The Information Society, 16:35–47, 2000

0197-2243/00 $12.00 + .00

The Internet Backbone and the American Metropolis

Mitchell L. Moss

Taub Urban Research Center, Robert F. Wagner Graduate School of Public Service, New York University, New York, New York, USA

Anthony M. Townsend

Department of Urban Studies and Planning, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

Despite the rapid growth of advanced telecommunications services, there is a lack of knowledge about the geographic diffusion of these new technologies. The Internet presents an important challenge to communications researchers, as it threatens to redefine the production and delivery of vital services including finance, retailing, and education. This article seeks to address the gap in the current literature by analyzing the development of Internet backbone networks in the United States between 1997 and 1999. We focus upon the intermetropolitan links that have provided transcontinental data transport services since the demise of the federally subsidized networks deployed in the 1970s and 1980s. We find that a select group of seven highly interconnected metropolitan areas consistently dominated the geography of national data networks, despite massive investment in this infrastructure over the study period. Furthermore, while prosperous and internationally oriented American cities lead the nation in adopting and deploying Internet technologies, interior regions and economically distressed cities have failed to keep up. As information-based industries and services account for an increasing share of economic activity, this evidence suggests that the Internet may aggravate the economic disparities among regions, rather than level them. Although the capacity of the backbone system has slowly diffused throughout the metropolitan system, the geographic structure of interconnecting links has changed little. Finally, the continued persistence of the metropolis as the center for telecommunications networks illustrates the need for a more sophisticated understanding of the interaction between societies and technological innovations.

Keywords cities, Internet backbone, metropolitan areas, technology diffusion

CITIES AND TELECOMMUNICATIONS

Telecommunications technology has had a powerful influence on the organization of urban space since Samuel Morse first demonstrated the telegraph in 1844, sending a message from Baltimore to Washington. By providing an alternative to the physical movement of messages, the telegraph and later the telephone permitted the centralization of corporate headquarters in the central business districts of cities as well as the decentralization of manufacturing and distribution activities (Gottman, 1977). By increasing locational and organizational flexibility within regions, communications technologies have also extended the functional geographic definition of a city to encompass large-scale metropolitan areas, a trend first noted by Lynch (1960) nearly four decades ago.

Major cities are points of intense investment in telecommunications technology because the production, exchange, and dissemination of information are critical to the function and purpose of the modern metropolis. As Abler (1970) notes, "[C]ities are communications systems . . . functionally identical to intercommunications media like the telephone and postal systems." As the function of central cities has quickly shifted from goods-handling to service- and information-based industries, major urban centers have emerged as key participants in the network of

---

Received 20 September 1998; accepted 20 September 1999.

This research was generously supported by National Science Foundation award 9817778, "Information Technology and the Future of Urban Environments."

Address correspondence to Anthony M. Townsend, Department of Urban Studies and Planning, Massachusetts Institute of Technology, Room 7-337, 77 Massachusetts Avenue, Cambridge MA 02139, USA. E-mail: amt@mit.edu

data nodes and flows that mediate the transactions of an integrated global economy. For Hall (1997), the rapid and massive flow of information through urban areas is one of the defining characteristics of the "postindustrial city."

The Internet represents the most fundamental advance in the distribution and exchange of information since the telephone. As the capacity of the Internet has rapidly increased during the 1990s, each of the traditional media[1] has been subsumed into this new technological framework. This versatility for conveying such a broad range of content has contributed to its immense popularity. Multimedia online news services integrate traditional printed media with video and audio broadcast as well as interactive features, and survey data indicate that television news outlets are rapidly losing viewers, particularly young ones, to Internet news sources (Pew Research Center, 1997). Internet telephony threatens the effectiveness of international telephone tariffs by passing digitized voice traffic over unregulated data networks. While this technology once required a personal computer and expensive hardware, access codes are now readily available that route standard voice calls across the Internet from any telephone. This innovation is driving an unregulated industry that is expected to reach nearly $2 billion in revenues worldwide by 2001 (de Repentigny & Khanna, 1997). As a Federal Communications Commission report observes, "The Internet potential proposes a threat for every provider of telephony, broadcasting, and data communications services" (Werbach, 1997).

Clearly, these new technologies will influence the form, function, and evolution of cities and metropolitan areas as they are woven into the urban fabric. Yet the urban planning profession has remained blissfully ignorant of both the negative implications and the potential benefits of new telecommunications technologies. In fact, compared to the effort devoted to the study of transportation systems or housing markets, the field of telecommunications has not been a subject of interest to urban planners (Graham & Marvin, 1996).

How can the Internet affect the future of cities and metropolitan areas? Two major explanations of the geographic consequences of telecommunications technology on cities can be found in the recent literature. The first, which has grown out of the urban studies community, argues that telecommunications have facilitated the centralization of corporate headquarters in a handful of global cities such as Tokyo, New York, and London. On the other hand, a growing number of voices from other fields hold that telecommunications technologies will cause the centrifugal scattering of human settlements and wholesale urban dissolution.

Friedmann and Wolff (1982) were the first to systematically articulate the concept of "global" or "world" cities and lay out a long-term research agenda. At the core of their argument was the observation that for a small group of special cities, it had become impossible to disentangle or understand their internal dynamics without considering the much broader processes of global economic restructuring. Advances in information and telecommunications technology are universally identified as a crucial factor in the process of globalization and world city development, providing the means for corporate control and coordination of far-flung production networks and increasingly complex business transactions (Sassen, 1995).

In opposition to the global cities concept, a long tradition of antiurban utopian thought has been resurrected, arguing that the rapidly declining cost and expanding capability of telecommunications eliminates the need for the face-to-face interactions that are the lifeblood of cities. This view has gained widespread acceptance in academic, political, and media discourse due to its direct appeal to a long tradition of American antiurbanism and its usefulness in marketing a wide variety of communications products and services.

In the 1960s, as the power of television delivered graphic images of urban riots into newly built suburban homes, media scholar Marshall McLuhan "repeatedly announced the obsolescence of the built city in the electronically mediated future" (Campanella, 1998). In the early 1980s, Toffler (1980) described a future in which the telemediation of social and economic activities by the "electronic cottage," the advanced home of the future, would usher in a radical decentralization of population and production. A new generation of voices has reintroduced this language of urban dissolution, with the Internet replacing television as the technological determinant. Futurist George Gilder (1996) announces that cities are "leftover baggage from the industrial era," while Negroponte (1995) authoritatively states that "the post-information age will remove the limitations of geography . . . and the transmission of place itself will start to become possible." Most recently, Cairncross (1997) resurrected Toffler's "electronic cottage," forecasting a drop in crime and revitalization of suburban communities as homes reemerge as the center of economic activity.

