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Report to the Subcommittee on Antitrust, Business Rights and Competition, Committee on the Judiciary, U.S. Senate

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TELECOMMUNICATIONS

Characteristics and Competitiveness of the Internet Backbone Market

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Accountability ★ Integrity ★ Reliability

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Contents

Abbreviations

ARIN	American Registry for Internet Numbers
CIDR	Classless Inter-Domain Routing
DOJ	Department of Justice
DSL	Digital Subscriber Line
FCC	Federal Communications Commission
IP	Internet Protocol
ISP	Internet service provider
NAP	network access point
NRIC	Network Reliability and Interoperability Council
NTIA	National Telecommunications and Information Administration

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Accountability ★ Integrity ★ Reliability

United States General Accounting Office
Washington, D.C. 20548

October 16, 2001

The Honorable Herbert Kohl
Chairman
The Honorable Mike DeWine
Ranking Member
Subcommittee on Antitrust, Business Rights
and Competition
Committee on the Judiciary
United States Senate

While most Americans are familiar with Internet service providers (ISP)—such as America Online or EarthLink—that provide consumers a pathway, or "on-ramp," to the Internet, many are less familiar with Internet backbone providers and the operations of backbone networks. At the core of the Internet—a vast network of interconnected networks—many high-capacity, long-haul "backbone" networks operate in a somewhat paradoxical context. Routing data traffic over long distances using high-speed fiber lines, Internet backbone providers both compete in the marketplace and cooperate in the exchange of data traffic. The cooperative exchange of traffic among backbone providers is essential to ensure that the Internet remains a seamless and widely accessible public medium. Because of your interest in the functioning and competitiveness of the Internet backbone market, you asked us to report on (1) the physical structure and financial arrangements for traffic exchange among backbone providers, (2) the nature of competition in the Internet backbone market, and (3) how this market is likely to develop in the future.

To respond to your request, we interviewed representatives of backbone companies, Internet service providers, other large users (such as corporations and universities) that purchase backbone services, and a local telephone company. In addition, we interviewed academic experts, representatives of relevant trade associations, and officials from the Federal Communications Commission (FCC), the National Telecommunications and Information Administration (NTIA) of the Department of Commerce, and the Antitrust Division of the Department of Justice (DOJ).

Results in Brief

Interconnection among Internet backbone providers—fundamental to the global connectivity of all Internet users—varies both in terms of the physical structure and financial arrangements of data traffic exchange.

The physical structure of interconnection takes two forms: (1) the exchange of traffic among many backbone providers at a “network access point”—a common facility—and (2) the exchange of traffic between two or more backbone providers at “private” interconnection points. Once viewed as an efficient way for multiple backbone providers to exchange traffic, network access points became increasingly congested and service quality deteriorated as Internet use and traffic flows increased in the 1990s. Backbone providers thus began to bypass these congested exchange points and establish “private” interconnections in many types of locations. According to many backbone providers with whom we spoke, the majority of their traffic is now exchanged through private interconnections. There are also two types of financial arrangements for interconnection among backbone providers: “peering” and “transit.” In a peering relationship, two providers agree to exchange traffic destined only for each others’ networks. This usually happens free of charge. By contrast, a transit arrangement entails the payment by one provider to another for the transmission of traffic between the two providers and for delivery of traffic to other providers. Although most traffic was initially exchanged under peering agreements, the largest backbone providers now generally only peer with other large providers and charge transit fees to smaller backbone providers and other customers.

No publicly available data exist to allow a precise economic evaluation of the competitiveness of the Internet backbone market. However, the industry participants we interviewed generally viewed the backbone market as competitive. Several companies that purchase backbone connectivity stated that the market has become more competitive in the last few years. In particular, they noted that the price of backbone connectivity has declined, and the ability of purchasers to negotiate other favorable contract terms has improved. Despite this generally favorable view of the market, some companies noted that only a handful of backbone providers (often called the “Tier 1” providers) have networks with extensive geographic scope and peering relationships with other large providers. Some companies that purchase backbone connectivity also noted that they consider themselves tied to their original backbone provider because they obtained Internet addresses—numeric codes specifying each user’s network location—from one provider and changing providers requires a disruptive “readdressing” of their networks. Finally, many companies noted that Internet connectivity is dependent not only on services from backbone providers, but also services from local telephone companies. We were told by companies we interviewed that limited choice for providers in a separate but necessary market—the market for local telephone providers—creates problems for providers of Internet service. On the other hand, a representative of one incumbent local telephone company we spoke with stated that there is growing competition in the local telephone market as evidenced by the recent finding of the FCC that lines served by competitors nearly doubled in 2000 to 8 percent of all local access lines.

Future evolution of this market is likely to be largely affected by two types of emerging services. First, demand is likely to increase for time-sensitive applications, such as Internet voice service. Second, it is expected that more "broadband"—bandwidth-intensive—content, such as video, will flow over the Internet in the coming years. Industry participants we interviewed were generally optimistic about the private sector's ability to address the need for "quality of service" routing—that is, dealing with the delivery of time-sensitive traffic across backbone networks. Similarly, industry participants were also optimistic that the capacity of backbone networks will be sufficient to support the delivery of broadband content. Many of the officials we interviewed were concerned about the availability of necessary infrastructure in the local telephone networks to support the delivery of broadband content. One local incumbent telephone company we spoke with noted that broadband service is being aggressively rolled out in local markets.

This report makes a recommendation that the FCC periodically evaluate whether existing data collection efforts are providing needed information on the Internet backbone market and, if deemed appropriate, exercise its authority to establish a more formal data collection program.

We provided a draft of this report to FCC, NTIA, and the DOJ for their review and comment. FCC and NTIA officials stated that they were in general agreement with the facts presented in the report. Technical comments provided by FCC, NTIA, and DOJ officials were incorporated in this report as appropriate.

