69 as assuming approximately 25,000 central offices.

- There were about 10,000 cell towers [70,71]. Note that this estimate of cell towers may be more reflective of 2002 than 2000.
- There were about 1 million miles of cable plant for the cable industry [72].
- There were approximately 200,000 route-miles of fiber in long distance [1].
- There were 500,000 sheath-km of fiber in the local carriers' (RBOC and CLEC) networks [1].
- There were 5 million sheath-km of copper in the local carriers' (RBOC and CLEC) networks [1].

Now let us look at the interdependencies between telecommunications and other infrastructures.

Transportation and Telecommunications

Telecommunications is somewhat cross-elastic with transportation, especially air freight services, for many applications. This is relevant if we wish to explore how critical telecommunications services are to the domestic economy. An old saw from telecommunications states, "Never underestimate the bandwidth of a semi filled with mag tapes." We can do a quick analysis to flesh out this idea.

Consider the bandwidth implicit in the nationwide mailing of an AOL ISP service disk. Let us assume production and mailing costs of a dollar a disk (probably an overestimate) and a mailing to 100 million consumers. A CD-ROM has over 600 megabytes of storage, and let us assume the mailing travels 500 miles in the United States to its destination (assuming two or three different CD-ROM mastering plants—East Coast, West Coast, and Central). This results in 10^{20} bit-miles of bandwidth. This is not real-time bandwidth, but it could occur relatively quickly. In the case of individual users, such a disk could easily be sent overnight. The cost we guess to be $100 million, which is significant but probably an overestimate.

Now consider the entire long-distance voice traffic for the United States. FCC (Federal Communications Commission) figures with which we are familiar estimate 300 billion switched-access seconds for long-distance. We assume an average long-distance call travels 1000 miles, and a voice-grade circuit is 64 kb/s. This corresponds to 10^{19} bit-miles for the entire year's long-distance traffic. The revenue from such traffic, again from FCC reports, would be $34 billion, on a cost base of $7 billion. Transportation can provide 10 times the bandwidth as the entire long-distance POTS traffic, for probably two orders of magnitude less money. Now, the important thing to note is that the telecommunications traffic is real-time, and the transportation bandwidth is batch. But when assessing the impact of a shock to the telecom system on industrial processes, batch data transfer via courier and CD-ROMs looks like a competitive and reasonable backup option for infrastructure robustness.

Electric Power Infrastructure and Telecommunications

Power Requirements

The primary critical dependency of the telecommunications infrastructure is on electric power. Given this vast infrastructure, power requirements are significant both in their sheer amount and extent of their distribution. Quantifying the amount of power used by IT has been a surprisingly controversial subject [73]. Estimates have varied over orders of magnitude. To get some real sense of power requirements, let us focus on the power requirements of the local POTS service. For a given central office, all the equipment in total requires 3–5 kA [65]. NEBS standards govern the everyday power requirements, interfaces, and limits on central offices and central offices' equipment. The voltage standard for telco equipment in central offices is 48 V [74]. Because power interruptions occur, all central offices have uninterrupted power supplies (UPSs), battery, and generator backup both on site and available via mobile platform to provide necessary power in the event of a power failure. The management of this backup power becomes a problem as the total power load of a central office increases. The limits on a building to support the sheer weight of a battery bank to back up such a central office, or the danger of storing that much diesel fuel for generators, puts operational and practical limits on the amount of power a given central office would draw.

Each subscriber line requires 2–25 W [65]. Depending on the bandwidth requirement for the line, a digital subscriber line (DSL) will draw more power than a simple voice-grade loop. This is the classic relationship between power and bandwidth: the more powerful the signal, the more information you can pack into and detect from such a signal. According to Reference 66, there were about 200 million subscriber lines in the United States in 2000 (RBOC loop plant, effectively voice-grade local phone service).

Power Backup

The standard for backup in central offices varies. Eight hours is the standard for backup in central offices. Smaller offices take four hours, while remote sites like regenerator stations take 24 hours or more. These hourly estimates are based on conversations with telco power engineers, as well as References 75, 76, 77, and 78. Most telco central offices are wired for external portable-generator hookup, with deployable generators on trucks. Wireline has had higher standards than cable, wireless, and ISPs, because of the lifeline and 911 availability requirements. Operators of leased data center space, who are building their own facilities, are meeting or exceeding the standards set by the telcos.

Power Backup Technologies

Since telcos are required to provide lifeline and 911 services, they must provide backup power at their sites to maintain the availability of such services to the public. There are three conventional backup-power technologies: batteries, UPSs (uninterruptible power supplies), and diesel generators. Also, there has been some experimentation with newer technologies such as flywheels, microturbines, and ultracapacitors. The two dominant battery technologies are regular lead-acid batteries and valve-regulated lead acid (VRLA) sealed batteries. The management and maintenance of remote battery banks is a problem—these bands are sensitive to their thermal environment, their performance degrades over time, they require some level of active maintenance, they vent explosive gases and can enter a positive feedback loop known as “thermal runaway” that can destroy the batteries. UPSs are battery backup with faster response times, but are generally smaller in scope and more expensive. Diesel generators have a slower start-up time upon detected failure, have a higher mechanical failure rate and require more sophisticated controls and more regular testing, and require on-site storage of a volatile fuel on site that itself degrades over time. There has also been some investigation into cogeneration at central offices, where a larger generator is collocated with a central office or data center and excess power is sold back to the power utilities. With some of the newer technologies, people are considering placing the backup power at the residence or business.

For further reading on this topic, see References 75, 79, 80, and 81.

Cooling Requirements

If one considers the “footprint”—the square footage required in an office to house a particular piece of equipment—the heat density (heat generated per square foot of equipment footprint) for current and future generations of computer and data processing systems, storage systems, and central office–type telecommunications equipment is increasing exponentially, as the performance of semiconductor-based technologies increases exponentially (Moore’s law). The same physical size of equipment performs exponentially more work, and thus generates roughly exponentially more heat. Increasing heat densities, however, are placing increasing demands on facilities to provide sufficient mechanisms for cooling the products. Upon moving from many large discrete electronic components in computers, switches, etc., in the 1960s and 1970s to the early introduction of large-scale-integrated (LSI) and very-large-scale-integrated (VLSI) technology in the early 1990s, there was a cooling load reduction. With the continuing shrinkage in components and the increase in integration in the early 1990s to the present, there has been an increase in cooling requirements as measured by a per-square-foot measure (see Figure 31). Figure 29 shows the annual rates of increasing product-footprint heat density [83].

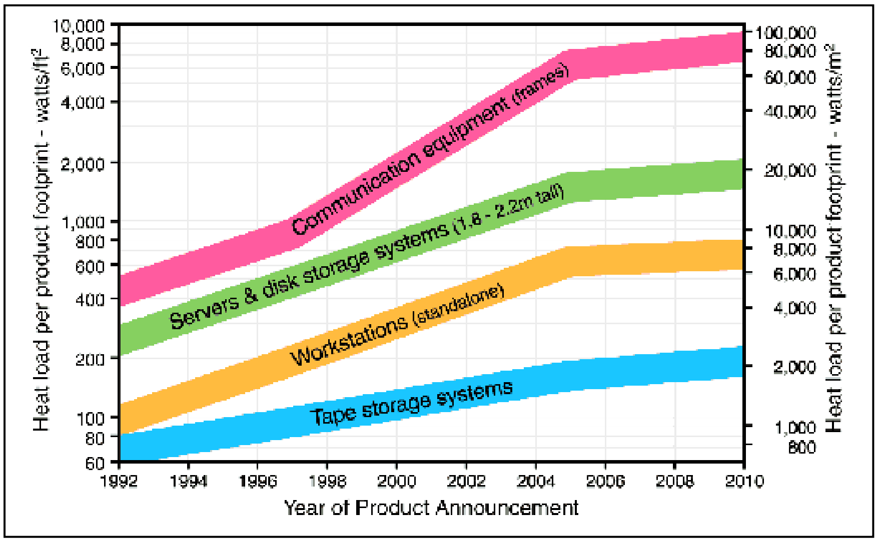


Figure 29. Trends in product heat density, 1992–2010. *Source:* The Uptime Institute [83].

From an infrastructure standpoint, since more cooling is required, failure in the cooling systems, which generally depends upon the water-utility infrastructure could become an increasingly more important interdependency. But we really do not know how the performance of telco central offices or data centers degrades as the ambient temperature.

Cooling Technologies

Cooling technologies for equipment in data centers is a difficult topic about which to obtain information. Heating, ventilation, and air conditioning (HVAC) is specific to the building design of the central office or data center. There are no equipment standards driven directly by service availability requirements to be met, just performance standards to maintain the proper operating conditions for the equipment. Since chilled water systems are the most popular systems in use today, and have been in use for many years now, we presume this is the dominant technology. We also speculate that the heat load from the very earliest telco electronic technologies was even higher than the load from the newest machines is today; thus the older central offices may have oversized chiller units relative to the actual load.