Both of these views are overly simplistic. The urban dissolution viewpoint is the most flawed, as it is overly deterministic, attributing inevitable consequences to technology that has yet to be adapted, discarded, regulated, or subjected to the dozens of social decision-making processes that will ultimately shape its role in society. As a result, "Technological determinism has dominated debate on the social and economic impact of new telecommunications technologies" (Thrift, 1996). On the other hand, while the global cities framework sees the geographic distribution of telecommunications technology largely as a consequence of corporate decisions, it does not leave room to account for the unique characteristics of individual technologies, instead seeing all as subservient to socioeconomic forces. The economics of communications systems based on packet switching (like the Internet) are clearly a result of their technical design, and as Shapiro (1999) argues, the cost structure of these technologies now offers individuals an unprecedented control over their own lives.

On the urban question, however, Hall (1997) offers a middle ground, suggesting that "changes in political, economic, and technological" frameworks might dramatically affect the selection and location of global cities. This article argues that the rapid growth of the Internet in the second half of the 1990s is an example of just such a change in technological framework. However, although Internet technologies do represent a fundamentally new type of communications technology, rather than dictate an entirely new spatial pattern, these technologies have and will continue to evolve within and transform the existing network of metropolitan areas in the United States.

THE GEOGRAPHY OF THE INTERNET

The geographic diffusion of recent innovations in telecommunications, and the Internet in particular, has eluded systematic analysis from the urban planning community. There is a growing recognition of this lack of knowledge, yet while geographers have been more responsive to the challenges of cyberspace to understanding space–time relationships, "There is still an unfortunate dearth of research on the geography of telecommunications and its attendant implications for urban and regional development" (Hepworth, 1989). Furthermore, sociologists such as Castells (1996) speak of a "new spatial process, the space of flows, that is becoming the dominant spatial manifestation of power and function in our societies," yet offer evidence lacking in scope and depth.

One might suspect that this oversight is due to a lack of exploration of these issues, yet the record indicates a rich history of research in this area during earlier eras of transformation. Several important studies have described the magnitude and character of intermetropolitan information exchanges among various media—telephone messages, overnight delivery parcels, and air transportation. Gottman (1961) analyzed daily telephone calling patterns in the sprawling Boston–Washington metropolis, while Abler (1970) expanded this technique to the entire United States. Pred's (1973) work systematically examined the flow of information among cities in colonial America, and was creative in its use of measures such as the diffusion of foreign news, the structure of postal systems, and the speed of interurban travel. However, because flows of information across the Internet are now extremely sensitive proprietary information, the few studies of this nature are now hopelessly outdated (see GVU, 1995). While new techniques for active geographic measurement of the Internet such as Murnion's (1998) analysis of network delays are slowly emerging, measures of Internet activity of interest beyond the computer science community are rare, inconsistent, and often lack a geographical component.

So how can we study the geography of the Internet and, more specifically, variations in diffusion rates among cities and metropolitan areas? In the United States especially, where the telecommunications industry is highly competitive, the empirical study of Internet geography has proven nearly impossible. The bulk of useful data has been published by a variety of trade magazines and nonprofit organizations in scattered locations and often with questionable accuracy. This section reviews two measures that are currently in use.

The most widely used geographic measurement of Internet activity is the number of hosts, or computers connected to the Internet. Matrix Information and Demography Services (MIDS) of Austin, TX, is the primary source of these data. However, there are fundamental conceptual problems with using this type of measurement for research. As Orlikowski (1999) reminds us, the analysis of technology is better served when it focuses upon the "in-use" properties of technology, rather than the "espoused" functions built into it by designers. Host computers have been adapted for a multitude of purposes, and at so many different scales as to render these measures almost meaningless. However, despite its flaws, because these data have been collected for many years and appear fairly complete, they are the best available archive of information on the geographical diffusion of the Internet since the early 1990s. We utilized this data set in the past in our first look at geographic patterns of Internet activity in the United States (Moss & Townsend, 1996), but rapidly abandoned it in favor of more meaningful measures.

Using a different approach to coax geographical information out of the technical systems that permit the Internet's addressing schemes to function, Imperative! of Pittsburgh, PA, and the defunct Internet Info of Falls Church, VA, have tracked the growth of the Internet based on the number of domain names registered by geographic area. The domain name is a form of Internet addressing that maps groups of numeric Internet addresses to intuitive names like nyu.edu or att.com. We find this technique vastly superior, as the domain name represents a social construct—a firm, government agency, educational institution, or nonprofit organization—rather than a technological one (Moss & Townsend, 1997). This measure has produced a remarkably similar and consistent set of results across independently collected data sets (Kolko, 1998; Zook, 1998; Moss & Townsend, 1998). While there are several shortcomings to this measure, these findings were within reasonable expectations based on the analysis of contemporary "cyberregions" (Saxenian, 1994; Nunn

& Warren, 1997; Joint Venture Silicon Valley Network, 1998).

Finally, while it is not feasible to obtain data on the flow of information between cities or points on national data networks, the geographic structure and capacity of backbone networks offer a third aspect of the developing Internet that can be measured relatively easily. More interestingly, if we consider that these networks are being built in a fairly well-functioning, competitive market, their geography can be used as an indicator of new communications relationships emerging among regions as a result of the Internet that could not detected by conventional methods.

The only primary source of information on the geography of Internet backbone networks at the time of this study was *Boardwatch Magazine's Internet Service Providers Quarterly Directory* (1997, 1999). This publication includes corporate profiles and network maps indicating intermetropolitan links and capacity for approximately two dozen major national data networks. This work has been an important resource to us as a source of data and well-written analysis of the technical underpinnings of the modern Internet. The Cooperative Association for Internet Data Analysis (CAIDA) has published similar data and has developed tools such as MapNet,[2] which permit a computerized visualization of network geography (Claffy & Huffaker). However, CAIDA has not kept its network data as current as has *Boardwatch*, as its goal is to develop visualization tools for improved network management rather than to accurately and comprehensively map the geographic diffusion of Internet networks. The maps compiled by *Boardwatch* are useful as a base point for data on backbone networks. Unfortunately, their reliability is based upon network operators' willingness to divulge accurate and timely information. Thus, while the data used are not suitable for making fine distinctions, the large number of networks and the sheer magnitude of overall trends mitigate these irregularities. Ongoing efforts to develop more accurate, time-sensitive, independent data-gathering tools on Internet backbone networks should improve these barriers to research in the future (Townsend et al., 1999).

This study explores the geographic structure of backbone networks. The backbone network can be seen as a market response to localized demand for long-distance data transport services. The next section discusses this measure, and the following section presents the findings of our analysis.

INTERNET BACKBONE NETWORKS—THE NEW URBAN INFRASTRUCTURE

In the past, economic transformations have been accompanied by the development of new infrastructure networks that enable the flow of goods throughout the nation. In the early 19th century, rivers and canals formed the backbone of the economic infrastructure, permitting the raw commodities of the hinterlands to be transported to the city for manufacture, shipment, or resale. Industrialization defined the need for reliable, rapid transportation of vastly more goods and people among the rapidly growing urban centers, spurring the construction of the railway network. Later, as the federal government sought to decentralize population and productive capacity during the nuclear era, suburban development and the Interstate Highway System accompanied each other into the countryside.