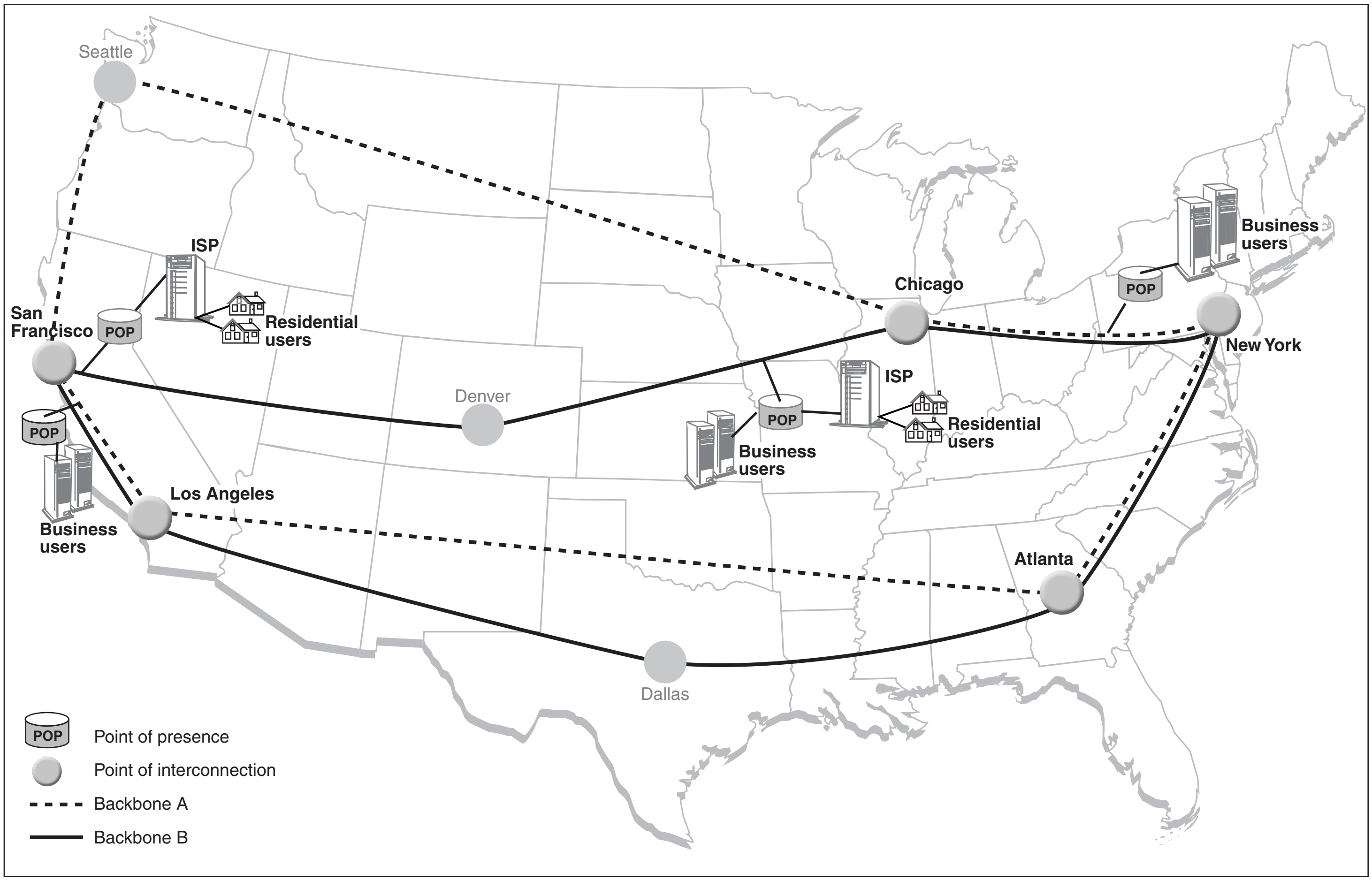
Background

To access the Internet, most residential users dial in to an ISP over a telephone line, although other physical means of access to the Internet[1]—such as through a cable television line—are becoming increasingly common.[2] For a residential customer, the ISP sends the user's Internet traffic on to the backbone network. To perform this function, ISPs obtain direct connections to one or more Internet backbone providers. Small business users may also connect to a backbone network through an ISP, however, large businesses often purchase dedicated lines that connect directly to Internet backbone networks. An ISP's traffic connects to a backbone provider's network at a facility known as a "point of presence." Backbone providers have points of presence in varied locations, although they concentrate these facilities in more densely-populated areas where Internet end users' demands for access are greatest. If an ISP or end user is far from a point of presence, it is able to reach distant points of presence over telecommunications lines. Figure 1 depicts two hypothetical Internet backbone networks that link at interconnection points and take traffic to and from residential users through ISPs and directly from large business users.

[1]The Internet was established through the funding of experimental research and educational networks by various federal agencies beginning in the late 1960s. Private sector companies began investing in long-haul data networks in the early 1990s and by the mid-1990s private firms came to manage backbone infrastructure originally funded by the government.

[2]For an in-depth discussion of consumers' access and use of the Internet, see *Telecommunications: Characteristics and Choices of Internet Users* (GAO-01-345), February 2001.

Figure 1: Hypothetical Internet Backbone Networks With Connections to End Users



Once on an Internet backbone network, digital data signals that were split into separate pieces or "packets" at the transmission point are separately routed over the most efficient available pathway and reassembled at their destination point. The standards that specify most data transmissions are known as the Internet Protocol (IP) Suite. Under part of this protocol, streams of packets are routed to their destination over the most efficient pathway. Other aspects of the protocol facilitate the routing of packets to their appropriate destination by examining the 32-bit numeric identifier—or IP address—attached to every packet. Currently, IP addresses for North America are allocated by the American Registry for Internet Numbers (ARIN).[3]

There are many Internet backbone providers offering service in the United States. *Boardwatch*—an industry trade magazine—reports 41 backbone providers with a national network[4] and many other regional backbones. Approximately five to eight of these national providers are considered to be "Tier 1" backbone providers.[5] A Tier 1 provider is defined by *Boardwatch* as having a network of wide geographic scope, having a network with many IP addresses, having extensive information for traffic routing determinations, and handling a large percentage of transmissions.

[3]ARIN is a nonprofit entity that provides for registration of IP numbers for North America, South America, the Caribbean, and sub-Saharan Africa. ARIN is one of three regional Internet Registries that collectively provide registration services to all regions of the world.

[4]*Boardwatch* identified 41 national Internet backbone providers as of July 2001. A national backbone is defined by *Boardwatch* as having three characteristics: points of presence in at least five states; four national public peering agreements; and a marketing focus on selling wholesale, high-bandwidth dedicated connections to ISPs. *Boardwatch* also considers whether a backbone network crosses the country to reach both coasts.

[5]There is no definitive list of Tier 1 providers. FCC's Office of Plans and Policy Working Paper, *The Digital Handshake* (2000), identifies five Tier 1 providers. Some other sources report a higher number.

Unlike telecommunications services, the provision of Internet backbone service is not regulated by governmental communications agencies. Dating back to the 1960s when data signals began to flow over public telephone networks, FCC determined that "basic services"—the *physical transport* of data over telephone networks—would be regulated, but "enhanced services"—the *data-processing or computer-enhanced functions* of data transmissions—was a vibrant and competitive market that should remain free of regulation. Congress maintained this distinction when it enacted the Telecommunications Act of 1996, terming these services "telecommunications" and "information," respectively.[6] No provisions were contained in the 1996 act pertaining to Internet backbone services; rather, the act sought to increase competition in other communications sectors, primarily the local telephone market. However, the treatment of these more established communications services and infrastructures under the Communications Act of 1934—as amended by the 1996 act—has indirectly affected the burgeoning Internet medium.[7] Additionally, the act provided FCC and states the authority to take actions to encourage the deployment of advanced telecommunications capability.[8]

Facilities and Financial Arrangements of Interconnection Among Backbone Providers Vary

Two types of facilities are used for the exchange of data traffic by interconnected Internet backbone providers. The first type of facility, known as a "network access point" (NAP), enables numerous backbone providers to interconnect with each other at a common facility for the exchange of data traffic. Internet data traffic is also exchanged by backbone providers at "private" interconnections. Independent of the type of facility at which backbone providers exchange traffic, two different types of financial arrangements exist among backbone providers for traffic exchanges. In a "peering" relationship, backbone providers exchange data destined only for each other's network generally without the imposition of a fee. Transit payments, which involve the payment by one backbone

[6]FCC has determined that the term "information services" contained in the 1996 act is broader than and encompasses "enhanced services." In a 1998 report to Congress, FCC determined that the provision of "pure transmission capacity" to Internet backbone providers is a telecommunications service.

[7]Several aspects of laws and regulations governing the telephone network are thought to have nurtured the growth of the Internet. For a discussion of this topic, see our recent report *Telecommunications: Technological and Regulatory Factors Affecting Consumer Choice of Internet Providers* (GAO-01-93), Oct. 2000.

[8]This authority was granted in section 706 of the Telecommunications Act of 1996.

provider to another for the mutual exchange of traffic and for the delivery of traffic to other providers, have become more common with time.

Internet Data Are Exchanged Among Backbone Networks at Two Types of Interconnection Facilities: NAPs and Private Interconnection Points

A NAP facilitates the interconnection of multiple backbone providers.[9] In the early to mid-1990s, the National Science Foundation designed and partially funded four NAPs, each of which was managed by a different company. Since that time, other interconnection points have been constructed, and for purposes of this report, the term NAPs refers to approximately 10 major traffic exchange points that host backbone providers.[10] Managed by different companies, NAPs are not uniform facilities; differences exist in terms of equipment, software, and data transmission rates.

Although most backbone providers we interviewed use the NAPs, a few providers voiced concerns about them. In the first years of their existence, NAPs became congested with the rapid rate of growth in Internet traffic. Two of the providers with whom we spoke said that some NAPs were not well managed. Also, originally some NAP technology was not "scalable"—that is, beyond some level, it was very costly to increase the amount of traffic that could be exchanged at a NAP. If traffic exchange at a NAP became congested, service quality could be compromised. Two typical problems that congestion causes include latency (delay in the transmission of traffic) and packet loss (when transmitted data are actually lost and never reach their destination).[11] For example, one backbone provider told us that the loss of packets at some NAPs had sometimes reached 50 percent.

[9]NAPs are commonly referred to as "public" interconnection points, even though no governmental entity is involved in administering these facilities. A provider need not connect to every other provider at the NAP.