Chiller units often require a significant source of water, which means there could be a dependency on the water-utility infrastructure from the telecommunications infrastructure. There is generally no backup supply of water maintained by telcos for cooling requirements. Water also comes into play in maintaining humidity requirements for certain equipment as well. Newer natural-gas-absorption coolers often do not need as much water [84]. For general information on chillers, see Reference 85.

Figure 30 illustrates an example of a process chiller [86].

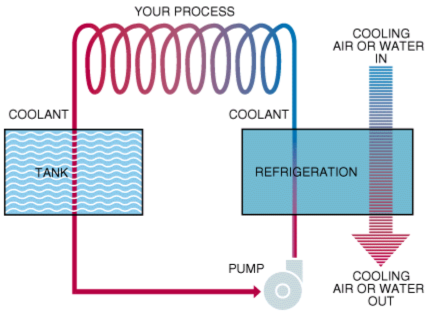


Figure 30. Cooling of a liquid passing through a process chiller. *Source:* GCI [86].

There is also a good animation in Reference 87.

As shown in Figure 31, cooling requirements will become more severe [88].

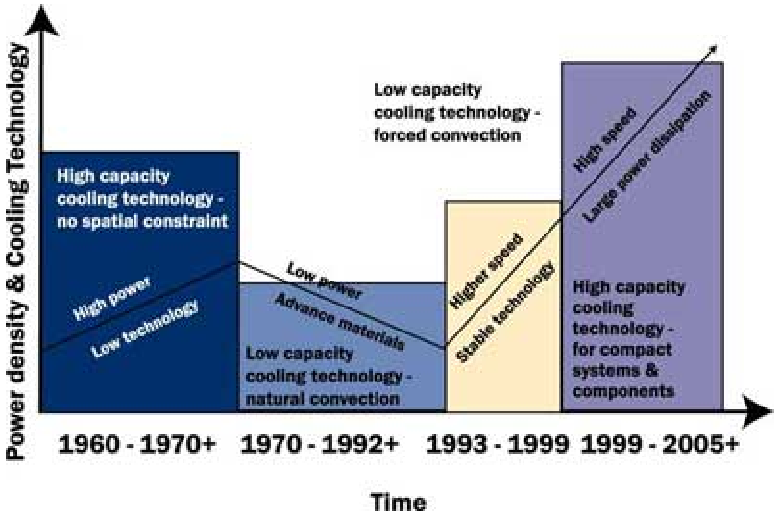


Figure 31. Trends in thermal and circuit technology over several decades. *Source:* Electronics Cooling [88].

Labor Needs for Telcos

Labor needs for a telco relate to transportation, public health and safety, and continuity of government. The labor requirements for telcos have been steadily declining over the last 20 years, and that decline is even more precipitous if the growth in capacity and services is considered [1 – Table and Chart 5.1]. This is a direct consequence of the efficiencies provided by automation combined with the deregulation of the industry. More interestingly, recent advancements in control systems and management-information-system (MIS) technologies, combined with the continually increasing reliability of equipment, reduce the need to staff many communications facilities. The growth of unmanned remote-switching/service nodes is a direct consequence of such a trend. Anecdotally, during a recent earthquake where a major central-office building was damaged and no personnel were allowed in, the normal switching and transmission services provided by the equipment in the building operated without a glitch (personal knowledge).

Thus, when considering the sort of events that strain infrastructure interdependencies, labor needs for a telco are embarrassingly small in the near term. Unless there is a new service order, capacity expansion, or repair, the system operates automatically. A general caveat can be made: The newer the service, the more handholding is required. There are two countermanding trends under those special conditions: special concern for lifeline services such as 911, and repair of traffic-dense technologies, such as fibers, that may be more likely to fail and must be manually repaired. The trend for greater concentration of traffic onto fewer and smaller pieces of equipment means that a single failure can put more traffic at risk. The availability of trained technicians and their ability to arrive at the scene of a failure becomes more of an issue. This sort of stress is seen during events such as hurricanes.

GIS Information

Up to this point, we have focused on the conceptual modeling of the processes relevant to telecommunications companies. We now turn to the data to support those process models. In a deregulated competitive environment, much of the relevant data are proprietary and thus unavailable for publication. There are, however, several publicly available databases available that describe ROW, buildings, and equipment for the U.S. telecommunications infrastructure. The largest and most complete of these databases is maintained by Common Language, a subsidiary of Telcordia which was BellCore and, previous to that, AT&T.

Telcordia’s Common Language database [89] provides location codes and coordinates for all telecommunications buildings and equipment. This database supports operations where telecommunications companies must interoperate and connect equipment in the offices of other companies. The underlying databases that provide such real-time location information could be used to get a current snapshot of the nodes of the U.S. telecommunications network.

Developed by RDI, TELCOmap [90] is a software product that illustrates the convergence between the telecommunications infrastructure and the power infrastructure in the United States. With TELCOmap, users can visualize major fiber-optic-backbone networks, high-voltage electric transmission lines, natural-gas pipelines, railroads, and highways in the same application.

COFinder [91] is a database application that compiles the wire-center information reported to the FCC by the National Exchange Carrier Association [92]. This includes the location of central offices, the nature of the carriers using these offices, the NXX exchanges served by these offices, and other features available at the switches in these offices.

Many communications consultants have produced industry survey reports that provide more detailed breakdowns of individual technologies and services, usually with an eye toward assessing their viability and profitability. These reports often include the network maps of individual companies, as well as market-share estimates and growth estimates. See References 93 and 94 for a sampling of Web addresses that can be accessed to obtain these kinds of reports.

Potential Adaptive Behaviors by Telco Agents in a Multiagent Simulation

Broad Categories of Telco Agents

We propose four categories for telco agents: **wholesale providers**, **retail providers**, **private networks** operated by large commercial customers, and **mass-market consumers**. There is actually a small business market as well, but it fits neatly between the categories of private networks and mass-market consumers. Depending on the scope of the agent-based model, these four categories would be replicated, with some overlap, for local wireline, local wireless, regional, nationwide wireline/fiber, global wireline/fiber, and satellite networks.

The telco market is moving in the direction of a standard wholesale/retail marketing scheme. This trend is implicit in the unbundling mandate of the 1996 Telecommunications Act and in the focus of new congressional legislation. Large customers design and manage their own private networks based on the retail and wholesale product offerings. The remaining customer base acts like a mass market for commodity services, where competition is present.

Wholesale Providers

Wholesale providers offer commodity products, e.g., the wholesale business units of AT&T and Qwest, and wholesale fiber-optic vendors such as Level 3 and LightCore. Thus wholesale providers tend to be more cost-sensitive than retail providers, unless the wholesale providers have some monopoly position that allows them to extract monopoly rents. The time constant of such a monopoly position would be several months to a couple of years in the absence of external governmental restrictions, such as those found in local cable systems, for example.

Wholesale providers also have large initial capital costs that must be recaptured in the pricing structure of the services. These capital costs are more sensitive to the cost of borrowing money than are the costs in retail markets. On the one hand, it is easier to make performance and cost comparisons for wholesale markets than it is to make such comparisons for retail markets. In retail markets, it is more likely that unique features differentiate services between competitors. On the other hand, there are higher barriers to entering the wholesale market, the time to enter the wholesale market is longer, and with larger purchases come special contract terms and the ability to add special requirements. Wholesale providers work with more technologically sophisticated customer bases than do retail providers, and each customer spends more per transaction with wholesale providers than with retail providers. These wholesale services influence the quality of service of those retail telco customers that use these wholesale services, as well as business operations that use those wholesale services directly.

The wholesale fiber and broadband market constitutes the vast majority of the wholesale telco products. This market is in its early stages, having been in existence for less than 10 years. The analogy is often made to the early stages of railroad construction, where there was unfettered, and uncoordinated, development of a national infrastructure. Since the retail products that expect to use such bandwidth are being developed at the same time, there are major revenue uncertainties and fluctuations facing the market. Recent scandals of mismanagement and accounting fraud by companies such as Qwest, Global Crossing, and Adelphia have also played a major role in the creation of market instabilities. Most of the major business collapses in the 2000–2002 time frame have been associated with companies that have only a wholesale product line. The construction costs and difficulties, though, are much more modest than those faced by the rail industry in the early days; and the pace of buildout of fiber is an order of magnitude or more quicker than was the pace of railroad expansion.

Other wholesale markets selling pieces of services are in their infancy, but there is little evidence that they will experience the same explosive growth as fiber/broadband. For example, the development of a CLEC (competitive local exchange carrier) market, which is based upon the purchase of wholesale RBOC (Regional Bell operating company) products by CLEC retailers, to compete with established RBOCs has gone so slowly that congressional hearings have been held on the matter.

The other common wholesale situation is for a competitor to receive a quantity discount on an entire telecommunications service from a wholesaler, and to add their own sales, marketing, and billing to provide services at lower costs. The phone-card market for long-distance and international calling follows this pattern.