The Internet backbone system represents a new urban infrastructure, designed to transport the valuable goods of the digital economy—information, knowledge, and communications—from production sites to markets. However, in contrast to the urban dissolution view discussed previously, new technologies do not necessarily dictate their own spatial manifestation. Just as the geographic structure of these earlier infrastructure networks both reflected and influenced existing and desired settlement patterns, the geography of the backbone system has in part been shaped by the economic and social realities of late 20th-century America and the specific properties of the technology.

The Internet is particularly interesting when considered this way, as it has evolved through three distinct periods during which a different policy framework governed its geographic diffusion. Like the Interstate Highway System, the Internet originated from the concerns of defense planners about the vulnerability of the nation's infrastructure systems, in this case the communications grid. Researchers at RAND, the defense think tank, wrote a series of influential papers in the early 1960s that touted the merits of distributed networks, which have many redundant pathways for the delivery of messages, versus decentralized and centralized networks, which have aggregating nodes that are vulnerable to attack (Baran, 1964) (Figure 1).

However, as control of the evolving network passed from the Defense Department to the National Science Foundation (NSF), and finally to the private sector in 1994, centralization of network infrastructure at regional nodes become increasingly necessary. The rapid growth of the network and difficulties in scaling the distributed structure led the NSF to establish a multitiered service model, which aggregated networks at regional levels and connected the regions with an interlinking superstructure dubbed the "backbone." As a result, by 1989, the Internet was more decentralized than distributed (Figure 2).

While NSFNet began to stray from RAND's ideal distributed model toward a more decentralized structure, geographically it was still highly dispersed, and uniformly so. Regional networks sponsored by universities and nonprofit organizations linked nearly every state to the network with a similar level of service. Additionally, NSFNet connected

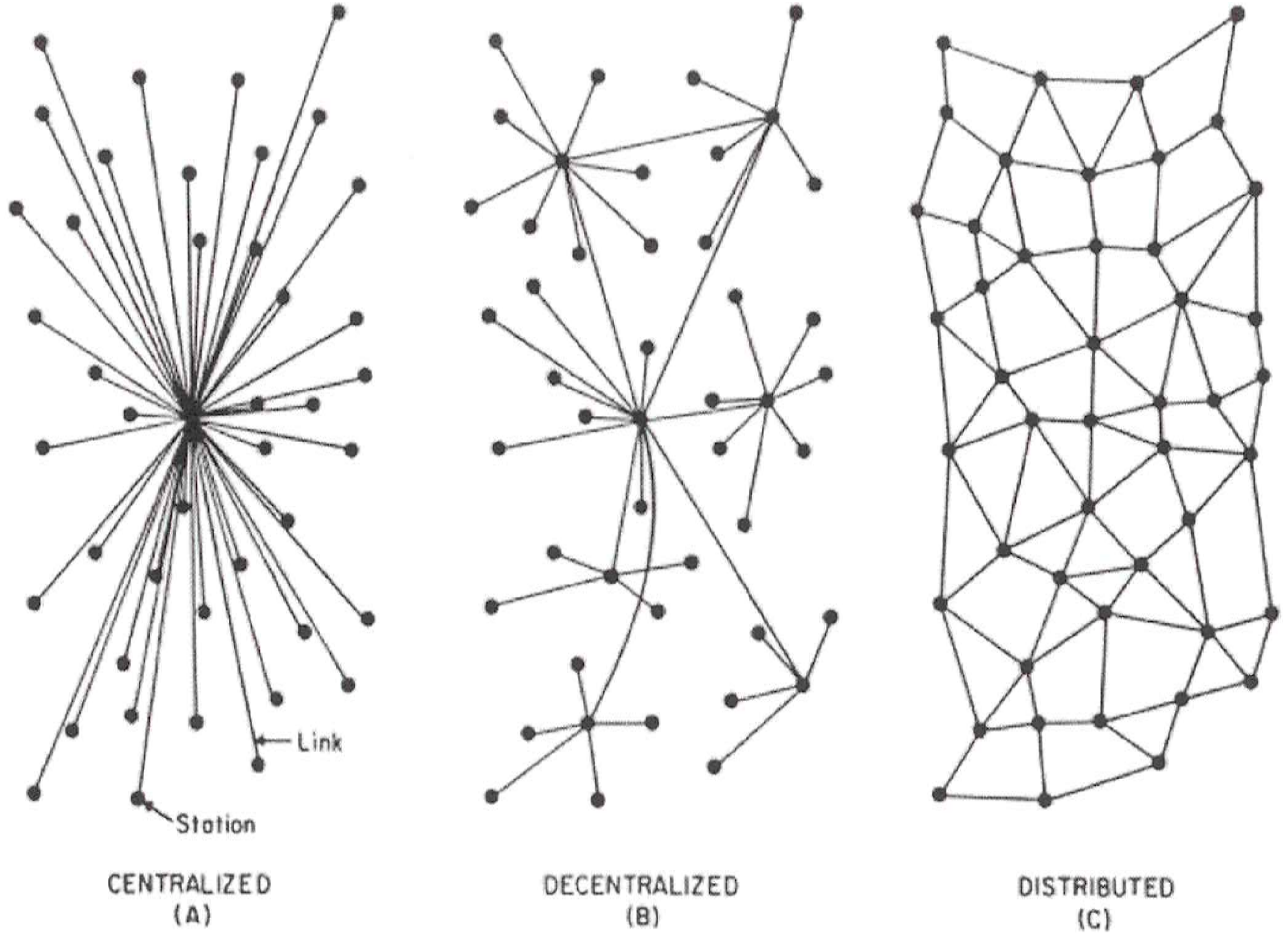

FIG. 1. Network topologies. From Baran (1964).

13 sites to its backbone, all at the same level of capacity. On the contrary, the commercial Internet backbone system is highly selective, concentrating the bulk of capacity and connections in a handful of metropolitan areas. In many ways, the present structure of the Internet backbone has largely erased the decentralizing objectives of earlier networks.

The data presented in this article indicate that seven metropolitan areas dominate the structure of links and nodes of the backbone system in the United States. Despite the potential for the decentralization of economic activity made possible by new technologies, deployment of backbone networks is concentrated in a group of large metropolitan areas for a variety of historical, economic, and geographical reasons. This article measures the aggregate capacity of the national backbone networks that make up approximately 95% of the wholesale Internet access market. Using maps and data from *Boardwatch Magazine's Quarterly Directory of Internet Service Providers*, we compiled a list of every unique linkage between metropolitan areas for each of the networks. This list was then aggregated by metropolitan area. There were 29 networks identified by *Boardwatch* as operating at a national scale in the summer of 1997 and 39 in the spring of 1999.

Internet backbone networks traverse private and public rights-of-way, often alongside highways or railroad lines, to connect metropolitan areas across the country. Each network is constructed to serve perceived market demand and often contains redundant links between a pair of cities and, to eliminate bottlenecks, bypasses less important intermediate locations. Network providers also install different amounts of capacity, or bandwidth, to provide an information pipeline sufficient for their customers. Like much else on the Internet, backbones are often only "virtual"—operated on high-speed data lines leased from long-distance or regional telephone companies. In many cases the only physical infrastructure actually owned by backbone providers is routers, the powerful computers that manage the flow of data packets at junctions in the network (Rickard, 1997).