[10]In addition to the NAPs, there are many other Internet traffic exchange points at which multiple providers meet. There is now a blurring between these collocation facilities and NAPs. Many of these traffic exchange points are smaller facilities that host local ISPs and businesses along with smaller backbone providers.

[11]When data packets are lost they should be resent; and while a user is not aware that this has occurred, he or she will experience slower responses due to this loss.

The congestion and poor quality of connections at the NAPs led backbone providers to engage in another type of traffic exchange known as "private interconnection." Private interconnection refers to the exchange of traffic at a place other than a NAP. Usually, these private interconnections involve two companies entering into a bilateral agreement to exchange traffic; no third party manages the traffic exchange. [12] The parties interconnect their networks at any feasible location, such as a facility of one of the providers.[13] Because of the private nature of these agreements, the number of private interconnections that currently exist across the United States, according to one company representative, is not known.

Despite a variety of technological developments that have improved traffic flow at NAPs,[14] we found that for the providers we interviewed, the majority of Internet traffic exchange occurs at private interconnection points. Of 17 backbone providers with whom we spoke,[15] 15 used both NAPs and private interconnections; the remaining 2 used only private interconnections, avoiding the NAPs entirely. Slightly more than half of the 15 providers using both NAPs and private interconnection said they exchanged more than 80 percent of their traffic at private exchange points. Of the 17 companies that we met with, 10 provided estimates of how their mix of private interconnection and NAP use would likely change in the future. Nine of the 10 stated that they either plan less use of NAPs in the next few years or do not see their mix of NAPs and private interconnection changing; only one company said that it was likely to make greater use of NAPs in the future.

We found that some Internet backbone providers value several features of NAPs. For example, when a company interconnects at a NAP, it saves on

[12]However, three or more companies could decide to establish a private interconnection arrangement.

[13]Third-party locations are also now being made available for private interconnection among backbone providers. For example, one industry representative described a private interconnection arrangement on the premises of a video store.

[14]For example, beginning in 1998, NAP administrators began augmenting the original technology employed at NAPs—Fiber Distributed Data Interface (FDDI)—with Asynchronous Transfer Mode (ATM) switches to ease the problems of dropped and delayed packets. More recently, optical switches are being deployed at NAPs. Congestion should be further relieved by the construction of new NAPs.

[15]This analysis does not include one backbone provider with whom we spoke that was not yet providing service.

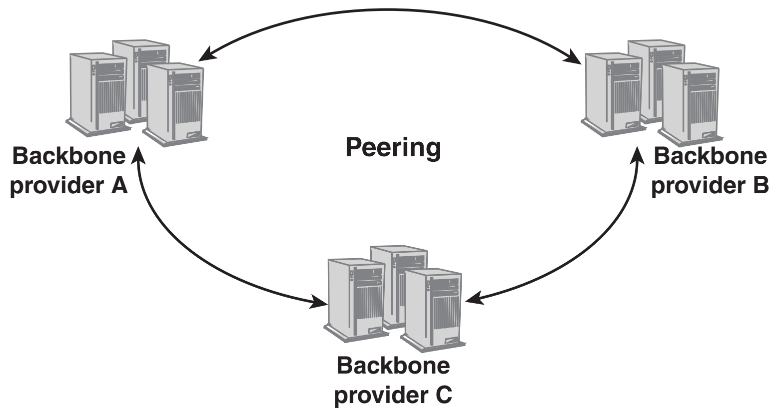
equipment costs and administrative overhead. Representatives of two companies with whom we spoke noted that the NAPs play an important role in helping to keep the market for backbone service open for entry, and thus more competitive, because NAPs provide new backbone firms an efficient, low-cost method for exchanging traffic with numerous other providers.

Interconnection Among Internet Backbone Providers Occurs Under Two Types of Financial Arrangements: Peering and Transit

When the commercial Internet began, only a few major backbone providers of relatively similar size existed, each of which sent and received roughly equal amounts of traffic. The similarities among these backbone firms led them to view each other as "peers." These providers elected to exchange traffic for free, rather than trying to measure the actual traffic exchanged and developing a payment method. In a peering arrangement, two backbone providers agree to exchange traffic destined only for each others' networks.[16] As depicted in figure 2, the peering agreement between backbone provider A and backbone provider B only covers traffic going from A's network to B's network and vice versa. For backbone A to move traffic to backbone C's network under peering, it must have a peering agreement directly with backbone C.

[16] A distinction is sometimes made between "public peering"—the mutual exchange of data traffic without payment at NAPs—and "private peering"—the mutual exchange of traffic without payment at private points of interconnection.

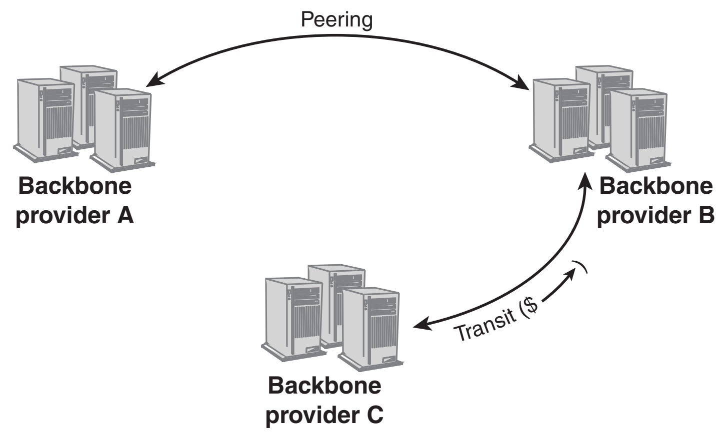
Figure 2: Movement of Internet Traffic in Peering Relationships Among Backbone Providers



By the mid to late-1990s, another financial arrangement known as "transit" emerged. Transit and peering are distinctive in two key respects. First, while peering generally entails traffic exchange between two providers without payment, transit entails payment by one provider to another for carrying traffic. Transit agreements thus constitute a supplier-customer relationship between some backbone providers, much like the relationship between a backbone provider and a nonbackbone customer (such as an ISP). Second, when a backbone provider buys transit from another provider, it obtains not only access to the "supplier's" backbone network, but also access to any other backbone network with which its supplier peers. Regarding physical locations, however, both transit and peering take place at NAPs as well as at private interconnection points. Currently, there is a segregation of backbone providers into "tiers." The top tier or "Tier 1" providers generally peer with each other and sell transit to smaller backbone providers. However, we found that smaller providers often peered with each other and were able, in some cases, to peer with larger providers.

The illustration in figure 3 shows backbone provider C as a transit customer of backbone provider B and backbone providers B and A as peers. In this case, traffic originating on backbone C can get to backbone B's network as well as to that of backbone A (with which backbone C does not have an independent relationship) because B will pass C's traffic off to A as part of its delivery of transit service to C. Thus, a smaller backbone provider generally need only buy transit from one or two large providers to achieve universal connectivity.