Retail Providers

Retail telco providers sell value-added services to a much broader range of customers than do wholesale providers, e.g., the retail business units of AT&T and Qwest, cellular providers such as Nextel and Cingular, and cable providers. Retail providers buy their bandwidth, connectivity, and perhaps entire services from wholesale providers. It is a fairly flat chain, with bandwidth, termination, and connectivity wholesalers selling directly to internal and external retailers. Market information, marketing research and advertising, plays a much greater role for retail providers than for wholesale providers, due to composition of the respective markets. There are many more smaller customers/decision makers in retail markets. Each customer influences a tiny amount of demand; though even for customers, there clearly are “market leaders” who are more influential in the marketplace.

Each of today’s major telecommunications carriers provides both a wholesale and retail product line. In addition, there are a number of niche players who provide only retail services, competing on price to a mass market. There is also some movement by a few companies to outsource their entire IT (information technology) operations to service providers. To the extent that those operations include a large telecommunications component, they also provide a significant amount of retail service.

Private Networks

The private networks designed by businesses to meet their own internal needs should be viewed as a retail telco operation within the large company itself. Such networks operate differently than commercial off-the-shelf (COTS) retail networks. Private networks are arguably more responsive to actual customer needs, and more trusted, than regular retail offerings. There are fewer people in the chain between revenue producer and telco provider, since the provider is the company itself. Those designers and provisioners of the private networks are closer to the design and needs of the individual business. Often, it is the only way to achieve high-reliability designs based on vendor diversity. A large retail vendor will offer a one-stop integrated solution, but one based upon its particular infrastructure. To diversify a network across several, hopefully diverse, infrastructures, one must use several suppliers, and thus is designing, perhaps by default, a private network.

The more critical IT is to a company, and the more likely IT management is seen as a differentiating strength of the company, the more likely the company is to maintain IT design and operations in-house, making purchases from both retail and wholesale channels. Because these are generally large purchases, a company is likely to have the option of negotiating special performance requirements and SLAs (service-level agreements) to provide incentives to these retail and wholesale providers to meet contracted performance levels. Such private networks are generally higher in cost than a single-vendor network solution because of the internal overhead associated with such a support function; however, security concerns and accountability within a company often make it easy to justify the additional expense.

Mass-Market Consumers

For the remaining customer base, which comprises mostly residential and small- to medium-sized business customers, a suite of service offerings is made to each household or business. These tariff offerings often require regulatory approval at the state level from public utility commissions (PUCs). Performance specifications are generally “best effort,” with no financial penalties for poor service. In the case of wireless, long-distance, and IP services, there is an option to choose alternative service providers, which provides a short-term and long-term financial feedback loop between quality of service and revenue to the telco provider.

For those who require wireline local services and cable, there are few, if any, alternatives. But technological alternatives (wireless for local wireline, satellite for cable) generally are available that meet some fraction of the need. The feedback loop on poor performance and high costs for RBOCs and cable is closed at the state-regulation/PUC level. If the RBOC or cable company does not provide an adequate quality of service, the only recourse a customer has is to complain to the state PUC. There is not an adequate feedback loop between the customer base, that is effectively captive, and the revenue stream of the telco vendor.

Characteristics of Telco Services

Telecommunications is unique among infrastructures in the wealth of technologies and associated service offerings. In today’s digital world, all information, with the exception of certain broadcast offerings, is a bit. To move a bit from A to B in the United States, we may use a satellite, a cellular phone or terrestrial wireless data network, or a wireline connection. The bit may be in a packet or on a channel and most likely will be transmitted via a series of individual carriers. The bit may ride a public network or a private network; and that network may be a data network, a voice network, or a converged voice/data network. The circuit the bit follows may have been constructed just for that unique packet, or the channel the bit rides on could have taken weeks to design. The reliability and availability of the service on which the bit rides may have been enhanced. The bit may even be charged a premium due to the demand present at the time and place the transport was initiated. The unit of capacity purchased is normally a discrete amount of bandwidth as measured by bits per second, e.g., 64 kb/s (a voice-grade circuit), 1.5 Mb/s (a T1 circuit). There may also be some customization of circuit design, for example, a teleconference bridge may be provisioned to allow several participants to share a single conversation.

For the purposes of our economics and outage modeling, we recommend reducing the list of differentiating characteristics of telco services to cost, bandwidth, time to provision, reliability/robustness, and penalties assigned when the service fails. These characteristics are discussed below.

Cost

Between the regulated and unregulated portions of telecommunications services, every sort of pricing structure has been applied to telco products: by time of day, by day of week, by the minute, by the mile, by service, etc. All of these pricing structures are in place for various sorts of telecommunications service offerings. For example:

- One-time fee: regular TV, radio broadcasts
- Per-month fee: plain old local telephone service, integrated services digital network (ISDN) service, DSL service, some cellular, ISP/Internet, satellite TV, cable TV, microwave, Centrex
- Per-minute: plain old long-distance service, certain private network services like FTS, some cellular services
- Per-minute, per-mile: plain old international service
- Per-month, per-mile: private lines, wholesale bandwidth
- Decreasing marginal prices with volume: wholesale bandwidth, cellular

For large customers, special rates are charged for custom private networks. These rates can be substantially discounted from public offerings.

The situation becomes much more complicated under unbundling, where each element of a local telecommunications service must be made available at a fair competitive price to all comers. That is, however, beyond the scope of our study.

Time To Provision

There are two flavors of telecommunications service. Some services are provisioned nearly instantly, e.g., a POTS (plain old telephone service) call is built and torn down in seconds. The other classes of services are custom-engineered. These services normally involve special requirements, such as the bridging of several circuits together or the need for a large amount of bandwidth.

Provisioning times are generally five to seven days for most generic services. Provisioning of a business service often involves coordination between two or more telecommunications companies. Thus the more companies involved, the longer the delay. Further, because some areas are still bandwidth-limited, the larger the amount of bandwidth requested, the more likely it is that new construction or reconfiguration of existing capacity would be needed. In such cases, provisioning times could run into weeks or months because they are very location- and service-specific.

Spikes in activity are particularly hard to assess. Most custom service requires at least some manual activity and human involvement. The staffs of technicians at telecommunications companies have been sized so carefully since divestiture that they can easily become overloaded. Consequently, actions that would take days under normal circumstances could take weeks or even months.

Availability (Outage Minutes, Time To Repair)

The availability of telecommunications services became a national concern in the early 1990s when the implementation of fiber, combined with other stressors on major carriers, led to a series of major, long-term service outages. As a result, an industry consortium, the Network Reliability Steering Committee (NRSC) managed by the Alliance for Telecommunications Industry Solutions (ATIS) [95], collects outage data on major circuit-switched failure events and provides regular summary reports to the FCC and to the nation. The major categories of failure events are as follows:

- Fiber cuts
- Switch failures
- Signaling failures
- Power system failures
- Transmission equipment
- Traffic overload

By root cause, this breakdown becomes the following:

- Telco equipment
    - Procedural flaw
    - Design flaw
    - Hardware failure
- External stressor
    - Weather
    - Man-made
    - Cable damage by rodents, soil movement, etc.
- Building failure
    - Flooding
    - Temperature control failure
    - Fire
    - Corrosion/contamination
- Traffic/system overload
    - Too much traffic
    - Reduced capacity
- Power failure
- Operations support failure

More detailed breakdowns on the observed rates and outage times for circuit-switched service failures for the last several years can be obtained from the NRSC. There is no formal reporting requirement for transmission failures that do not affect circuit-switched services, e.g., for packet networks like the Internet, for private networks, or for cable-based networks.

Telecommunications is the most robust and self-healing of all the major infrastructures. Much of this is due to the ease with which diverse routing schemes can reroute traffic and the relatively low cost of provisioning capacity for exploring such restoration schemes. Compared to the electric power infrastructure, the telecommunications infrastructure has implemented more sophisticated automated algorithms and has a lower downside risk if such schemes fail, i.e., no equipment can be damaged if an automated scheme fails or was poorly designed.

A failure in a telecommunications network can be restored in as little as 50 milliseconds (e.g., restoration of a broadband circuit on a protection channel) or as long as 24 hours (e.g., the case of the recent AT&T frame relay failure). Most fiber services are restored relatively quickly in the event of a fiber failure, but the physical fiber repairs themselves normally take several hours. If a building is destroyed, it could take several days or weeks to restore fiber service that terminates on that building, although cellular service can be used to restore narrowband voice and data more quickly.

Failure events can be as limited as a single circuit to a single home or as extensive as the outage of an entire nationwide network, as in the case of the January 1990 AT&T direct-link-node (DLN) failure of the switched network [96]. Generally, a failure affects a single service for a single carrier. Since most major carriers now have their own fiber networks, there are few telecom-specific events that would affect multiple carriers. Multiple services can be affected, though, on a single carrier if fiber routes or central offices or data centers fail. If failures occur outside of the control of telecommunications systems, e.g., power failures and civil emergencies, then both multiple services (because of the risk to fiber routes and telecommunications buildings) and multiple carriers (which share the same power infrastructure) could be affected.

Based upon those insights, it is clear that there is no generic failure mode for telecommunications, nor are there generic impacts from failures. In fact, the most severe failures have often been those that are the most exquisitely specific to the particular implementation of a particular service.