FIG. 2. NSFNet backbone and regional research networks, 1989. Compiled from individual maps in Quarterman (1989) and Salus (1995). Gbps, gigabits per second.

Although any one city connected to any of the backbone networks is theoretically as accessible as any city on any other network (because data travels at the speed of light over fiber-optic networks), there is significant congestion at network hubs and junctions. We focus solely upon the direct links vendors provide between pairs of cities. In this way, we capture both the geographic and market advantages that benefit particular cities. Important pairs of metropolitan areas will be joined directly to minimize delay of transmission, while less important pairs will have intermediate hubs between them in a location convenient for the aggregation and switching of other traffic. These assumptions are derived from the observed structure of these networks, which indicate the importance of direct links between key metropolitan areas.

The economics of high-speed data networks dictate that speed and capacity bottlenecks typically occur in the long-distance *intermetropolitan*, rather than local *intrametropolitan*, backbone links.[3] For the purposes of this study, we have assumed that backbones terminating in a metropolitan area are equally accessible to all parts of a metropolitan area via local telecommunications infrastructure which is typically more robust than that which connects metropolitan areas to each other.[4] Based on this assumption, we aggregated the network data at the metropolitan area level rather than at the level of individual cities or localities.[5] This allowed us to focus on the largest capacity fiber-optic networks, constructed of DS-3 (45 megabits per second [Mbps]), OC-3 (155 Mbps), and OC-12 (622 Mbps) technology.[6] The smaller capacity DS-1 lines (1.5 Mbps), which link many smaller cities and outlying areas to the Internet, were excluded from this analysis, as they are no longer used as primary transcontinental network links.

Several questions arise regarding what an analysis of backbone network structure and capacity indicates. We concede that backbone structure has little effect upon Web browsing speed and responsiveness to the average home user connected to the Internet via telephone and modem. This type of service is nearly universally available throughout the United States (Greenstein, 1998). However, the location and capacity of backbone networks and particularly interconnection points has a powerful effect on the ability of firms in any metropolitan area to distribute large amounts of data and information via the Internet. The robustness of the Washington, DC, metropolitan area's Internet infrastructure was well demonstrated after the Starr

Report was released on 11 September 1998. According to one source, traffic at the MAE-East exchange point surged over 100 Mbps after the document became available through the Library of Congress' website at 2 p.m. (Dawson, 1998).

Finally, mergers, acquisitions, and bankruptcies are reshaping the national fiber backbone industry, and networks can quickly become obsolete when new technology is deployed to gain comparative advantage. Therefore, this analysis must be considered within the temporal context of the Internet's growth and development. For example, while MCI, Sprint, and AT&T are major providers of long-haul Internet data transport, Qwest, Inc., is currently deploying a fiber network that is believed to have a greater capacity than those three networks combined.

In summary, this analysis of the capacity of data networks that connect metropolitan areas provides a framework for understanding the communications landscape of the American metropolitan system. The pattern of links between and among American cities and metropolitan areas establishes a hierarchy of information flows that influence development patterns. The Internet, because of its versatility and explosive popularity, has the potential to redefine this hierarchy more rapidly and fundamentally than any recent technological development. The geography and topography of backbone networks are increasingly the subject of scholarly attention, yet we have identified only a single published study that analyzes the aggregate intermetropolitan capacity in a similar fashion. Malecki and Gorman (forthcoming) used techniques of network analysis to further analyze the significance of locations centrally located within the topological structure of networks. As such, this represents an expansion of our technique, which does not consider the "distance" of indirect linkages. However, their results do not make any effort to explain the concentration of backbone links other than noting the proximity of these clusters to the continental coasts. We feel that rooting an analysis of current Internet backbone infrastructure in historical, social, and economic framework is necessary to extract meaning from what is ultimately a collection of fiber-optic cables and packet routers.

THE GEOGRAPHY OF THE INTERNET BACKBONE

Network Capacity

In this section, we present the major findings of our analysis. Between 1997 and 1999, the average capacity of intermetropolitan backbone links grew from 37.8 Mbps to 196.8 Mbps. However, despite this fivefold explosion in network construction and deployment, the number of metropolitan areas with a direct link to national backbones increased much less rapidly, from 72 to 105. Furthermore, the hierarchy of metropolitan areas has changed little during this period of rapid growth. A core group of seven metropolitan areas (San Francisco/San Jose, Washington, DC, Chicago, New York, Dallas, Los Angeles, and Atlanta) maintained their dominance as the central nodes of the Internet in the United States.

Table 1 lists the top 20 metropolitan areas by total capacity of all backbone links to other metropolitan areas in fall 1997 and spring 1999. In 1997, the dominance of the top seven metropolitan areas is clearly distinct from other regions. Los Angeles, with the smallest capacity of this core group, still had two-thirds greater backbone capacity than Denver, the next largest hub. Additionally, these top 20 metropolitan areas contained the bulk of all backbone capacity, with 85.6% of all capacity in the United States passing through them.

However, backbone infrastructure has spread to a slightly more inclusive group of metropolitan areas over the study period. In 1997, fully 60.4% of nationwide backbone capacity originated in these seven regions. By 1999, these top seven metropolitan areas contained only 41.5% of total national backbone capacity. This simple measure, however, obscures the nature of the diffusion, which is due to two trends.

First, new ultra-high-capacity networks such as AGIS and PSINet's 2048-Mbps OC-48 systems have installed several additional routing points at intermediate locations on their paths between major metropolitan areas, presumably in order to capture these marginal but unserved markets. For example, while one segment of the AGIS OC-48 network has intermediate nodes in Mexia, TX, and Bryan, TX, it is clear that its main purpose is to connect Dallas and Houston, which are the link's endpoints. This analysis has tried to catch as many circumstances of this type of structure as possible, but there is little beyond educated guesswork to determine which nodes actually generate traffic.

The second and more important reason that backbone capacity appears to have diffused is that a whole range of centrally located metropolitan areas like St. Louis, Kansas City, Indianapolis, Houston, and Salt Lake City have rapidly grown as hubs for new, large network links (Table 2). These metropolitan areas have replaced more economically successful regions such as Seattle, Denver, Phoenix, and Miami as the second tier of backbone hubs below the top seven metropolitan areas and have sapped much of the growth that might have occurred in the top seven metropolitan areas. However, these regions have not been shown to possess large, locally generated levels of demand for Internet services, based on both the number of domain name registrations among businesses and the penetration of Internet use among consumers (Zook, 1998; Inetco, 1999). It is therefore likely that these metropolitan areas are also merely waypoints on the important transcontinental links.