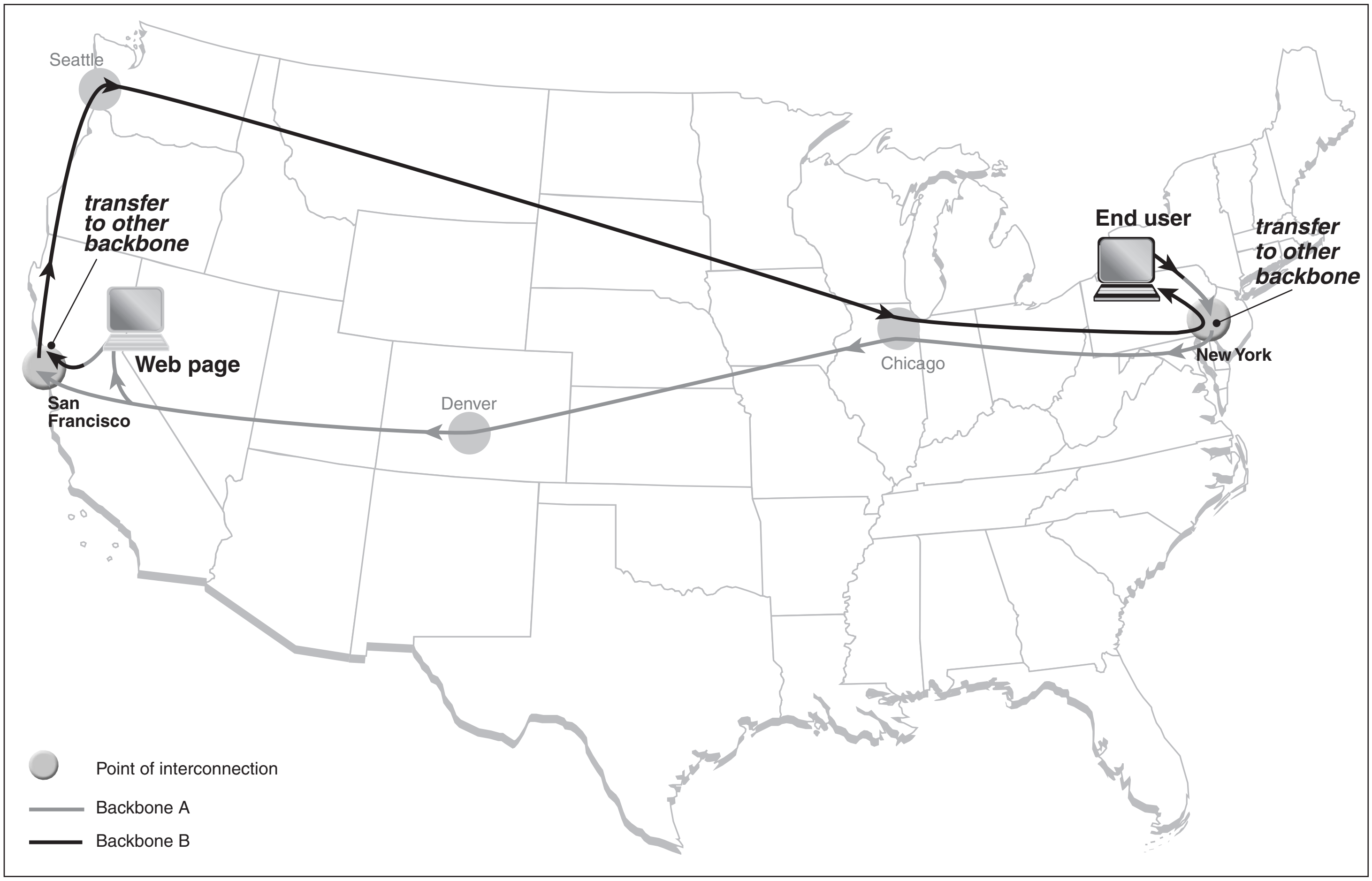
Figure 3: Movement of Internet Traffic in Transit and Peering Relationships Among Backbone Providers



We found that it is generally not viewed as economical for a backbone provider to peer with a less geographically dispersed backbone provider. Thus, even if there were equal traffic flows, the larger provider will tend to carry traffic a further distance—which, according to a larger backbone provider we spoke with, ultimately means more costs are imposed on its infrastructure—when it peers with a provider with a smaller or less widely dispersed network.

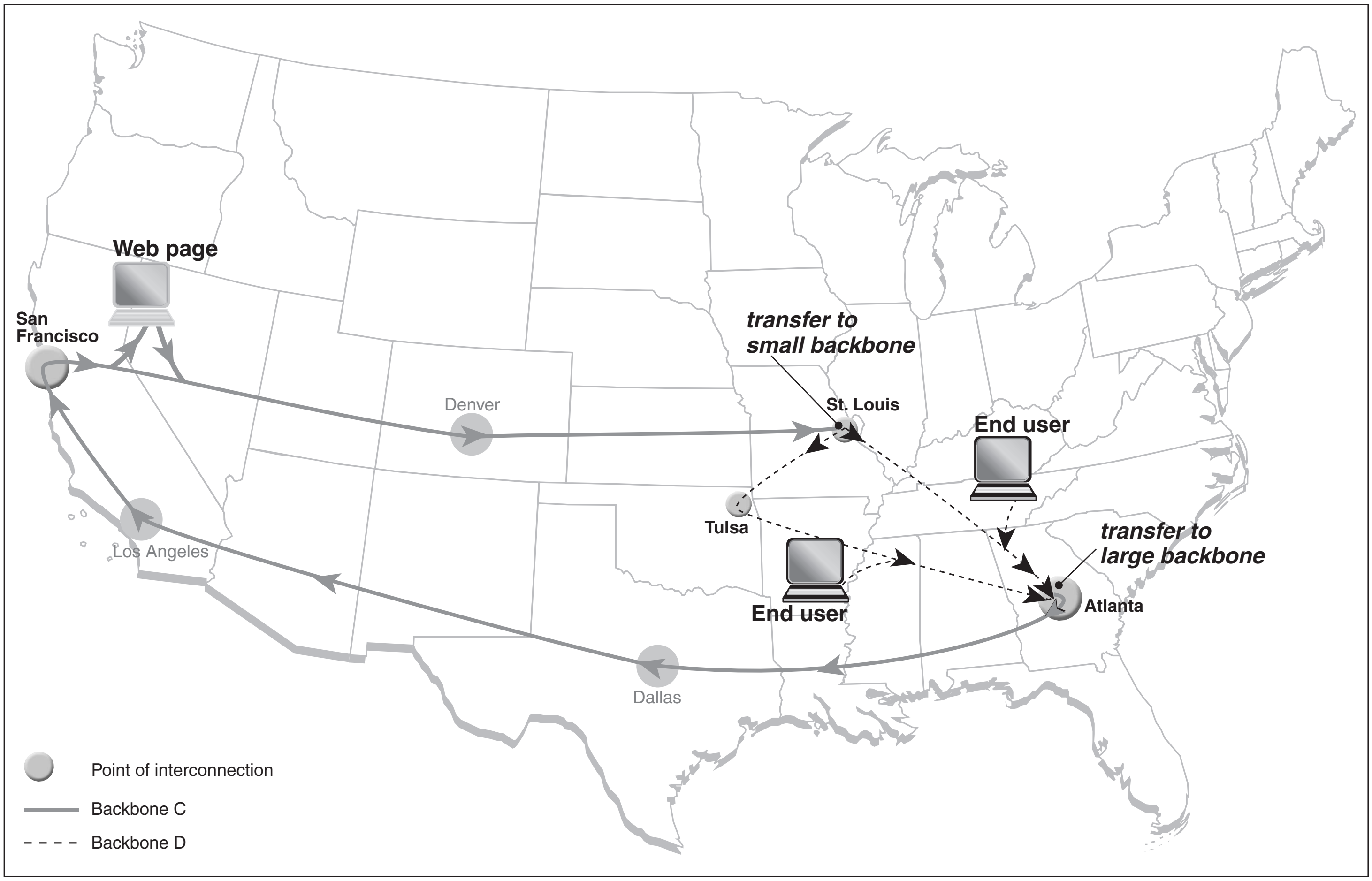
Figures 4 and 5 illustrate this paradigm. In figure 4, backbone providers A and B are of similar size, and traffic between the two could be carried mostly by one backbone provider in one direction, but mostly by the other in the opposite direction.

Figure 4: Routing of Internet Traffic Among Comparably Sized Backbone Providers



In figure 5, backbone provider D is smaller than backbone provider C, with more limited points at which traffic can be brought onto the network. When backbones C and D exchange traffic, C must carry the traffic much farther on the return path before it can hand off the data packets to D. Therefore, C might consider D to be benefiting from C's network investment and thus, C would be more likely to view D as a customer purchasing access to its network than as a peer in traffic exchange.

Figure 5: Routing of Internet Traffic Among Differently Sized Backbone Providers



The “tiering” of Internet backbone providers and the dual system of peering and transit agreements have caused controversies. Several of the non-Tier 1 backbone providers with whom we spoke expressed concerns about their inability to peer with the largest providers. In particular, we were told that the inability of non-Tier 1 providers to peer with Tier 1 providers puts smaller companies—which must therefore purchase transit service—at a competitive disadvantage. We were also told that peering policies should be made public.