On the plus side, restoration options have become much richer for the creative telecommunications consumer. There are wireless and wireline options, cable and twisted-wire-pair options, satellite and cellular options (and Wi-Fi), circuit and packet options, along with several options for broadcast messages. Therefore, it can generally be assumed that critical narrowband messages can always be reestablished quickly if thought is given beforehand to the kinds of systems in place.

Another telecommunications advantage to the nation in terms of reliability is the competitive availability of parallel physically diverse services on alternative vendor networks that can be turned to when a service on a given carrier network fails. The migration from one carrier to another has been noted in failures such as the AT&T frame relay failure, where customers turned to ISDN options on other carrier networks. For certain types of failure modes, e.g., frame relay, options such as ISDN may be available almost immediately after the failure. Sometimes, alternative channels require a more significant lead-time or a change of content format, e.g., wireless text messages rather than voice messages.

Bandwidth/Congestion

Another major characteristic that differentiates telecommunications services is the amount of bandwidth (bits per second) required for a service and how that service is affected by a reduction in provisioned capacity.

Bandwidth can be purchased as an always-on service between two points. This service can be purchased in various capacities:

- Circuit (56 or 64 kb/s) – a regular voice telephone call
- T1 (1.5 Mb/s)
- OC1 (45 Mb/s)
- OC3, 12, 48, 192 (3xOC1, 12x, 48x, 192x)

One way to meet future bandwidth needs is to lease fibers without the electronics. This kind of network solution is referred to as *dark fiber*. Later, the electronics can be added for transport at whatever level is desired. For example, with dense wavelength division multiplexing (DWDM), the carrying capacity of fibers can be increased to 10 Gb/s and beyond.

This sort of bulk capacity takes weeks or months to provision. Once an initial switched or packet private network is provisioned with bulk capacity in a backbone network, then smaller incremental units of capacity can be provisioned much more quickly to service new demands on the network. These networks are generally limited to T1 levels of capacity, but allow the sort of fast establishment of circuit-level sorts of connections on these private networks that are found in public POTS networks, discussed below.

At a microlevel, e.g., an individual 64 kb/s circuit, capacity can be provisioned in milliseconds. On a shared public network, a switched circuit is leased for the duration of a call on the POTS network. On the Internet, each packet's worth of capacity is independently routed on shared bandwidth. There is no provisioning lead-time, but there are also trillions of those packets riding the network and using a slow-to-provision switched or packet network.

Generally, packet networks are more robust to congestion effects and network-element failures than are switched networks. Reconfiguration can naturally occur at a packet level in real time. But packet networks are not designed to carry the sort of streaming content streams for which a circuit-switched network is designed. If a voice call involves a 56 kb/s stream of data between the same two stations for an hour, there is less benefit from routing each individual packet than there is for transmitting a large series of small (100 kb) messages between a large set of origin and destination pairs.

Congestion manifests as a delay in transmission in packet networks, whereas congestion is reflected in failed connection attempts in switched networks. In some sense, connectivity is never lost in packet networks, but bandwidth is reduced. In circuit networks, a station does lose connectivity to large regions of the network, or to the entire network, during congestion events.

Penalties for Noncompliance in Performance (Customers and Carriers)

Since CommAspen is an economics model, feedback processes are important. These feedback processes have major problems when service is disrupted, as discussed below.

First, the only way that carriers can justify investments in new plant is by an increase of revenue, short-term or long-term, or by a decrease in costs. If a carrier perceives no new revenue from an improvement, there must be an avoidance of costs. The revenue impacts of outages on telecommunications customers are generally poorly understood by the customers themselves, so there is often little willingness-to-pay on their part—until a major event occurs. But, by that time, the capacity and systems are not in place to achieve what would be a profitable level of restoration for both customers and carriers. It would seem that neither carriers nor customers can properly assess the cost of an outage and make informed build and purchase decisions based purely upon a narrow consideration of near-term revenue and costs. Normally, the free market assists by making available competitive alternatives, so we would expect new entrants to provision new capacity that is physically diverse from existing capacity. But in the case of telecommunications, and fiber routes in particular, there is often no economic justification for more than one capital investment in, say, a fiber route. There may be several telecommunications companies who *are* competing in that market, but on price and availability, and not the availability of diverse routing options, so see no advantage from not leasing existing capacity. This is especially true since unbundling regulations require incumbent carriers to lease such capacity at a competitive price.

Second, carriers do not pay a proportionate penalty when their services do not meet an availability requirement. Carriers operate under "best effort" terms: If they fail to provide service, they may be prohibited from billing for the outage period; however, carriers do not feel the economic penalty faced by the customer, who may lose many times the billing expense in lost revenues. While there has been some effort made over the last few years to develop binding SLAs (service-level agreements) with appropriate financial penalties, these agreements have had limited penetration for anything but the largest telecommunications customers with the most leverage over a given set of carriers. With few consequences for failure to provide service, carriers tend to underinvest in robust options for their customers. Carriers do not do not feel their customers' pain from a fragile network, nor do they perceive an enhanced revenue stream from a more expensive robust network.

Consumer Behaviors During Telco Outages

Two kinds of consumer behaviors are expected during telecommunications outages, as described below.

No Response/Use of Readily Available Alternatives

In the case of small failures, or for mass-market consumers, there may be no real change in how people purchase and exploit telecommunications services. Failures that occur in off-hours may not even be noticed, and carriers in scheduling maintenance activities during these times exploit this fact.

Using our four-level market categorization, we offer the following speculations:

- **Mass-market consumers:** This will be the expected response for the vast majority of users. The new products and services that already are available to service this sector provide greater robustness anyway, so consumers, by purchasing such services, are fixing their own problem without an explicit acknowledgement of the problem. For example, cable Internet provides a second line into the residence, making households less affected by interruptions resulting from failures in loop lines or central offices.

- **Private networks:** If a failure made no substantive impact on business operations for anyone in its business sector, it is unlikely that a private network would take any action because of that single event. Reconfiguration of private networks is costly in many ways, so we would speculate that no one would act unless it was clear that revenues were at risk.

- **Retail providers:** Unless the failure was modest in its impact, we speculate that it would be unlikely that no change would occur in the retail providers, i.e., carriers, if the failure was due to any of their suppliers. At the least, a retail provider would perform an assessment of its current suppliers and would request compensation in the form of a rebate for those hours where service was interrupted. If the failure were due to its own actions, a retail provider would assess whether the failure is acceptable from a revenue or regulatory standpoint. If the failure affected few customers and did not affect E911 or other critical services, the retail provider might perform a root-cause analysis but do little else. If the failure reached the threshold levels of FCC reporting, we assume the retail provider would meet the reporting requirement.

- **Wholesale providers:** We assume that the conditions under which a wholesale provider would do nothing would be equivalent to those under which a retail provider would do nothing. For wholesale providers, we assume the failure would need to be much smaller for no actions to occur, since a smaller event leverages much more traffic, the customers are more technologically savvy, and, in the 2001–2002 time frame at least, the competition was fierce with significant overcapacity.

Business-Level Disaster Recovery Options

Near-term response to massive telecommunications failures falls under the umbrella of a disaster recovery plan. For private networks, the disaster recovery plan is part of an individual firm's risk-management approach. There are no standards in any industry that specify the elements that must be part of a disaster recovery plan, or even whether an emergency disaster recovery plan is needed. There is anecdotal evidence, however, that such a plan is crucial to the survival of a company in the event of a long-term collapse of IT services, but the full appreciation of those vulnerabilities is not reinforced by standards promulgated by insurers who help manage a firm's risk exposure or by government regulators.

A typical disaster recovery plan for telecommunications does not exist. The elements of the plan are in great part determined by what the firm produces. For example, if the firm is dependent on a bulk of customer orders over the phone, its disaster recovery plan would differ from the plan of a chemical plant or even an emergency response service that worries about very few, very time-critical communications. We can, however, make two general observations. If such a plan exists, there is usually an option to relocate operations to a location whose telecommunications services are relatively independent of the original site. This is an acceptable option if the failure is localized to a small geographic region.

There are also ad hoc approaches that involve obtaining alternative services from the same provider, or from other providers in a short (1–2 day) time frame. The availability of these options is specific to the private network services and available provider capabilities relevant to a specific firm. Normally, a provider is very anxious to maintain a relationship with a customer and will work in a cooperative fashion to restore service, or provide an alternative, in a timely fashion. The larger the firm's telecommunications bill, the more anxious the incumbent provider is to maintain the firm's business.

Impacts of Telco Outages

Here, we speculate on near- and long-term losses, as well as on concerns for public health, security, and safety.

Loss of Near-term Revenue

There have been a few consulting studies on the topic of information system outages and their financial impact. Since this information is part of any marketing pitch for value-added high-availability technologies, the essential results of these studies have made their way onto the Web. These numbers are the ones bandied about in the trade press, in the marketing literature, and occasionally in Senate hearings.

Let us first make an important caveat: Although credible consulting firms in the communications arena (e.g., Gartner) performed these studies, there is *no* motivation for any study to underestimate the outage costs and some strong reasons for these costs to be overstated. The costs are used in advocacy or marketing situations to increase expenditures on outage-reduction technologies. The companies or external groups paying for copies of the studies are the ones who stand to profit financially from increased internal or external expenditures.