The growth of these secondary hubs illustrates a process of diffusion of Internet backbone capacity across the

TABLE 1
Internet backbone capacity by metropolitan area

Fall 1997			Winter/spring 1999		
Metropolitan area	Backbone capacity (Mbps)	Percent of national capacity	Metropolitan area	Backbone capacity (Mbps)	Percent of national capacity
Washington, DC	7826	10.4%	Washington, DC	28,370	7.2%
Chicago, IL	7663	10.1%	Dallas, TX	25,343	6.4%
San Francisco, CA	7506	9.9%	San Francisco, CA	25,297	6.4%
New York, NY	6766	8.9%	Atlanta, GA	23,861	6.1%
Dallas, TX	5646	7.5%	Chicago, IL	23,340	5.9%
Atlanta, GA	5196	6.9%	New York, NY	22,232	5.6%
Los Angeles, CA	5056	6.7%	Los Angeles, CA	14,868	3.8%
Denver, CO	2901	3.8%	Kansas City, MO	13,525	3.4%
Seattle, WA	1972	2.6%	Houston, TX	11,522	2.9%
Phoenix, AZ	1890	2.5%	St. Louis, MO	10,342	2.6%
Houston, TX	1890	2.5%	Salt Lake City, UT	9867	2.5%
Philadelphia, PA	1610	2.1%	Indianapolis, IN	9307	2.4%
Miami, FL	1567	2.1%	Denver, CO	8674	2.2%
St. Louis, MO	1350	1.8%	Boston, MA	8001	2.0%
Boston, MA	1325	1.8%	Seattle, WA	7288	1.9%
Kansas City, MO	1080	1.4%	Phoenix, AZ	6701	1.7%
Cleveland, OH	1080	1.4%	Cleveland, OH	6201	1.6%
Detroit, MI	900	1.2%	Columbus, OH	5641	1.4%
San Diego, CA	870	1.2%	Charlotte, NC	5191	1.3%
Baltimore, MD	810	1.1%	Las Vegas, NV	4791	1.2%
Rest of United States	10,702	14.2%	Rest of United States	123,212	31.3%
Entire nation	75,606	100.0%	Entire nation	393,574	100.0%

metropolitan system in the United States but also highlights the need for more sophisticated data. Figure 3 shows a comparison of the Internet backbone system in 1997 and 1999, indicating the location of the largest links representing 85% of capacity (this limit is to make them more legible). Clearly, the structure of the Internet backbone system in the United States is a great deal more concentrated and organized in 1999 than in 1997. As alluded to earlier, many of the secondary hubs such as St. Louis, Kansas City, and Salt Lake City appear to be functioning as hubs for supplementary routes to complement the direct routes between the top seven metropolitan areas. Until we understand the points between which information and messages flow along these network links, it will become increasingly difficult to decipher the meaning of these structures.

Network Links

While our measures of network capacity have indeed shown the rapid emergence of a group of secondary centralized hubs, the distribution of the number of links across metropolitan areas (irrespective of capacity) tells a very different story. The distribution of network links among metropolitan areas has been extremely consistent over the study period. While the total number of backbone links in the country doubled from 641 to 1209 over the study period, the top seven metropolitan areas were still the endpoints of 50.5% of all links in 1999, declining just slightly from 55.6% in 1997. Figure 4 shows a rank-size distribution plot for network links, showing the number of links for each city, ranked by total number of links. The distribution of links follows a similar exponential curve for both 1997 and 1999, and the proportion between the top seven metropolitan areas and the rest has remained stable over the study period. Thus, despite the fivefold growth of network capacity over the 18-month study period, there has been no significant shift in the geographic structure of network connections among the metropolitan areas. A stable hierarchy of network hubs and spokes apparently has emerged.

It is still unclear how to compare the importance of capacity versus a diversity of linkages to the value of Internet access and use in a particular region. On one hand, it is

TABLE 2
Growth in backbone capacity, 1997–1999

Metropolitan area	1997 Capacity (Mbps)	1999 Capacity (Mbps)	Growth rate (relative to nation)
Washington, DC	7826	28,370	69.6%
Dallas, TX	5646	25,343	86.2%
San Francisco, CA	7506	25,297	64.7%
Atlanta, GA	5196	23,861	88.2%
Chicago, IL	7663	23,340	58.5%
New York, NY	6766	22,232	63.1%
Los Angeles, CA	5056	14,868	56.5%
Kansas City, MO	1080	13,525	240.6%
Houston, TX	1890	11,522	117.1%
St. Louis, MO	1350	10,342	147.2%
Salt Lake City, UT	270	9867	702.0%
Indianapolis, IN	90	9217	1967.3%
Denver, CO	2901	8674	57.4%
Boston, MA	1325	8001	116.0%
Seattle, WA	1972	7288	71.0%
Phoenix, AZ	1890	6701	68.1%
Cleveland, OH	1080	6201	110.3%
Columbus, OH	495	5641	218.9%
Charlotte, NC	90	5191	1108.0%

reasonable to argue that links are a more important representation of intermetropolitan relationships in the networked information economy. As Table 3 shows, larger, more well-established metropolitan areas should tend to benefit from an agglomeration of network links, as this indicates a greater level of competition. The top seven metropolitan areas clearly lead in the level of competition in the market to provide direct network links from them to other metropolitan areas. The emerging secondary hubs, which were identified earlier in the analysis of backbone capacity, do not experience a similar level of competition because much of their growth in capacity is attributable to the construction of large-capacity networks by a handful of companies. However, it is interesting to note that while metropolitan areas such as Philadelphia and Baltimore, which do not boast very large capacities or diversity of

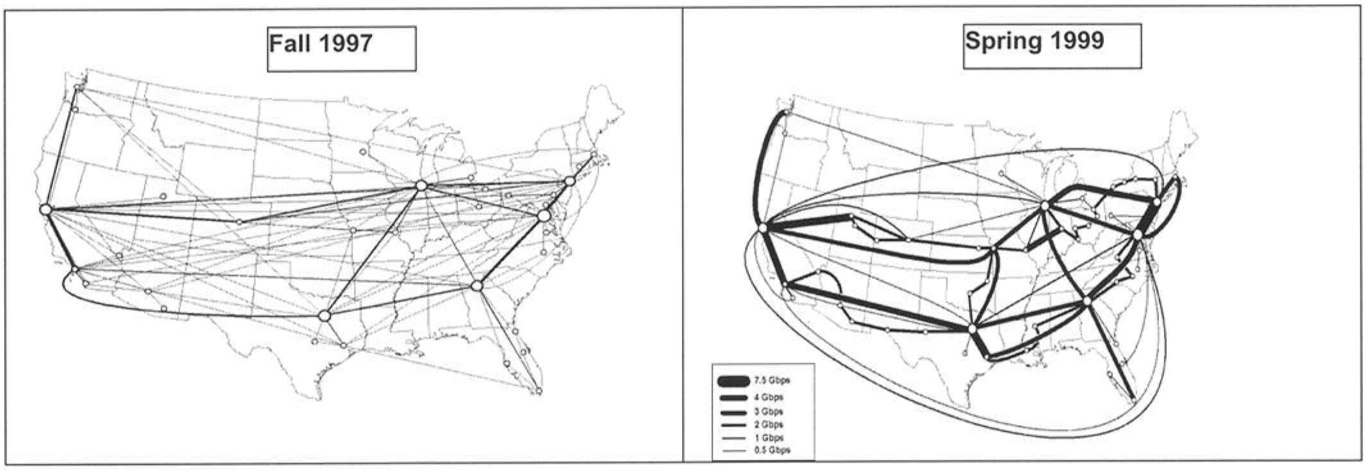

FIG. 3. U.S. Internet backbone, 1997 and 1999. Compiled from individual network maps in *Boardwatch Magazine Internet Service Providers Quarterly Directory* (1997, 1999).