To some extent, market forces may be relieving some of these problems. First, despite the view that smaller providers have no choice but to buy transit, some backbone providers with whom we spoke stated that the market is competitive, and transit rates have been decreasing. Second, eight of the backbone providers with whom we spoke (some of which were Tier 1 providers and some of which were not) said they already had posted or soon would be posting their peering policies on their Web sites or otherwise making them publicly available.[17]

Perhaps most interesting, we found that some non-Tier 1 backbone providers do not want to peer with the largest backbone providers. For example, one provider spoke critically of the quality of peering connections and the quality of service provided between peers. Some stated that it is difficult to guarantee their own clients a certain level of service if they receive few guarantees themselves—a common occurrence under peering. Transit customers, however, do contract for a specified level of service for such items as "uptime"—the functioning of a network without impairment or failure.

Despite Competitiveness of the Backbone Market, Various Concerns Exist

No official data sources were identified that would provide information on the structure and competitiveness of the Internet backbone market. Market participants we interviewed—Internet backbone providers, ISPs, and other end users—described the Internet backbone market as competitive. Several characteristics were described by market participants, such as increasing choice of providers and lower prices, as evidence of the competitiveness of the market. However, officials also described to us factors that may reduce competition in this market or cause other problems, such as the limited number of Tier 1 providers, the limited choice of providers in rural areas, the manner in which Internet addresses are assigned, and the lack of control or knowledge about the movement of traffic across backbone networks. We were also told that the choice of local telephone companies providing access to Internet backbone

[17]Making Internet backbone providers' peering policies publicly available has been recommended by the current Network Reliability and Interoperability Council (NRIC), a federal advisory committee that serves to develop recommendations for the FCC and the telecommunications industry to assure optimal reliability, interoperability, and interconnectivity of, and accessibility to public telecommunications networks. Originally formed in 1992 and in its fifth term, NRIC V is comprised of senior representatives of providers and users of telecommunications services and products.

networks may be limited, creating problems for providers of Internet services.

Little Economic Data Are Available on Internet Backbone Networks

We found no official data source that could provide information to allow an empirical investigation of the nature of competition in the Internet backbone market. In particular, we found little in the way of official or complete information on the relative size of companies—even the largest companies—operating in the market. Neither FCC nor NTIA collect data on the provision of Internet backbone services.[18] However, FCC does solicit public comments on the deployment of underlying telecommunications infrastructure that support backbone services for their report on advanced telecommunications capabilities under section 706 of the Telecommunications Act of 1996.[19] DOJ often collects data for merger-specific analyses—as it did in two cases that involved an assessment of backbone assets—but such data are not publicly available. We also found that neither the Bureau of Labor Statistics nor the U.S. Census Bureau currently collects data directly on Internet backbone providers. In the case of both of these agencies, aggregate data on services provided by telecommunications providers is collected.

[18]In 2000, FCC discontinued a voluntary annual survey of telecommunications providers on the deployment of fiber optic facilities and capacity. We asked FCC whether it has the authority to collect data on capacity, traffic volumes, other economic indicators, as well as on outages, from Internet backbone providers. In a letter signed by FCC Chairman Michael Powell to Susan A. Poling, Associate General Counsel, U.S. General Accounting Office (July 17, 2001), FCC stated that "The Commission has the legal authority to collect data relevant to its regulatory mission. That mission covers 'all interstate and foreign communication by wire or radio'…." The letter also noted that "the Commission has authority to collect information about communications-related aspects of the Internet if necessary."

[19]On the basis of nearly unanimous public comment, FCC determined that it would not monitor or exercise authority over peering arrangements of Internet backbone providers, as stated in its section 706 report on the deployment of advanced telecommunications capabilities in January 1999. Further, FCC recognized that "'[t]he Internet and other interactive computer services have flourished, to the benefit of all Americans, with a minimum of government regulation' and that it is the policy of the United States to preserve the vibrant and competitive free market that presently exists for the Internet and other interactive computer services, unfettered by Federal or State regulation….'" CC Docket No. 98-146, January 28, 1999, at paragraph 105.

Internet Backbone Market Appears Competitive; Many Market Niches Filled

To investigate the degree of competition, we spoke with an array of buyers and sellers of backbone connectivity and asked questions that were designed to provide information about the competitiveness of the market. For example, we asked questions about the availability of choice among providers in the market, the viability of purchasing transport to a distant location to connect to a backbone provider, the length of contracts for backbone connectivity, the types of service guarantees buyers receive from sellers, the ability of buyers to negotiate favorable contract terms, and the factors that were important to buyers when choosing a backbone provider.

Representatives of ISPs and end users we interviewed throughout the country described the Internet backbone market as competitive. Most of these providers stated that they have several choices of backbone providers from which to obtain services. Although a few ISP representatives noted a relatively limited number of companies among the Tier 1 providers, they nonetheless considered the market to be competitive with greater choices across the entire range of backbone providers. Similarly, most non-Tier 1 backbone providers stated that they can purchase transit from a number of Tier 1 backbone providers. A few ISPs and other purchasers of backbone services also noted that the extensive choice of backbone providers enables them to engage in “multihoming”—purchasing backbone services from more than one provider—to provide redundant access that enhances ISPs’ assurances to customers of uninterrupted Internet connectivity.

We found, based on our discussions with ISPs and other purchasers of backbone connectivity, that several characteristics of the market show evidence of its competitiveness. In particular:

- Many ISPs noted that, coincident with increased choice of backbone providers throughout the country, the price of backbone connectivity had declined significantly in recent years.
- Representatives of several companies told us that although they were presented with standard contracts by backbone providers, they were able to negotiate terms and conditions in their contracts that were important to them.
- A few ISP representatives with whom we met said they receive frequent sales calls from multiple backbone providers.
- An ISP representative noted that many backbone providers are working to increase the speed and decrease the latency of transmissions of their networks to improve their competitiveness in the market.

- Even though there have been bankruptcies and consolidation in this market, a few new backbone providers have entered the market in the recent past.
- Some backbone providers are filling market niches by offering customers additional or unique services to complement their backbone services.[20]

Despite Competitiveness of Backbone Market, Several Market Participants Expressed Various Concerns

The majority of market participants with whom we spoke expressed the view that the Internet backbone market is competitive, if not highly competitive. At the same time, many of these respondents noted factors that might be reducing the level of competition or creating other problems in this market. In particular, we were told that (1) a small number of large backbone providers stand out as the premier providers, (2) choice among backbone providers may be more limited in rural areas, (3) ISPs are concerned about the way Internet addresses are assigned to users, and (4) ISPs and other end users are frustrated by their minimal control and understanding about how their traffic moves across Internet backbone networks.

Tiering of Internet Backbone Providers

ISPs and other end users indicated to us a general perception that Tier 1 companies are "different" or superior when compared with other backbone providers. For example, 17 of the 24 ISPs and all 8 of the end users we interviewed purchase backbone connectivity from at least 1 of the 5 Tier 1 backbone providers identified in a recent FCC Working Paper. Similarly, 11 ISPs and 3 end users we interviewed explicitly stated that it was important to them to purchase service from a Tier 1 provider. Finally, many ISPs and end users stated that it was important to them to purchase backbone connectivity from a provider possessing certain network characteristics. Commonly cited characteristics of importance were a network with a broad geographic scope, many customers, significant capacity, and good peering arrangements with other providers. These are all common characteristics of Tier 1 backbone providers.

Because Tier 1 providers are viewed as a special class of backbone providers, the existence of approximately 40 national backbone providers may not fully reveal the competitiveness of this market. Instead, it appears

[20]For example, some backbone providers offer customers an array of services such as Web hosting, collocation, and network security in order to better compete in the market.

that only the 5 to 8 Tier 1 backbone providers are viewed as competitors for primary backbone connectivity. However, most of the ISPs and end users with whom we spoke nonetheless stated that the market is competitive and they have significant choice of provider. It appears that even if the “relevant” market for primary backbone connectivity is the Tier 1 providers, that market segment may be viewed as competitive.