The cost of an outage to an industry is specific to the industry in question. A much-cited high-end figure is $6 million per hour for brokerage services [97] down to $100,000 per hour for reservation services [98]. A range from $1 million to $3 million per hour is quoted for various IT-intensive businesses [99], as shown in Figure 32. A broader survey found that one-half of U.S. companies would suffer less than $50,000 loss for an hour outage [100]. And a 1992 survey of network managers estimated the loss at $4,000 per hour [101].

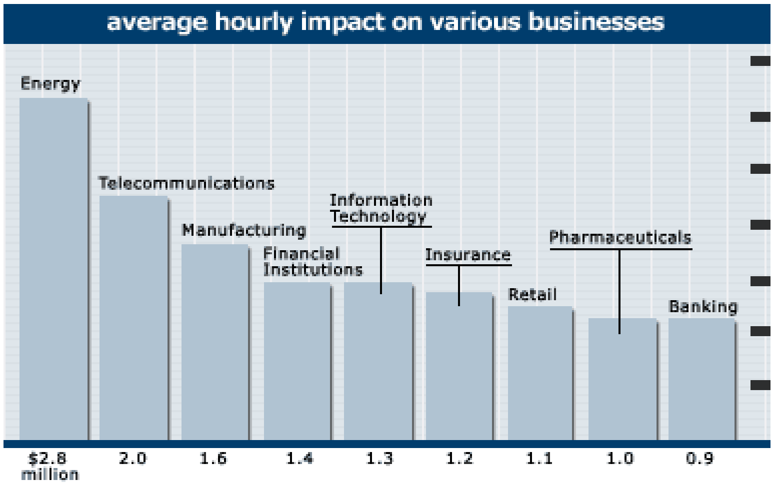


Figure 32. Average hourly impact on various businesses. *Source:* Meta Group, cited in Reference 99.

Most of the cost estimates listed below refer to a total failure of the information systems supporting a company. If a communications service fails, and the company's information system is designed to be robust to a single-service failure, there is no financial impact.

Another way of assessing the costs of outages, especially long-term outages, is in the continued viability of the firm.

These costs are disproportionately greater than the rebates and compensation paid by carriers that cause customers to suffer such outages. About $30 million was paid to 3,000 MCI customers over a 10-day frame relay outage in the way of compensation [102]. This compensation would be less than 1% of the imputed cost of the outage.

Long-term outages jeopardize business survival.

For every five companies affected by a very long-term outage, two will not reopen their doors, and a third will fail in the subsequent two years [103]. It is claimed that "a company that experiences a computer outage lasting more than 10 days will never fully recover financially" [104]. According to the National Archives and Records Administration, cited in Reference 99, 93% of firms that lose their data center for 10 days or more declare bankruptcy in the first year. And 50% of those businesses file for bankruptcy immediately [105].

According to Reference 106, the average company loses 2–3% of its gross sales within 10 days after losing its data processing, and critical business functions cannot continue for more than 4.8 days without a recovery plan in progress. Half of the companies that do not restore their data center to operation within 10 business days never fully recover. Ninety-three percent of the companies lacking a recovery plan are out of business within five years of a major disaster.

☐ Most of these outage estimates are based on surveys, which reflect perceived rather than actual costs.

Unfortunately, most of these estimates on outage costs are based upon surveys, or cursory in-house analyses, and reflect both biases and a lack of quality in the underlying analysis. In-house analyses of structured operations that depend heavily on a single IT infrastructure probably provide the best estimates. Our cited cost estimates are based upon responses to surveys. The respondents most probably provided estimates based on informed guesses since in-house assessments are generally considered company-proprietary.

The range of estimates suggests that there may be orders of magnitude of error in the reported numbers. For example, in Reference 100 by the Eagle Rock Alliance, 20% of the respondents said that an eight-hour IT outage would put their company at risk of failure. Although there may be a few ultrahigh-reliability applications that could not accept such a risk, they are very few. For a continuous manufacturing process, a pure eight-hour outage during a year constitutes a 0.1% reduction in production. Assuming a restart time of 16 hours, this would still be a 0.3% reduction in production. And this does not even consider the option of increased inventory, which is reflected as a holding cost rather than a revenue reduction. This impact is equivalent to a one-day walkout of staff. It is hard to believe a one-day walkout would constitute a threat to the survival of 20% of U.S. companies.

There is no incentive for respondents or survey administrators to underestimate their outage costs. There would be every financial, political, and psychological reason to overestimate such costs. It is so hard to extract funding for support functions like IT, much less funding for IT upgrades when there is no direct revenue enhancement, that any case must be stated in the strongest possible terms. The embarrassment suffered by the company and its board from a major IT failure will drive senior executives to find some way to make a financial case for an iron-plated IT system that does not fail catastrophically. So the pressures may be from above to pad such numbers to make any business case work. The survey compilers are in the position to make contracting dollars by supporting the development and implementation of such successful business cases.

☐ Formal published methodologies to assess IT outages have become more sophisticated, but the market penetration of such methods in formal business planning is unknown.

The two documents we have that document methodologies to estimate outage costs are from IBM [107] and the Gartner Group [108].

The IBM document outlines how an IT shop should go about assessing the value of availability, which is the complement to the cost of outages. The basic steps are as follows:

- Compile an IT inventory of systems.

Note that the IBM document is circa 1990 and refers heavily to centralized mainframe functions, IBM's bread and butter at the time.

- Inventory the user base for each system.
- Assess the revenue and profit value of the IT system by each user.

  There is mention of using a marginal analysis that captures the profit per unit after fixed costs are recaptured.

  For support functions, a replacement cost (how much it would cost to do this function without computers) is calculated. This reflects the Zeitgeist in the sense that if IBM did not exist, the process would have to be done manually. It was before IT outsourcing became popular.

- Assess the service outage costs to the business.

  To assess the costs, the method proposes various categories of costs:

  - Direct costs versus indirect costs
  - Tangible costs versus intangible costs
  - Fixed costs versus variable costs (variable = costs that are a function of the length of service outage)

- Map the IT systems to user services.

  Included is a measure of the level of dependency or criticality.

- Map IT components to IT systems as they provide user services.
- Value IT components in terms of their value to maintaining user services.

  This potentially involves capturing the system reliability as it logically depends on individual components.

Any quantification is assumed to follow from expert opinion. There is a brief description of the Delphi technique as an approach to collect expert opinion. The IBM document is supplemented by an Excel spreadsheet.

The 1998 Gartner Group assessment goes into less formal detail than the IBM document but is more sophisticated from an overall "value to the business" sense. The costs of outages include revenue impacts, productivity impacts, damage to reputation, financial performance, and expenses associated with catching up on lost time. In particular:

- The revenue lost due to outages includes both direct loss and long-term revenue loss, such as losses due to delays in billing and losses from investments.

- Productivity includes the number of employees times the number of hours affected times the burdened hourly rate.

- Damage to reputation includes the damage suffered by customers, who may not return to do business, and to suppliers who get reimbursed late, whose pain then trickles down to bank and financial partners.

- Financial performance includes revenue lost and contractual compensation payments to customers, as well as increased inventory costs, reduced discounts from suppliers as a response to paying late, and even stock market performance.

- Catching up may involve overtime to employees, additional shipping costs, equipment rental, and litigation.

More specific points from the Gartner study include the following:

- By the year 2000, it was forecasted that 80% of high-IT-intensity companies and 40% of low-IT-intensity companies would use intangible costs to assess the cost of outages.

  This means that including intangible costs in determining IT availability targets, although explicitly discussed in the 1990 IBM document, had not become universal, even for large companies, by 1998.

- The costs of outages should be lower for those industries that dominate and control their market and where the loss of market share should be expected to be small in the face of major outages.

- An individual piece of hardware alone is not assigned a specific number that reflects its contribution to an outage since the overall system and its design and operation are what provide reliable service, not any given box.

- There are second-order costs associated with outages.

  Examples of second-order costs are billing losses and compensatory payments associated with missing billing or fulfillment targets.

- The time the outage occurs can be crucial.

  You should assume the worst possible time for the outage for your calculations.

- There should be some consideration of how critical IT is to employee productivity when assessing IT outage costs.

> If employees can be doing useful work otherwise, that should be credited in some ad hoc but quantified fashion.
>
> *This is alluded to, but the summary document still uses the full burdened cost of an employee to assess productivity impacts. That is, the Gartner Group report mentions modifying the full burdened costs, but the IBM report does not.*

In both the Gartner Group assessment and the IBM study, the option of telework or other work employees can be doing on their local PCs seems to be downplayed. This may reflect a research and development (R&D) bias, but few knowledge workers are without other work options if the IT system goes down, especially if there are company-secure PCs waiting for them at home. Manufacturing and retail may be another issue. We can learn from the December 1998 San Francisco power outage and 9/11 events to assess whether that is actually true.