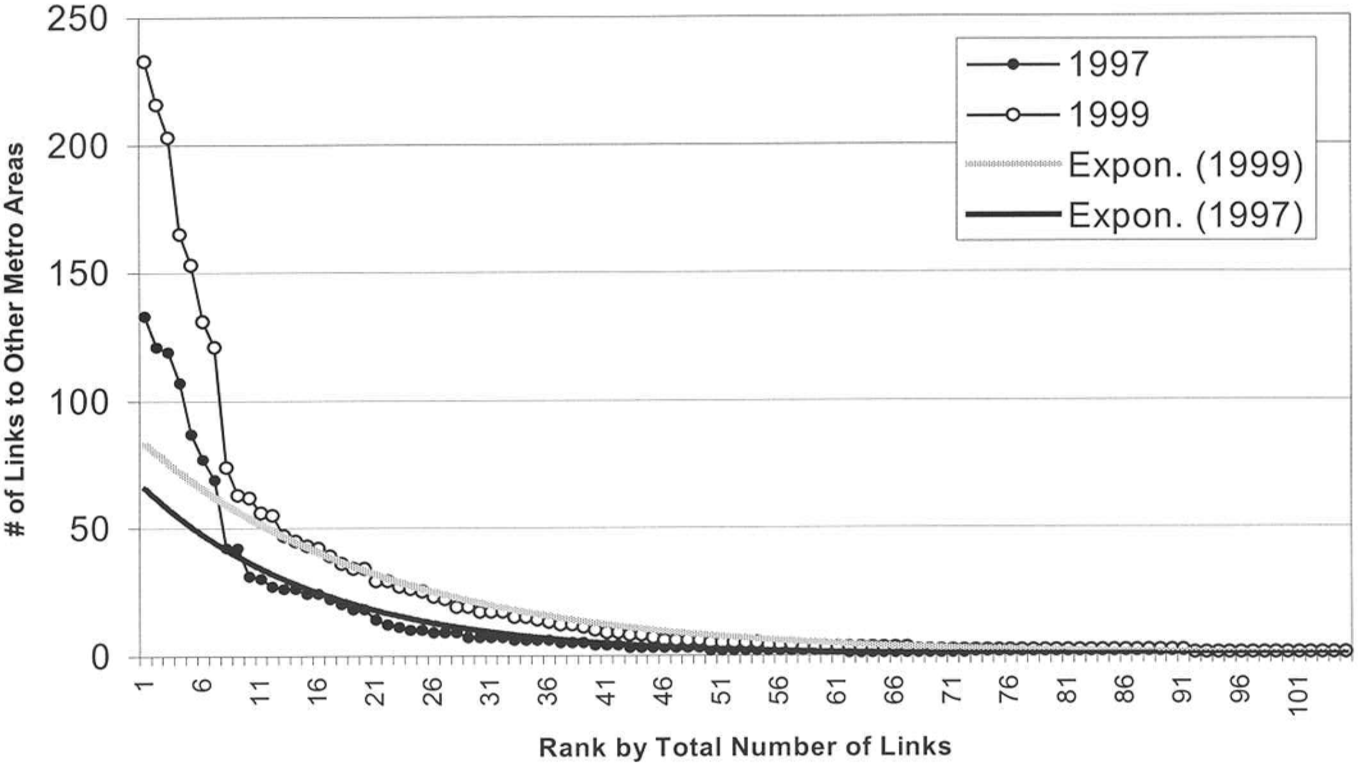

FIG. 4. Distribution of backbone links among metropolitan areas.

backbone links, benefit from their geographic position between large backbone centers such as New York and Washington, DC, providers often tap these markets using indirect backup links that supplement their main, direct links between the major hubs.

Individual Metropolitan Areas

This subsection briefly summarizes our observations on the position of individual regions in the geography of the aggregate Internet backbone network.

Washington, DC, and the San Francisco Bay Area undoubtedly serve as the major hubs for their respective coasts. We are not surprised by the role of San Francisco, since it was the part of the nation that started the trends that are just now beginning to transform our society. However, the important role of Washington, DC, greatly exceeds its traditional position in the communications hierarchy of the United States. One explanation may be that much of this capacity is dedicated to distributing content from the enormous Internet presence maintained by the federal government. Additionally, several large Internet companies, such as America Online and Network Solutions, Inc., are located in the Virginia suburbs. Finally, Washington serves as an aggregation point for traffic from not only the Northeast but also the Southeast, as well as internationally (Townsend, forthcoming).

The relative weakness of the three metropolitan areas in the United States that are most commonly identified as "global cities"—New York, Chicago, and Los Angeles—is one of the most striking findings of this analysis. Among urban scholars, there is a growing consensus that these global cities have become increasingly isolated from their national economies, while increasingly integrating operations and activities with each other (Sassen, 1995; Castells, 1996). Thus, an examination of Internet backbone networks on a national scale is inappropriate for understanding these cities' roles in global telecommunications networks. We are currently gathering an independent set of data on international backbone links to determine whether global cities have retained their traditional roles as hubs for international communications infrastructure, or if this historical pattern has begun to erode as well due to the new capabilities of the Internet.

Los Angeles is a global entertainment, high technology, and media center, and it is the second largest metropolitan area in the United States. Furthermore, Los Angeles County ranked third in the nation in the number of computers connected to the Internet in 1996 (Moss & Townsend, 1996). However, the region ranks lowest among the major

TABLE 3
Average number of competing backbone operators per link to other metropolitan areas

Metro	Number of competitors per external link
Los Angeles, CA	7.6
Baltimore, MD	6.8
Austin, TX	6.3
New York, NY	6.1
San Francisco, CA	5.8
Dallas, TX	5.7
Chicago, IL	5.6
Washington, DC	5.5
Seattle, WA	4.9
Atlanta, GA	4.7
Portland, OR	4.6
Philadelphia, PA	4.0
Houston, TX	3.9
San Diego, CA	3.7
Cleveland, OH	3.5
St. Louis, MO	3.5
Boston, MA	3.5
Kansas City, MO	3.3
Phoenix, AZ	3.1
Las Vegas, NV	3.0

metropolitan backbone nodes. One possible explanation is that the region's entertainment industry is strongly concentrated in fictional visual programming, which has not yet been suitably adapted to distribution over the Internet. We expect to see dramatically increased deployment of backbone capacity in southern California as emerging "broadband" technologies increase the ability to deliver large amounts of data directly to the home.