A remaining concern regarding the “tiered” segmentation of the market is the potential for the number of Tier 1 providers to decline or for one of these providers to become dominant. For example, the recent economic downturn in the communications sector may portend a further shakeout of backbone providers. Several of the company officials we interviewed expressed concern that there would be consolidation among the Tier 1 providers and thus noted the importance of antitrust oversight of this industry. Moreover, both an FCC Working Paper and the Antitrust Division of DOJ have noted that in industries such as the Internet backbone market, interconnection among carriers is critical to the quality of service consumers receive. As such, a much larger provider may have less incentive to have good interconnection quality with other providers because without quality interconnection, customers may have an incentive to buy service from the largest provider with the best-connected network. This would give the larger provider a competitive advantage, which in turn could cause the market to “tip”—that is, more and more users would choose connectivity from the larger network—risking a monopolization of the industry. Because of this concern, both agencies have noted that if one of the Tier 1 providers were to grow considerably larger than the rest, there could be competitive concerns.[21]

Companies Purchasing Backbone Connectivity in Rural Areas May Have Fewer Providers From Which to Choose

Members of Congress are often concerned about whether telecommunications services reach rural areas. Several representatives of companies we interviewed noted that there are less Internet backbone facilities running through rural areas and fewer points of presence in those areas. As such, purchasers of backbone connectivity in rural areas may have fewer choices among providers than their counterparts in more urban locations. One point made by two rural providers is that rural areas sometimes have subsidized networks (e.g., state networks or networks

[21]A recent study suggests that “tipping” in the Internet backbone market is unlikely. See David A. Malueg and Marius Schwartz, “Interconnection Incentives of a Large Network,” Georgetown University, Department of Economics Working Paper 01-05.

funded, in part, by governmental subsidy) that may actually discourage private backbone companies from entering and thriving in such markets.

Despite the view that rural areas have fewer choices among backbone providers, most companies we interviewed in rural areas purchased "transport" services to connect to an Internet backbone network.[22] That is, they were able to transmit their traffic over fiber lines, most often owned by one or more local telephone carriers, to a backbone provider's point of presence that was perhaps hundreds of miles away.[23]

Eighteen of the 24 ISPs and 3 of the 8 end users we interviewed used transport from their location to another location for at least some of their Internet traffic. Sometimes transport was used to move data traffic to a nearby city that was not very far away—perhaps 30 to 50 miles. But in some cases—particularly for ISPs in rural areas—traffic was transported a few hundred miles to a point of presence of a backbone provider. The majority of officials from these companies told us that the quality of Internet service is not diminished by transporting traffic across such distances. Because many ISPs and end users told us that distant transport was a viable option for obtaining Internet backbone connectivity, even ISPs and users in more rural areas told us that they generally had choice among backbone providers that could receive traffic at varied distant locations. The one disadvantage of distant transport noted by several providers, however, was cost. Some company officials noted that it generally costs more to purchase transport to a distant location than it does to connect to a backbone at a local point of presence. Two companies specifically mentioned that they had or were planning to move their facilities to more urban locations because of the cost of distant transport.

[22]Purchase of transport to distant locations also occurred among companies located in more urban areas.

[23]Responding to a request by 10 senators, NTIA and the Rural Utilities Service (RUS) issued a report in April 2000—*Advanced Telecommunications in Rural America*—which states that access to Internet backbone networks in rural areas is generally not a significant problem. Similar to our finding, the NTIA-RUS report notes that while dedicated Internet backbone networks primarily connect urban centers, there are many indirect means of access to backbone networks in rural areas, such as over leased facilities or through private connections (p. 9).

Many ISPs and End Users Feel Tied to Their Backbone Provider Because of IP Address Allocations

Several ISPs and end users with whom we spoke expressed concern about the manner in which Internet addresses are allocated. Most ISPs and other end users—except for fairly large organizations—do not directly obtain their own IP addresses, but they instead receive a block of IP addresses from a backbone provider. In particular, when an ISP obtains an Internet *connection* from a backbone provider, it also generally receives a *block of IP addresses* from among the addresses that are assigned by ARIN to that backbone provider.

This method of IP address allocation was adopted for technical efficiency reasons—that is, allocations made in this manner reduce the number of addresses that need to be maintained for traffic routing purposes. (See app. II for detailed information on IP address allocations). While the method of allocating IP addresses in large blocks enables backbone routers to operate efficiently, some of the ISPs and end users with whom we spoke also told us that it makes it difficult for smaller entities to switch backbone providers. In particular, if an ISP were to change its backbone provider, it would generally have to relinquish its block of IP addresses and get a new block of addresses from the new backbone provider. Several ISPs and end users with whom we spoke told us that changing address space can be time consuming and costly. We found that the degree of difficulty in changing address space depends on how an individual company's computer network is configured.[24] Two respondents expressed concern about the loss of customers due to a change of IP addresses. A few also told us that it is not uncommon for an ISP to retain a relationship with its original backbone provider—paying for a minimal level of connectivity to that provider—in order to avoid having to go through a disruptive readdressing process. It appears, therefore, that customers' feelings of being tied to a provider may lessen the effective level of competitiveness in this market.

[24]Although IP address changes can be disruptive and somewhat costly, businesses can minimize the impact of the changes and reduce any readdressing costs by using an Internet standard called dynamic host configuration protocol (DHCP). With this protocol, the IP address settings for individual computers are assigned dynamically from a central server. Thus, when an ISP changes the IP addresses, all that a business has to do is change the address ranges stored in a central server and change the IP configuration of a few computers. However, businesses that do not use dynamic IP address allocations do have to reconfigure the IP address settings for many more computers if their ISP were to change backbone provider. Moreover, we were also told that in the new IP address format that is to be rolled out in the coming years, IP address changeovers will be less difficult. However, there are some concerns that this new format may not be implemented any time soon.

Assuring High Level of Quality for Internet Services is Difficult

A concern among several market participants we interviewed was the difficulty of guaranteeing customers a given level of quality for Internet services. We were told that this difficulty is related to the way that the Internet is engineered. In particular, several of those with whom we spoke noted that Internet traffic is exchanged among providers on a "best efforts" basis—that is, Internet traffic is routed according to a set of protocols aimed at providing the best routing possible at a given time. However, the Internet was not engineered to enable extremely high quality service at all times—as are telephone networks—and the quality of Internet services can be compromised when high levels of traffic flow lead to congestion.

Several of the market participants we interviewed were particularly concerned about their ability to understand where and why problems have occurred. These company representatives told us that when they contact their backbone provider to report service degradation they are sometimes told that the problem is with another interconnected backbone network. Because the Internet is a network of interconnected networks with little data available or reported on service disruptions or outages, finding the source, cause, or reason for a problem may be difficult. Thus, ISPs and end users expressed frustration that accountability for traffic transmission problems is lacking. Several ISPs noted, for example, that they receive service level guarantees from their backbone provider but that collecting remuneration for "downtime"—the time that a network has failed or otherwise is nonfunctional—is difficult because they are unable to prove that the problem occurred on their backbone provider's network. One backbone provider with whom we spoke also noted that the quality problems inherent in the Internet lead some customers—particularly business clients—to purchase expensive private network services.

One of the initiatives of the current and fifth Network Reliability and Interoperability Council (NRIC V) is a trial program for voluntary reporting of outages by providers not currently required to make such reports to FCC, such as Internet backbone providers.[25] A focus group of the Council will evaluate the effectiveness of the program upon its completion and analysis of trial data, and it will make a recommendation on outage reporting of these networks. We were told that, due to concerns by some Internet providers about reporting network outages to a governmental

[25]Reporting of certain outages of wireline common carrier networks is currently required by FCC. No required reporting currently exists for outages in wireless, satellite, cable, and data networks (backbone providers and ISPs).

agency,[26] there was little participation in the program by Internet providers through the first half of 2001.

The Internet Backbone Market Does Not Exist Independently—Lack of Competition for Local Telephone Services Affects Connectivity to Internet Backbone Networks

Although the Internet backbone market appears to be competitive, another market that is essential to the functioning of the Internet may be less so. Most ISPs and other end users connect to a backbone provider's point of presence through the local telecommunications infrastructure. These systems are typically owned and operated by incumbent telephone companies—those providing local telephone service prior to enactment of the 1996 act. Many of the market participants with whom we spoke noted that local telephone markets are, in their view, close to monopolistic; and some noted that several companies attempting to compete against incumbent local telephone carriers have recently gone out of business.