Additionally, selecting the worst outage time for assessment of damages seems to be excessive. This could affect outage impacts by factors of 2 to 10 or more for certain industries. Those damages seem closer to the costs assessed against a malicious IT system attack, which is only a small fraction of the total-outage scenarios. Selecting the worst outage time might be further evidence of subtle upward bias in outage costing.

The Website availability.com has an on-line cost-of-outage calculator [109]. The calculator captures revenue and salary costs at risk in a simple calculation. It does include a factor that explicitly reflects the percentage of work that cannot be done if a given system is down, rather than assuming all work in a department stops. This would allow the tool to be used to reflect short-term versus long-term outage costs from the standpoint of an increasing fraction of wasted time as workers run out of things to do.

Loss of Long-term Revenue

The loss of reputation and associated long-term revenue is even harder to quantify than the short-term revenue impacts, whose estimates we mentioned before range over five orders of magnitude. There are no well-publicized instances of a carrier going bankrupt because of long-term concerns with communications reliability, nor of major IT or service companies failing due to a problem with obtaining a reliable telecommunications provider. It is difficult to estimate any smaller revenue impacts from such events since the time frames involved include many other events that affect revenues.

Public Health, Security, and Safety Concerns

Public health, security, and safety concerns have been explicitly addressed by the NRSC (Network Reliability Steering Committee) in their FCC reporting since its inception. The NRSC's categorization of sensitive locations and functions is probably the most sound unclassified characterization available. The data collected by the NRSC does not suggest any unique characteristics of these outages. The outages are also rare, e.g., only four events reported in 2001 met NRSC guidelines.

State PUCs generally require additional detail on any E911 outages in their jurisdiction and provide another regulatory feedback loop to the carriers if the rate or causes of such outages are deemed unacceptable.

Characterization of Customer Behaviors after Telco Outages

There are no academic studies on business and economic behaviors after service outages, and there is no academic subdiscipline in economics that focuses on the response of economic systems to shocks in the infrastructure. The studies that have been done to predict or evaluate the impacts of price shocks on an economic system (a major focus of economists over the years) are of little use in identifying the impact of a single technology failure. There is no "infrastructure input/output matrix" for modeling the impact of infrastructure shortages over various time frames. The technical understanding of the impact of past outages would be buried in the corporate history and proprietary disaster-recovery plans of industrial sectors that depend on telecommunications, and in the proprietary studies that carriers would have done after major events. What little information that is available in the trade or popular press is anecdotal, but relevant.

Based upon our historical understanding of telecommunications and past outage events, we will speculate on the likely responses by customers to major outages. Since this report spans the period that includes 9/11/01, we will also comment on the customer responses as reported in the press.

Change Network Design

Wholesale (Broadband) Providers

Changing a network design, either a wholesale rearchitecture or just the provisioning of additional capacity in the face of unexpected user utilization or demands, is a rare but normal occurrence in wholesale networks. A wholesale network rearchitecture usually is done when a new technology is introduced or upon major changes in strategic marketing. Since new technologies have been arriving fast and furiously, changing a network design is a continual process, at 5- to 10-year intervals. Even in the face of dramatic technology change, e.g., fiber, this process can take a few years. There is a "critical path" for such changes:

1. Changes requiring several years: obtaining ROW, obtaining regulatory approval
2. Changes requiring a couple of years: next-generation technology improvements, feature-set changes within current technological limits
3. Changes requiring six months to a year: building a new office and installing new equipment, coordinating the installation of network capabilities via software
4. Changes requiring a month: ordering and installing new equipment in an office

5. Changes requiring days or a week: major coordinated provisioning of new transmission capacity.

With the amount of dark fiber provisioned in the nationwide network, new network designs that primarily require new transmission capacity on certain major routes would be initiated and could occur in about a one-month time frame. This is not true in many metropolitan areas. There is not, though the technology is becoming available for there to be, a wireless option at the broadband wholesale level to bridge the gap at metropolitan levels. Therefore, for many routes and customers, the redesign option for broadband services would not be available in the one-month time frame. Note that narrowband is primarily retail and will be discussed in the next subsection.

With the availability of cybercenters and the unbundling requirements on RBOCS, redesign no longer requires the construction of new offices, but simply the ordering, installation, and configuration of new equipment.

Redesign activities probably are a six-month planning activity for any major carrier. Determining what to do is likely to take longer than actually doing it.

Because of the amount of coordination across various carriers required to provide new connectivity, the amount of delay is driven by a "weakest link" dynamic. This is partly why large customers choose to construct their own networks from wholesale components in the first place—to better control the scheduled turn-up of new network services by choosing whatever suppliers can deliver a given component of the service in the necessary time frame to meet milestones.

Although wholesale carriers compete, the knowledge of their target architectures can probably be gleaned from publicly available records. There is no real advantage gained in hiding knowledge of the topology of the network that is designed, or to be provisioned in the near term, since that information is needed by the sales staff to market to customers. Capacity available on routes, on the other hand, could be of competitive advantage and might not be generally advertised. In addition, the actual timing of some deployments and full implementations are fundamental unknowns for competitors and for the carrier itself.

Post-9/11 follow-up: *The above was written pre-9/11. The provisioning process mentioned above was dramatically accelerated during the days following 9/11, when 2 million circuits were physically and logically reprovisioned over six days, instead of a month. Mobile switching centers and cell towers were temporarily rolled in as well, cutting the normal time to install equipment from a month to a couple of days. But the observation that the rearchitecture of a network takes months to years was reinforced with the announcement of a new robust Securities Industry Automation Corporation (SIAC) network (more properly considered a private network, but large enough to fall under the wholesale market aegis) to support the 9/11-battered New York Stock Exchange (NYSE), over a year after the 9/11 event.*

Retail Providers

Retail networks are characterized by narrowband services with a richer set of potential features provided to a broader set of customers than is found in wholesale networks. The redesign of retail networks, however, depends upon the availability of wholesale network service offerings as one of the production inputs. The planning of a retail network redesign must take customer relations and marketing considerations into account much more thoroughly than the planning of a wholesale network redesign. Because of the richer set of features in retail networks, coordination and testing takes a much greater amount of time. On the other hand, there are few, if any, long-lead-time (as measured in years) items that must be obtained and provisioned. Because it is not a commodity, like wholesale, there are higher profit margins in retail networks, and the relative speed with which these networks can be provisioned means that capital to pursue such redesign activities should be more widely available. There may be proprietary design and technologies associated with such networks, at least more than those associated with wholesale networks.

Post-9/11 follow-up: *There were few changes evidenced in retail network design after 9/11. The instabilities resulting from the consolidation and convergence trends in telecommunications, combined with the collapse in stock prices in telecommunications that followed from the dot-com bust in 2001–2002 swamped in magnitude the impact from 9/11. Movement towards more robust architectures such as packet was neither accelerated nor slowed by the 9/11 event, although certain niche services like video-teleconferencing and wireless data received a bump. The impact was more directly felt in purchases in the same retail services to support new or enhanced disaster-recovery options.*

Private Networks

Private networks are "retail on top of retail." Everything that distinguishes retail from wholesale, when applied to a greater degree, distinguishes private networks from wholesale networks: speed, development of customer requirements, highly implicit profit margins (as reflected by revenue-at-risk, or new revenue potential), and smaller networks with less bandwidth but richer features. Coordination is made more difficult by the relative lack of market leverage in purchasing component elements, but made easier by the smaller size of such networks. Because there is no governmental oversight, private networks can reconfigure faster but have no leverage to enforce standards beyond those of caveat emptor, "best effort," and SLAs.

The decision-making process for the design of private networks involves executives whose expertise is not in IT, and thus you might expect longer redesign implementation times than would be found with carriers selling retail services. The richness of the feature set makes testing more difficult, but the knowledge of the specific configuration that is to be implemented (as contrasted to testing to all possible configurations by retail carriers for general service offerings) far offsets the difficulty of testing. The smaller size of the network means that performance issues that benefit from economies of scale, such as congestion management and spare capacity, are more problematic for private networks.

On the other hand, performance issues that suffer from diseconomies of scale, like testing, are less problematic for private networks.

Post-9/11 follow-up: *The demand for disaster recovery increased in the post-9/11 period. There had already been some movement towards treating disaster recovery as a requirement for business operations. Failures of large data centers and other crucial business sites, both terrorist- and nonterrorist-related, had led businesses to implement backup sites and supporting telecommunications infrastructure. Those whose telecommunications and business architecture were shown to be deficient during 9/11, notably the NYSE, have moved to implement more robust IT architectures.*

Redesign Effects by Technologies and Services

There are specific details associated with individual technologies and services that are relevant to redesign decisions:

- Wireless options such as cellular and satellite are fundamentally limited by those who hold the spectrum. Costs will go up proportional to the number of players who believe wireless holds greater promise in their redesign. Management-control features are more limited for wireless, as is security. Wireless is still primarily an option for narrowband and broadcast wideband.