Seattle and Boston have far greater reputations as centers for technological innovation, yet they are trumped in this analysis by hubs such as Atlanta and Dallas. Some of the most interesting questions about this study must go answered because we lack data on the flows of information that actually take place over the potential pathways we have measured and mapped. But because remote cities like Seattle and Boston lie at the end of network pathways, instead of at the center, like Atlanta and Dallas, we can infer that their backbone capacity is being used entirely for local activity and not as a transiting facility. Until data are available on the flows of information between points on the backbone system, there may be little hope of resolving this puzzle.

CONCLUSIONS

This article highlights the need for experimentation with new empirical techniques and measurements to study the relationships between information technology and urban systems. While a substantial legacy of research in the geography of communications networks and information flows exists, contemporary scholars have not aggressively pursued similar lines of inquiry regarding the Internet.

First, the data presented in this article suggest that a group of seven metropolitan areas has been established as a core communications switchboard for the long-distance transport of communications across the Internet. Despite the deliberate design of the Internet as a distributed network, the collective behavior of dozens of backbone network companies has created a highly organized system. Although the Network Access Points established at the end of the NSFNet era were important in providing seed points for private networks to converge, we have seen commercial backbone providers establish private connections in these same regions as well.

As a result, the Internet has neither reinforced the importance of a few global cities nor ushered in a radical decentralization of the population into rural areas. In the United States, the three commonly identified global cities of New York, Los Angeles, and Chicago have less backbone capacity than either the San Francisco/San Jose or Washington, DC, metropolitan areas. However, while the Internet has erased many of the geographic barriers that previously isolated remote locations, it has not undermined the need to cluster people and businesses in metropolitan areas. Despite fivefold expansion of Internet backbone capacity in the United States during the study period, in 1999, 67% of this capacity remained concentrated in the top 20 metropolitan areas, down only slightly from 86% in 1997. Thus, while some diffusion has occurred, it hardly warns of a doomsday scenario for cities.

Second, the empirical evidence presented here challenges the conventional wisdom that telecommunications technology will undermine some of the comparative advantages of large, centrally located metropolitan areas. The decisive shift from satellite to fiber-optic technology for long-distance data transmissions has reintroduced physical geography into the decision-making process governing telecommunications infrastructure deployment. Central locations like Atlanta, Chicago, and Dallas can benefit by serving as regional hubs for telecommunications infrastructure in a way that is similar to the way in which their airports serve the transportation sector. When considered with our past analysis of Internet domain registrations, the structure of the Internet backbone illustrates a strong relationship between the concentration of information industries and physical and virtual telecommunications infrastructure. The deregulation of the telecommunications industry in the United States is favoring focused, market-based investment decisions in new telecommunications technologies over universal deployments, and as a result there is a great disparity among cities with regard to the telecommunications capabilities that are available for businesses and homes. However, as has been shown, providers are often prone to segment their networks by using intermediate nodes on long-distance links. Distressed cities and remote areas can and should lobby regulators and corporations to provide these types of arrangements whenever possible. Although there is no clear evidence that merely providing access to telecommunications infrastructure will generate economic development, at the very least it is a prerequisite for competition in attracting and fostering new businesses.

Third, public officials and urban planners should recognize the importance of information infrastructure in economic development and formulate research agendas that include systematic data collection about investment and deployment of new telecommunications technologies. The Internet backbone has grown from a handful of federally subsidized sites exchanging a few thousand e-mails per day to a major industry threatening the viability of century-old communications companies. The flow of information in, through, and out of a city is an essential element of urban economic life, yet we lack both the political desire and the necessary tools to gather this data. The physical infrastructure that helped to shape earlier urban forms—the seaport, the railroad, and the highway—is being superceded by a new network of optical fibers, Cisco routers, cellular antennas, and mobile telephones, yet we have not turned our attention to meeting this challenge.

Fourth, the uneven geographic diffusion of Internet technologies can no longer be doubted; it exists not just between rural and urban areas, to which some attention has been paid but also among the largest cities and metropolitan areas. There is a compelling need for public policies that can foster investment in telecommunications infrastructure and the creation of a skilled workforce that will allow workers to utilize it. Those without adequate skills to process and handle information will not be able to compete in the labor market as higher levels of technological skill become essential to gain and hold employment. The widespread deployment of advanced telecommunications systems is affecting all urban activities, and illiteracy in information and communications technologies may contribute to an increasing "digital divide" in the social and political sphere as well.

Finally, our findings show that the infrastructure that supports the production and movement of information is now a major unifying structure within our cities and metropolitan areas, rather than a contributor to their destruction. The data presented in this article refute claims that advances in telecommunications technology will lead to urban decline, yet these misleading explanations remain powerfully simple. On the contrary, Internet backbone networks are rapidly integrating the social and economic metabolism of major metropolitan areas, using speed to overcome distance. These same technological advances are permitting individuals and firms in urban areas to adapt their activities creatively in highly complex ways, both organizationally and spatially, and thus to remain competitive and vital in the global economy. Our cities and metropolitan areas are undergoing a massive transformation due to the introduction of these technologies, yet we have barely begun to take notice, let alone understand and react.

NOTES

1. Post, print, radio, telephony, and television.
2. MapNet, http://www.caida.org/Tools/Mapnet/
3. While the bottleneck between the telephone company's central switching offices and the home (the so-called "last mile") has received far more attention in recent years, the intermetropolitan capacity bottleneck has been an issue since at least the early 1980s.
4. Metropolitan Fiber Systems, "Metropolitan Area Ethernets" (MAEs), are the best example of this type of local infrastructure. However, the fiber networks of regional Bell Operating Companies as well as emerging data networks provided by cable television operators are also substantial components of metropolitan data networking infrastructure.
5. The following is a list of backbone nodes aggregated at the metropolitan area level. Links between cities in the same metropolitan area were excluded from this analysis. *Los Angeles, CA*: Anaheim, CA, Orange, CA, and Rialto, CA. *Washington, DC*: Bethesda, MD, Herndon, VA, McLean, VA, Reston, VA, and Vienna, VA. *Boston, MA*: Cambridge, MA. *Miami, FL*: Fort Lauderdale, FL, Pompano Beach, FL. *Chicago, IL*: Downers Grove, IL, Schaumburg, IL, Willow Springs, IL. *New York, NY*: Whippany, NJ, Trenton, NJ, Hackensack, NJ, Newark, NJ, Pennsauken, NJ, West Orange, NJ, White Plains, NY, and Troy, NY. *San Francisco, CA*: Concord, CA, Hayward, CA, Oakland, CA, Palo Alto, CA, San Jose, CA, San Rafael, CA, Santa Clara, CA, and Santa Rosa, CA.
6. Mbps, megabits per second. A DS-3 line, operating at 45 Mbps, is over 1600 times as fast as the typical 28.8-kilobits per second modem now standard on most personal computers.