Based on our interviews with market participants, it appears that a limited choice of local carriers may affect the providers of Internet services. In particular, interviewees stated that incumbent telephone carriers take a long time to provision or provide maintenance on special access services and other high speed access lines—which are often used to link businesses (such as an ISP) to an Internet backbone point of presence.[27] Additionally, some companies we spoke with expressed concern about slow or limited deployment of high-speed Digital Subscriber Line (DSL) service in residential areas.[28] Some backbone providers and ISPs said that these problems were more severe or more limiting in rural areas. For instance, we were told that rural areas are least likely to have competitors to the local carrier, and the incumbents were less likely to roll out DSL in their more rural markets.

[26]Outage reports by companies are made to the National Communications System/National Coordinating Center for Telecommunications and, maintaining the confidentiality of the provider, passed on to NRIC V.

[27]This would include high capacity lines such as T-1s, T-3s, and DS and OS fiber lines. FCC issued a notice for public comment in January 2001 to determine how competition for the provision of these special lines can be best accomplished. Three of the four Bell Operating Companies submitted a joint petition to FCC in 2001 seeking a determination that the market is competitive and the special lines need not be subject to regulations under the Telecommunications Act of 1996.

[28]For a discussion of the development and deployment of DSL technology, see *Telecommunications: Issues Related to Local Telephone Service* (GAO/RCED-00-237, Aug. 31, 2000).

Incumbent local carriers, on the other hand, have stated that there is considerable competition in the provision of special access service. One such carrier with which we spoke noted that any delay in its own provisioning of these lines is due to the high expense of deploying the necessary infrastructure and to technical difficulties in rolling out DSL, especially in more rural areas. This carrier also noted that FCC found the percentage of all local lines served by competitors had doubled to approximately 8 percent in 2000.[29]

The Introduction of New Services Over the Internet May Be Constrained by Limits in Capacity

New Internet services, such as video streaming and voice telephone calls over the Internet, are expected to become increasingly common in the coming years. Both Internet backbone networks and local communications infrastructure must have sufficient bandwidth and technical capabilities to support such services. In response to problems of latency and packet loss associated with Internet transmissions, various initiatives and efforts are under way to make improvements in the functioning of the Internet and to build alternative networks that are more robust and reliable. We found that most of those with whom we spoke were optimistic that backbone capacity and technical features would adapt to new needs, but concern was expressed that limited broadband capabilities in local telephone markets could stall certain new applications. Incumbent local telephone companies have stated that the rollout of DSL service is hampered by the cost of reengineering parts of the network and existing regulations that require them to sell piece parts of their networks to competitors at cost-based rates.

Two New Types of Services Are Expected to Be Introduced in the Coming Years; These Services May Challenge the Capabilities of Communications Networks

A variety of the company representatives with whom we spoke told us that new services and some services that were traditionally regulated (such as telephone calls) are expected to become more commonly provided over the Internet in the coming years. Many companies are developing technologies to enable voice services to be provided over IP networks. At present, however, many backbone networks are not well designed to provision such “time-sensitive” services. Specifically, real-time services such as IP telephony and interactive video require “bounded delays”—that is, these services require very low and uniform delays between sender and

[29]See FCC’s report *Local Telephone Competition: Status as of December 31, 2000*, issued May 21, 2001.

receiver in order for the service to be of adequate quality. Also, more broadband content is expected to be transmitted over the Internet. Before such broadband content can be provided, both the backbone and the local communications infrastructure must have sufficient bandwidth.

The Rollout of Time-Sensitive Service Will Require Some Changes in the Way Data Traffic Is Routed

Many industry representatives with whom we met told us that latency and the loss of data packets due to traffic congestion is a consequence of the current protocols for transmitting Internet traffic. As transmissions of time-sensitive applications over the Internet become increasingly common in the future, these problems may become particularly acute. A few of those we interviewed noted that these applications can run well across one backbone network, but when traffic must transverse across more than one network, quality cannot be assured given current routing protocols. We found that participants in Internet markets have begun to address latency and reliability problems in Internet backbone networks. For example:

- In addition to its experimental outage reporting initiative, NRIC V is in the process of evaluating and will report on the reliability of "packet-switched" networks.[30] The council is also examining issues related to interconnection and peering of Internet backbone providers and the sufficiency of the best efforts standard for Internet transmissions as more time-sensitive services are provided over the Internet.
- Companies have emerged to build and provide services over networks that do not rely as much on traffic exchange across networks. For example, we found that a few providers are building and relying on private data networks—rather than the Internet—for the transmission of voice services.
- Similarly, some companies are building "virtual private networks"—networks configured within a public network for data transmissions that are secured via access control and encryption.
- Companies reduce reliance on backbone service—and thus increase transmission speed—by caching frequently used content on their servers. In addition, companies have emerged that specialize in caching frequently accessed content and storing it in varied geographic locations, thus making it more quickly accessible to customers.

[30]Packet-switched networks employ a message delivery technique in which data is split into packets—small pieces of information—and transmitted separately over the most efficient pathway to their destination point where they are reassembled.

- Because the Internet is not viewed as conducive to supporting research capabilities of high-speed technologies and other advanced functions, alternative methods for such research have emerged. For example, “Internet2” is a partnership of universities, industry, and government formed to support research and the development of new technologies and capabilities for future deployment within the Internet.

The Rollout of Broadband Content May Be Constrained by a Lack of Capacity in Local Telecommunications Infrastructure

According to many of the company officials we interviewed, there appears to be ample deployment of fiber optic cable in Internet backbone networks to support high bandwidth services. Similarly, we were told that capacity continues to be built by backbone providers and others and that backbone networks’ capacity will not be a bottleneck for the deployment of broadband applications. However, concerns were expressed to us that shortcomings in the local telephone market were likely to intensify in the future due, in part, to the increase in demand for broadband applications and content. We found that some companies are offering services to address this problem by attempting to bypass incumbent telephone companies’ facilities and bring services directly to customers. However, the majority of these efforts are focused on business customers in urban areas. For example, we found:

- Metropolitan fiber rings—fiber optic cables encircling central business districts of urban areas—are being constructed as an alternative to using incumbent carrier services. Business customers purchase a direct connection to the fiber ring, which is connected directly to the backbone point of presence.
- Wireless direct access is also becoming available that will enable a company’s data traffic to bypass local telecommunications infrastructures.

While solutions such as these hold promise for greater choice for business customers in urban areas, market forces may not naturally address constraints in capacity of local telecommunications infrastructure in certain areas, particularly in rural, residential locations. Instead, representatives expressed concern that the deployment of broadband telephone facilities in residential and rural areas may not keep up with demand. Some of those we spoke with gave the example of limited DSL deployment in many areas.

An incumbent local telephone provider we spoke with stated that they are aggressively rolling out DSL service, but that the service is costly to roll out and often requires significant reengineering of their networks. These providers also have noted publicly that DSL rollout is hampered by certain regulations that require incumbents to sell parts of their network (including DSL lines) to entrants at cost-based rates. Legislation is pending in the 107th Congress that would address these concerns, and proponents of this legislation have stated that this will advance the deployment of broadband in residential and rural areas.[31] Opponents of the legislation believe the bill will not foster increased deployment of broadband services and may stifle competition in the local telephone market. Other bills have been introduced in Congress proposing various other approaches and strategies to accelerate the deployment of high-speed data services.[32]

Conclusion

In the 6 years since the federal government ended its sponsorship of a key backbone network, the Internet has changed the way people of the world live, work, and play. Its rapid growth is seen in the substantial investments made by private sector firms in backbone networks and interconnection facilities, by the proliferation of interactive applications and content, and by the exponential increase in the connectivity of end users. These developments are particularly noteworthy in light of the dynamic nature of the Internet backbone marketplace—Internet backbone providers not only compete with each other for customers but also cooperate for the exchange of traffic. The success of the Internet, as evidenced by its growth, evolution, diversity, and cooperative structure, has occurred with minimal government involvement or oversight.

Despite the Internet's success and the competitiveness of the Internet backbone market, several issues of concern regarding this market were raised to us during the course of our study. Market participants noted the importance of Tier 1 backbone providers and the potential for reduced competition if consolidation were to occur at the Tier 1-provider level. The inability of backbone customers to ascertain the causes of service

[31]See H.R. 1542, the "Internet Freedom and Broadband Deployment Act of 2001." In addition, this bill would allow the Bell Operating Companies (BOC) to provide Internet backbone services within their service regions without prior approval of the Commission as currently required in section 271 of the Communications Act of 1934. BOCs can currently provide out-of-region service.