  Post-9/11 follow-up: *There was no evidence of an increase in demand for wireless solely based on the robustness requirements after 9/11. Wireless is still early in its life cycle, and new technologies and spectrum availability are driving demand. An emergency in a schoolyard is more important to the mass market as availability of communications during a national emergency and is driving behaviors.*

- The availability of dark fiber is unevenly distributed throughout the United States, with some areas having more spare fiber than others. The robustness of well-designed fiber networks is most sensitive to the number of available alternative physical routes in an area.

  Post-9/11 follow-up: *The availability of dark fiber is proving to be an important issue as disaster recovery plans are being implemented and as alternative sites demand diverse fiber routings, which are not available in many areas of the country.*

- The same lack of even distribution is true for carrier hotels, though to a lesser degree. For alternative carriers, there is the option of RBOC central offices. With the shrinking of the form factor for telecommunications equipment, there are more options to collocate these facilities at customer-premise data centers. This leaves the reliability of such networks dependent on the reliability of the support services at such premises.

Post-9/11 follow-up: *There is no evidence of an increase in alternative data centers solely due to 9/11. The overbuild of data centers during the dot-com boom has left a significant overcapacity that is being drawn down in the post-9/11 era, and this is the dominant dynamic.*

- Commercial products to provide telecommunications services, both circuit and packet, are generally available from a small handful of vendors—both domestic and international. Any inventory problems from these vendors would delay deployment. This is not true for software, only hardware.

  Post-9/11 follow-up: *In the period immediately after 9/11, there were several stories of heroic acts by vendors to support customers immediately impacted by the events. If the logistics are in place to support the vendors, the vendors will sacrifice short-term gain to support the customers if at all possible. Since there was a significant inventory of hardware to be made available because of the post–dot-com economic environment, the vendors had little problem supporting additional customer needs.*

- Personnel issues are probably the most manageable of the issues regarding redesign. Professional IT staffs are remarkably flexible in managing to new technologies.

  Post-9/11 follow-up: *Again, there were heroic stories of how IT centers moved to support workers who worked at home during the emergency.*

- Interoperability standards often lag behind the availability of features in new hardware releases. The delay in such standards and testing will result in a reluctance to use these new features in any future redesign.

Select Higher-Reliability Services

Wholesale and Retail Providers

Major carriers offer a spectrum of services with increasing reliability performance. At one end, account managers will work with network engineers to customize the design and layout of customer services to an engineered standard. This option is more available to circuit services than packet at the present time, but it is a focus of ongoing development in the packet worlds as well. The primary difficulties are in obtaining such services for nonmetropolitan areas and in guaranteeing that designs achieve reliability and maintain engineering standards. At the other end, reliability standards vary across generic service offerings of various vendors, and it becomes an exercise in shopping around.

Post-9/11 follow-up: *There is also evidence of the metropolitan area itself, and its business councils, working to put pressure on the carriers, especially dominant players like RBOCs, to make available high-reliability service offerings. This pressure extends to the real estate/landlord markets as well, arguing for the need for two diverse entrances into buildings for fiber lines.*

Private Networks

There is a continuum of management philosophies in managing private networks. At one end, a single carrier is chosen to coordinate the design and management of the enterprise network. At the other end, the private network is designed from customer-premise equipment and wholesale bulk transport, all purchased and integrated by the customer.

In the case of the former (a single carrier) philosophy, the decision is at an executive level, perhaps even with the board of directors' approval. Just the threat of such a switch can get the attention of a carrier and improve the management of the services to improve reliability. The problem is that this costs more, is generally slower to respond to business needs, and assumes that the unique performance characteristics of the company's communications network is not a unique differentiator that provides a competitive advantage in the marketplace.

In the case of the latter, the decision involves buying the same generic widget from A rather than B. The problem in this case is that no telecommunications widget, short of bulk transport, is generic. There is a major price to be paid in testing, evaluation, removal, and installation to ensure the device performs as advertised and is integrated into the specific private network with all of its quirks.

Post-9/11 follow-up: *One additional feature unique to the telecommunications industry that has arisen is the de facto monopoly RBOCs continue to hold in providing regional telecommunications services. There is no secondary carrier that private networks can turn to if the RBOC in the region does not choose to provide services that meet the reliability needs of the customer. The attempt to create a CLEC industry has not been particularly successful, while at the same time the regulatory pressures that had historically been able to be placed on RBOCs have been weakened. The only fortunate event that is partially mitigating this problem is the availability of alternative technologies such as cellular and packet. Unfortunately, some of these are early enough in their life cycle to lead to trust issues for the private network managers.*

Mass-Market Consumers

There are many fewer high-reliability offerings available to the mass market, short of selecting a more reliable vendor. The information on which to base such a decision is scanty and anecdotal, becoming a process limited by the available information and the rate at which reliability changes over time for various vendors. History has shown this rate to change more quickly for new entrants that are quickly growing their networks and facing greater proportional increases in traffic loadings and service churn. There is good data on nationwide reliability performance levels over time. One would expect these rates to vary across geographic regions for a given vendor.

The relative shortcoming in service offerings is more critical to small businesses that cannot justify the initial and ongoing costs of a private network.

Post-9/11 follow-up: *The relative shortcoming in service offerings can be seen from the relatively slow recovery of approximately 10,000 small businesses after the 9/11 event.*

Change Vendors, Diversify across Vendors

Wholesale and Retail Providers

Changing vendors, or even diversifying across vendors, is difficult for wholesale and retail providers. There are a limited number of vendors available for the hardware to drive service offerings at the wholesale or retail level. There are no objective measures testable by a customer to determine subtle differences in the reliability of such hardware. Changing or diversifying hardware vendors means additional investment in support systems (software, procedures, etc.). The larger the purchase of equipment from a given vendor, the greater leverage a customer has in obtaining information, support, and future features. All of this must be balanced against the benefits of protecting the network against catastrophic failure from a common-cause failure in a single vendor's equipment. There are ways to minimize such impacts by staging the deployment of new equipment so as to see any potential problems only on the fraction of the network on which the new devices are deployed. The same argument is true, to a lesser extent, for software support systems.

Ironically, these issues are less true for the vendor relationship where a wholesale bandwidth provider offers commodity transport for a retail provider. "A bit is a bit is a bit" as the saying goes, and it is easier from an operational viewpoint to change wholesale vendors. On the other hand, the geographically uneven availability of bandwidth provides fewer vendors from which to select, especially for metropolitan fiber.

Mass-Market Consumers

The above issues are less true for mass-market services. Long distance POTS and related services are commodities, with easily characterized, and slowly changing, quality of service. In this case, it is the sophistication of the customer that is most in question. Determining the quality of service of a phone carrier is not everyone's favorite thing to do, even if failure in that service potentially affects the quality of life of the customer more than he might first imagine. But the price of diversification is trivial with the availability of phone cards and equal access to alternative vendors via 1-0-NXX carrier select codes. The same argument is true for satellite broadcast, ISPs, and cellular carriers.

The lack of alternative vendors in the local market makes the question of vendor diversity moot. This lack of competition for the local market POTS is an acknowledged problem at the federal level and was the target of legislation in 1996 to reduce the barriers to entry for new entrants into the local market. It is also true for cable services, which provide the only meaningful near-term wireline alternatives to RBOCs in the local loop. On the other hand, wireless services provide a technologically diverse POTS-equivalent service offering for the local markets.

Private Networks

There is little difference in the problems faced by private network designers and retail telco marketers when diversifying across vendors. In both cases, the number of meaningful options and the operational cost of diversification are large enough to create a significant barrier-to-entry for other vendors. This is somewhat lessened when vendor diversity is designed up-front into the original design. The engineering costs in making mistakes in diversifying are smaller for most private networks, but the revenue impacts are greater. This means that provisioning parallel vendor-diverse networks is more feasible and desirable for private networks than for retail networks.

Change Communications Technologies

Wholesale Providers

The migration of domestic communications from satellite and microwave to fiber was driven by service quality and marginal cost concerns and has taken well over a decade to occur in both long-distance and local markets. Any technology changes would be an acceleration or deceleration of future potential trends; firms would not go back to satellite for Continental United States (CONUS) communications, for example. Any migration to a broadband wireless option (e.g., some sort of adaptive 802.11b or ultrawideband [UWB] networking for technology diversity) would take at least as long. The other technology option for wholesale would be a layer 2/3 technology like IP-on-fiber or Gigabit Ethernet, which would also be a several-year undertaking.

Post-9/11 follow-up: *The above speculation seems to be proven post-9/11. There has been no clamoring for a new Internet or accelerated implementation of satellite phones, or any other technology, outside of proven normal business needs. The lessons of 9/11, as reflected in changes in the IT investment strategy of the United States, focus on increased concerns over security, rather than robustness. But this was already a leading interest for IT even before 9/11, as a result of a series of well-publicized cracker attacks.*

Retail Providers

The migration to IP-based services from circuit-switched, and from wireless to wireline, would be the major technology moves expected for retail. Again, this would be acceleration or deceleration of current trends.

Private Networks

We would expect private networks to more quickly take advantage of technology change, since this would involve new purchases rather than new technology development. If a new technology would provide enhanced value after some major event or change, the adoption of such a technology would be accelerated. Again, it would follow the natural trajectory of technology advances: moves to all-optical, wireless over wireline, packet over circuit.