REFERENCES

Abler, Ron. 1970. What makes cities important. *Bell Telephone Magazine.*

Baran, Paul. 1964. On distributed communications: I. Introduction to distributed communications networks. RAND Memorandum RM-3420-PR. Santa Monica, CA: RAND.

Boardwatch Magazine Internet Service Providers Quarterly Directory. 1997. Fall. Littleton, CO.

Boardwatch Magazine Internet Service Providers Quarterly Directory. 1999. Winter/Spring. Littleton, CO.

Cairncross, Frances. 1997. *The death of distance.* Cambridge, MA: Harvard Business School Press.

Campanella, Thomas J. 1998. Antiurbanism and the image of the city in new media culture. Paper given at Imaging the City faculty colloquium, Department of Urban Studies and Planning, Massachusetts Institute of Technology, Cambridge, MA, fall. <http://web.mit.edu/imagingthecity/www/abstracts.html>

Castells, Manuel. 1996. *The rise of the network society*, Vol. I. Cambridge, MA: Blackwell.

Claffy, K., and Huffaker, Brad. Macroscopic Internet visualization and measurement. National Laboratory for Applied Network Research. <http://www.caida.org/Tools/Mapnet/summary.html>

Dawson, Keith. 1998. The Net handles the Starr Report in stride. *Tasty Bits from the Technology Front*, September 14. <http://www.tbtf.com/archive/0161.html#s01>

de Repentigny, François, and Khanna, Kiran. 1997. Internet telephony: Form and functionality. Frost & Young, July. <http://www.frost.com/verity/newsletter/telecom/97-07/art01.htm>

Freidmann, John, and Wolff, Goetz. 1982. World city formation: An agenda for research and action. *International Journal of Urban and Regional Research* 6:309–344.

Gilder, George. 1995. *Forbes ASAP* February 27:56.

Gottman, Jean. 1961. *Megalopolis.* Cambridge, MA: MIT Press.

Gottman, Jean. 1977. Megalopolis and antipolis: The telephone and the structure of the city. In *The social impact of the telephone*, ed. Ithia de Sola Pool. Cambridge, MA: MIT Press.

Graphics, Visualization, and Usability Center, Georgia Institute of Technology. 1995. GVU's NSFNET backbone statistics. <http://www.cc.gatech.edu/gvu/stats/NSF/Extrap.GIF>

Greenstein, Shane. 1998. Universal service in the digital age: The commercialization and geography of US Internet access. January. <http://skew2.kellogg.nwu.edu/~greenste/research/papers/ISPACCES2.pdf>

Hall, Peter. 1997. Modeling the post-industrial city. *Futures* 29(4/5).

Hepworth, Mark. 1990. *The geography of the information economy.* New York: Guilford Press.

Inetco Corporation. 1999. San Francisco Bay Area tops list of wired cities, INETCO survey finds. 1 February. <http://www.inetco.com/public/pu990201.htm>

Joint Venture Silicon Valley Network. 1998. Silicon Valley comparative analysis. January. <http://www.jointventure.org/resources/analysis/intro.html>

Kolko, Jed. 1998. The death of cities? The death of distance? Evidence from the geography of commercial Internet usage. Unpublished paper, Harvard University, Cambridge, MA.

Lynch, Kevin. 1960. *The image of a city*. Cambridge, MA: MIT Press.

Malecki, E. J., and Gorman, S. P. In press. Maybe the death of distance, but not the end of geography: The Internet as a network. In *Wired worlds of electronic commerce*, eds. S. D. Brunn and T. R. Leinbach.

Moss, Mitchell L., and Townsend, Anthony M. 1996. Leaders and losers on the Internet. Taub Urban Research Center, New York University, September. <http://urban.nyu.edu>

Moss, Mitchell L., and Townsend, Anthony M. 1997. Tracking the 'Net: Using domain names to measure the growth of the Internet in U.S. cities. *Journal of Urban Technology* 4(3).

Moss, Mitchell L., and Townsend, Anthony M. 1998. Spatial analysis of the Internet in U.S. cities and states. Paper given at Urban Future—Technological Futures Conference at Newcastle, England, 23–25 April. <http://urban.nyu.edu/>

Murnion, Shane. 1999. Cyber-spatial analysis: Modelling web server information flows. Paper given at NCGIA Project Varenius Specialist Meeting on Accessibility in the Information Age, Pacific Grove. CA, 20–22 November. <ftp://www.artsci.washington.edu/nsfPapers/murnion.doc>

Negroponte, Nicholas. 1995. *Being digital.* New York: Knopf.

Nunn, Samuel, and Warren, Robert. 1997. Metropolitan telematics infrastructure and capacity for economic development in the information society. Bloomington: Center for Urban Policy and the Environment, Indiana University.

Orlikowski, Wanda. 1999. The truth is not out there: An enacted view of the "digital economy." Paper given at Understanding the Digital Economy, 25 May, U.S. Department of Commerce, Washington, DC. <http://mitpress.mit.edu/UDE/orlikowski.rtf>

Pew Research Center for the People and the Press. 1996. Fall off greater for young adults and computers users: TV news viewership declines. 13 May. Washington, DC.

Pred, Allan R. 1973. *Urban growth and the circulation of information.* Cambridge, MA: Harvard University Press.

Quarterman, John S. 1990. *The matrix: Computer networks and conferencing systems worldwide.* Bedford, MA: Digital Press.

Rickard, Jack. 1997. The Internet—What is it? *Boardwatch Magazine—Internet Service Providers Quarterly Directory.* Fall. Littleton, CO.

Salus, Peter, H. 1995. *Casting the Net: From ARPANET to INTERNET and beyond.* New York: Addison-Wesley.

Sassen, Saskia. 1995. On concentration and centrality in the global city. In *World cities in a world system*, eds. Paul L. Knox and Peter J. Taylor. Cambridge, England: Cambridge University Press.

Saxenian, Annalee. 1994. *Regional advantage: Culture and competition in Silicon Valley and Route 128.* Cambridge, MA: Harvard University Press.

Shapiro, Andrew. 1999. The Net that binds: Using cyberspace to create real communities. *The Nation* 21 June. <http://www.thenation.com/issue/990621/0621shapiro.shtml>

Thrift, Nigel. 1996. New urban eras and old technological fears: Reconfiguring the goodwill of electronic things. *Urban Studies* 33(8).

Toffler, Alvin. 1980. *The third wave*. New York: William Morrow.

Townsend, Anthony. In Press. Networked cities and the global structure of the internet. *American Behavioral Scientist.*

Townsend, Anthony M., Murnion, Shane, and Dodge, Martin. 1999. NetCensus: Planning for an Internet census. April. <http://www.netcensus.org>

Werbach, Kevin. 1997. Digital tornado: The Internet and telecommunications policy. March. Washington, DC: Federal Communications Commission.

Zook, Matthew. 1988. The web of consumption: The spatial organization of the Internet industry in the United States. Paper prepared for the Association of Schools of Planning Conference, Pasadena, CA, 5–8 November. <http://socrates.berkeley.edu/~zook/pubs/acsp1998.html>