[32]For example, H.R. 1697 and H.R. 1698 would ensure the application of antitrust laws against incumbent local telephone companies; and S. 88 and H.R. 267 propose tax incentives for the deployment of broadband services in low income and rural areas.

degradation or traffic disruptions was also expressed to us, along with concerns about the adaptability of the Internet to new services. These and other concerns underscore the need for adequate information on such items as, for example, the geographic scope of backbone networks, the number of backbone providers' customers, the number of IP addresses assigned to providers, traffic flows, and outages. In the absence of adequate information, it is difficult to fully ascertain the quality of service, the reasons for problems when they occur, and the extent of market concentration and competition in the Internet backbone market.

The adaptability of backbone networks for new services, such as Internet-based voice and video services, foretell a trend commonly identified as "convergence" in the broader communications sector and the increasing importance of the Internet to the U.S. economy. This expectation of greater convergence was widely shared by the market participants we interviewed for this study and for other studies we have conducted at your request over the past 3 years.[33] There is a strong expectation that traditionally regulated services—such as voice telephone and video services—are already migrating to the Internet and will soon become common applications used by residential and business Internet users. Moreover, advances in technology are changing the very nature of the Internet. In the last half decade, the Internet has evolved from a nascent but promising information tool to a 21st century medium central to commerce and communications for Americans and citizens the world over. The implications of convergence and greater future reliance on the Internet are at present largely unknown.

[33]See *Telecommunications: The Changing Status of Competition to Cable Television* (GAO/RCED-99-158), July 1999; *Telecommunications: Development of Competition in Local Telephone Markets* (GAO/RCED-00-38), January 2000; *Telecommunications: Technological and Regulatory Factors Affecting Consumer Choice of Internet Providers* (GAO-01-93), October 2000.

No evidence came to light in the course of this study to suggest that the long-standing hands-off regulatory approach for the Internet has not worked or should be modified. Further, FCC said it believes that the appropriate means to collect information on Internet backbone networks at the present time is through informal and experimental efforts, which are currently under way. Because of the trend towards convergence in the communications marketplace and the nation's increasing reliance on the Internet, however, FCC may need to periodically reassess its data collection efforts[34] to evaluate whether they are providing sufficient information about key developments in this industry.

Recommendation

FCC should develop a strategy for periodically evaluating whether existing informal and experimental methods of data collection are providing the information needed to monitor the essential characteristics and trends of the Internet backbone market and the potential effects of the convergence of communications services. If a more formal data collection program is deemed appropriate, FCC should exercise its authority to establish such a program.

Agency Comments

We provided a draft of this report to the FCC, NTIA of the Department of Commerce, and DOJ for their review and comment. FCC and NTIA officials stated that they were in general agreement with the facts presented in the report. Technical comments provided by FCC, NTIA and DOJ officials were incorporated in this report as appropriate.

As agreed with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report for 14 days after the date of this letter. At that time, we will send copies to interested congressional committees, the Chairman, FCC; the Assistant Secretary of Commerce for Communications and Information, Department of Commerce; the Assistant Attorney General, Antitrust, DOJ; and other

[34] In its 2001 report, *The Internet Coming of Age*, the National Research Council's Committee on the Internet in the Evolving Information Infrastructure also recommended that the "present policy of nonregulation of the Internet should be accompanied by close monitoring of the Internet's structures and operations by government, the Internet industry, and Internet users to ascertain enduring trends and identify what problems, if any, are due to persistent—as opposed to transient—phenomena."

interested parties. We will also make copies available to others upon request. If you have any questions about this report, please call me at 202-512-2834. Key contacts and major contributors to this report are listed in appendix IV.

Peter Guerrero
Director, Physical Infrastructure Issues

Scope and Methodology

To obtain information about the characteristics and competitiveness of the Internet backbone market, the Chairman and the Ranking Member of the Subcommittee on Antitrust, Business Rights and Competition, Senate Committee on the Judiciary, asked us to report on (1) the physical structure and financial arrangements among Internet backbone providers, (2) the nature of competition in the Internet backbone market, and (3) how this market is likely to develop in the future. To respond to these objectives, we gathered information from a variety of sources, including government officials, industry participants, and academics familiar with the functioning of this market.

We interviewed officials and obtained documents from the Federal Communications Commission, the Department of Justice, the National Telecommunications and Information Administration of the Department of Commerce, the National Science Foundation, the Bureau of Labor Statistics, and the Census Bureau. We also interviewed two national Internet industry trade associations and three academics with expertise in this area.

To obtain information from a wide variety of participants within the Internet backbone market, we visited locations in 12 states with varying characteristics. We included large and small cities and rural areas from various regions of the country. Other criteria used for selection of areas were proximity to Internet points of presence, which are access points to the Internet, and proximity to network access points (NAP), which are points where Internet backbones interconnect. Also considered were the presence of other features, including regional backbone networks, statewide educational or government networks, state Internet Service Provider (ISP) associations, or Native American reservations.

In the selected localities, we conducted 55 semistructured interviews with participants in the Internet backbone market between January and June 2001. For these interviews, we used interview guides containing questions concerning background information about the company, connectivity to backbone networks, business relationships in the backbone market, service quality issues, and views on competition in this market and on other public policy issues. We interviewed

- eighteen Internet backbone providers of varying size;
- two miscellaneous Internet companies that provide backbone-like services;
- twenty-four Internet service providers of varying size;

- eight end users of backbone services, including a college, a state government, corporations, and providers of content and Web hosting;
- two state-level ISP associations;
- one Internet equipment manufacturer; and
- one incumbent local telephone company.

Responses from interviewees were evaluated and general themes were drawn from the aggregated responses and from the aggregated responses of relevant subsets of respondents. These themes are presented in this report.

We contacted an additional 32 market participants and industry representatives for purposes of conducting interviews to support this study. In these instances, we were not able to schedule an interview. In some cases, our request for an interview was declined, our telephone contacts were not returned, or we were unable to schedule an interview after repeated discussions with company officials.

In addition to the information collected through interviews, we also conducted technical, legal, and regulatory research on the characteristics and competitiveness of the Internet backbone market.

Internet Protocol Addresses and Backbone Routing

Each individual network or node that is connected to the Internet is identified by an Internet Protocol (IP) address—a number that is typically written as four numbers separated by periods, such as 10.20.30.40 or 192.168.1.0. When information is sent from one network or node to another, the packet of information includes the destination IP address.

Because the IP deals with inter-networking—the exchange of information between networks—the IP address is based on the concept of a *network address* and a *host address* that uniquely identifies a computer connected to the Internet. The *network address* indicates the network to which a computer is connected, and the *host address* identifies the specific computer on that network.

Devices known as "routers" send data packets from one network to another by examining the destination IP address of each packet. In its memory, the router contains a "routing table" which contains information specifying all of the IP addresses of other networks. The router compares a packet's destination IP address with the information contained in the routing table to determine the network to which the packet should be sent. In order to ensure that packets from one network can reach any other network, the router must include an entry for each possible network. As more and more network addresses come into use, there is concern about the growth in the number of routing tables entries.

Historically, IP addresses were organized into three commonly used classes—Classes A, B, and C. For Class A, there are 126 possible network addresses, each with nearly 17 million hosts. Slightly more than 16,000 networks may have a Class B address, each with over 65,000 hosts. Finally, there can be approximately 2 million networks with a Class C address, each with a maximum of 254 host addresses. As the Internet grew, engineers quickly identified the problems associated with exhaustion of class B addresses and the increasing number of Class C address entries in routing tables and developed a solution known as Classless Inter-Domain Routing (CIDR). CIDR treats multiple contiguous Class C addresses as a single block that requires only one entry in a routing table. This method of IP address allocation was adopted for technical efficiency reasons—the number of IP addresses that must be maintained in each router for traffic routing purposes is substantially reduced. However, this method of IP address allocation presents unique problems for smaller ISPs and other entities. If an entity seeking IP addresses cannot utilize a large block of address issued by ARIN, the entity must obtain their addresses from among the allocations made by ARIN to their Internet backbone provider. ISPs and end users with whom we spoke expressed concern about method of IP address allocation.

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