Post-9/11 follow-up: *The development and deployment of a more robust private network to support the NYSE and associated brokerage houses within a year of the 9/11* *aftermath is an example of such a response. The peak in demand for videoconferencing observed in the weeks and months after 9/11 are a nearer-term example. This latter trend has continued to be observed after events such as the Severe Acute Respiratory Syndrome (SARS) outbreaks [110].*

Mass-Market Consumers

The accelerated use of new technologies would also be expected by the mass market. For example, after a disaster like the World Trade Center, cellular or broadband wireless services might be in greater demand by those whose wireline services were cut. It is unclear whether the inertia from the sheer size of the consumer market would make new technology adoption slower than would the integration requirements of a commercial private network. Equipment and bandwidth shortages are more likely if the mass market tries to quickly adopt, as compared to the commercial sector.

Change Business Processes To Be Less Sensitive to Service Outages

Wholesale and Retail Providers

There is little opportunity to apply this sort of business-process re-engineering approach when your revenue stream comes directly from offering communications services. The only real option from a business standpoint would be diversification of the corporation outside of telecommunications services. This is a real option, though, if the long-term view suggests that reliable communications are more difficult to provide and higher in cost. That is unlikely to be the case under small, marginal changes in network reliability.

Mass-Market Consumers

The ability of the “average consumer” to change his or her lifestyle to be less sensitive to communications services is dependent upon the consumer’s particular lifestyle. A telecommuter with a Small office Home office (SoHo) is probably more dependent than a retired couple on communications services, although the Internet may provide the latter with a wealth of entertainment options. The question is the need for *immediate* information updates by the average consumer. There are enough broadcast, cable, and CD/VHS/DVD entertainment options to keep most consumers entertained. And with the wealth of technology options available, even residential customers have a choice of cellular voice, cellular data, the Internet, even satellite voice, in addition to just POTS. So it is unlikely any major lifestyle changes, other than buying such technologies, would be pursued.

But industries that operate on fast production cycles, as well as social and family networks that need to be maintained, often require the consumer to have access to immediate point-to-point information for which there are no alternatives to modern communications technology. Air-freight services, carrier services, and mail services provide a competitive alternative for the distribution of information in one to three days and can cover a significant part of the demand, albeit in a less efficient way. Fortunately, there are so many point-to-point options available (cellular, wireline and Internet, even satellite, along with creative uses of broadcast media) that the likelihood such options must be pursued would be vanishingly small, even during localized major events like the World Trade Center during 9/11.

Private Network Designs

This is the area where alternatives to reliability communications are the most likely to be found. Since communications performance has improved so dramatically over the last couple of decades or more, the trend has been to exploit these exponential improvements to make business processes more dependent on reliable communications. There is probably a division that can be made between those industries that are dependent upon communications for their revenue and those industries that are less dependent.

There is no practical way to use existing microeconomics models to determine this sort of partition. Common-sense understanding of the nature of the business and the engineering issues underlying it can probably provide such a first-order partition. But there must be some creativity applied in the analysis. For example, consider national TV broadcast channels. If they only distributed information to local broadcasters via fiber links and those fiber links failed, one would assume a short-term loss in revenues. But in the mid- and long-term, producing DVDs that contain the content that would normally be broadcast, combined with a mail service and consumer availability of DVD units, would allow equivalent consumer access to the entertainment and perhaps even enhanced revenues to the distribution channels.

Post-9/11 follow-up: *An additional complication occurred during 9/11 that limits the re-engineering of business processes to make them more robust to telecommunications failures. There was a major shutdown of air traffic during the aftermath of 9/11 that, combined with greatly reduced demand in the weeks and months following the event, limited the ability to substitute air passenger travel and freight for telecommunications.*

Telco Behaviors after Telco Outages

The threshold that must be exceeded before telecommunications firms react to an individual outage event is much higher than the threshold that exists for consumers. First, telecommunications networks have a greater and more carefully provisioned robustness to outages; therefore, a better restoration process is in place for telecommunications networks than for most services. Second, whereas many customers can simply change carriers, a telecommunications carrier’s response is to re-engineer a system, which is a much larger undertaking. And third, the inertia to improve system robustness is exacerbated by the relative lack of financial penalties felt by carriers that provide less than stellar service to customers. Financial penalties for poor service simply do not exist for any but the very largest consumers of telecommunications services. Thus it takes a demonstrated loss of long-term revenue to occur, e.g., after a large number of customers leave a carrier, before any significant engineering improvements could be justified economically.

In the months following 9/11, security concerns have led to a reduction of information that is publicly available about individual telecommunications network improvements stimulated by those events, so we will not be able to comment on long-term carrier responses to 9/11.

Diversify Equipment, Routing, Etc.

This sort of action is normally stimulated by the availability of new technologies more than by economic advantages to the carriers. Often, customers undervalue reliability and robustness until an event occurs, so enhanced revenues cannot be used to justify the deployment of robust technologies. When a major failure occurs, that changes, at least for the customers affected.

The greatest challenge to providing diverse services is in the deployment of a suite of fiber routes rich enough to support diverse routing at a metropolitan level and in those more sparsely populated portions of the country. As mentioned previously, building these routes has a high initial cost and lead times of many months to a few years.

Choose Alternative Suppliers or Diversify Supplier Base

Changing suppliers is a larger decision with a longer lead time for telecommunications firms than it is for consumers. Often, price breaks are given to large purchasers of equipment of a single vendor’s equipment or services. Also, operations and training costs increase dramatically with the introduction of a new supplier’s products. This is a strategic IT decision and, as such, has long lead times on the order of months or years. The smaller the company, the faster such decisions are generally made. If, for example, a frame relay network goes down, companies have turned to alternative suppliers to provision ISDN lines in a matter of hours or days.

Design New Restoration Schemes

There has been no known case of a new restoration scheme being developed in the near term as a response to a major outage. Such schemes require a few years of planning and implementation, usually including new hardware and software features, before they are introduced.

Offer New Robust Services

These services can be implemented on an ad hoc basis relatively quickly (weeks to months) for large customer networks if there is evidence that there is a public health and safety concern or if there is a threat the customers will take their business elsewhere. Carrier-wide service offerings involve longer lead times (months to years) to ensure that general availability and proper pricing are offered. Maintaining the robustness of those services is often a sticking point, with limited assurance that a service that, say, provides a diverse routing will maintain that diversity as the network changes over time.

Offer Financial Rebates

There is often an offer after a major outage not to bill customers for the amount of time the service was actually not provided. This is small comfort for most large customers, as well as some smaller ones, who either lose revenue or an ability to respond to some local event that far exceeds the prorated cost of the service. Although the cost estimates of outages cited previously vary over a wide range, it is clear that for some industries the lost revenue under any interpretation exceeds costs by orders of magnitude.

Some SLAs over the last few years have started including financial penalties proportionate to the financial damages suffered by the customer. These have been successfully negotiated by the largest customers first, but are trickling down to some smaller customers as well. There are few figures available on the penetration of SLAs in the marketplace, but these agreements are growing. *The lack of a clear linkage between the quality of service provided by carriers and the financial penalties the customer base experiences as a result of the provided quality of service is probably the major problem facing any economic model of the telecommunications sector modeling the impact of outages.*

New Entrants and Technologies To Improve Reliability

This issue warrants a paper all on its own. The collapse of the vast majority of new start-ups that were stimulated by the success of the Internet, both the dot-coms and the carriers that were hoping to carry all that new Internet traffic, and the vendors selling equipment to those new carriers have been the subject of several recent books. The telecommunications industry is in a consolidation-and-convergence mode, and new start-ups will be hard-pressed to obtain the venture capital and customer base to ensure their continued survival. Thus we probably cannot count on the availability of new start-ups to offer options for relieving major quality-of-service concerns such as reliability. Even CLECs continue to struggle, and they have received major stimulus from the government and only attempt to compete on POTS traffic. Combined with the lack of appropriate feedback on the quality of service of today’s large carriers, this suggests a potential problem that could lead to service degradation over time with little an individual customer can do to address the issue.

There are rays of hope. One is the fact that many, if not most, new technologies are inherently more robust, e.g., packet, or can be made so with modest incremental investments, e.g., incremental bandwidth on fiber for diverse routing or restoration capabilities, cellular services as a cheap and widely available backup to wireline voice service. And as the costs of these technologies follow Moore’s law, especially wireless, the simple option of purchasing two technology-diverse options becomes more acceptable. This argues that technology policy, rather than economic policy, still dominates the dynamics of sector changes in telecommunications.

In spite of the above argument that suggests more robust telecommunications service options will naturally evolve from current technology trends, meeting stringent reliability standards will still be a practical challenge in the foreseeable future

- for high-bit rate connectivity (OC-3 and above) where there are no alternative diverse fiber-routing options available and little economic incentive for carriers to provide such, and

- where ultrahigh reliability standards must be maintained for services dependent on multiple suppliers, many of which do not have the proper economic incentives to meet required reliability standards.

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