Network Cities and the Global Structure of the Internet

ANTHONY M. TOWNSEND
New York University

Cities have played an important role in the process of globalization as centers for information exchange. Urban scholars note that a handful of dominant financial services centers—so-called global cities—has dominated international telecommunications networks. Yet, these and others have failed to understand how new telecommunications technologies, particularly the Internet, are enabling a far broader diffusion of international interurban connectivity, a far more complex global web than in earlier eras. This article presents evidence on the Internet backbone in which traditionally dominant urban hubs for international communications—London, New York, and Tokyo—are increasingly being supplemented by other hubs within their regions. The global structure of the Internet reflects a shift in the geography of telecommunications networks and the emergence of a network of network cities. To cope with this challenge, urban planners are urged to address three issues: dependency on other cities and urban areas, accessibility to global Internet backbone networks, and proficiency with communications technology.

One of the greatest ironies of the age of globalization has been the continued prosperity and growth of cities. Even while new technologies permit firms, households, and individuals an unprecedented degree of locational freedom and mobility, the forces of agglomeration driving urbanization throughout the world remain powerful. According to the World Bank, by 2000, about 50% of the world's population lived in urban areas, compared with 36% in 1970 and just 28% in 1950. This period of rapid urbanization occurred at the same time as new information and communications technologies began to be widely deployed by institutions throughout the world.

Throughout the 1960s and even today, futurists and pundits have frequently pronounced the death of cities. Arguing that new communications technologies rendered the density of cities unnecessary for conducting business or cultural activities, they interpreted the spatial reorganization of corporate activity (globalization) as a loosening of ties between economic activity and locational

Author's Note: *This material is based on work supported by the National Science Foundation under Grant No. SBR-9817778, Information Technology and the Future of Urban Environments. The author would like to acknowledge the cooperation of Martin Dodge in collecting data to complement this analysis with a European perspective, and Bram Dov Abramson of Telegeography, Inc. for supplying additional background data and insightful criticism.*

AMERICAN BEHAVIORAL SCIENTIST, Vol. 44 No. 10, June 2001 1697-1716

proximity. (See Graham & Marvin, 1996, for an exhaustive survey of this literature.) In contrast, urban scholars have argued that the continued success of cities lies in their key role in this process of globalization, as sites where transnational flows of goods, capital, and people are tied into national and regional economies, and far-flung corporations concentrate decision-making and coordination functions (Sassen, 1997). As these far-flung, horizontally integrated "network corporations" have become the norm, a select group of cities with access to the world through the most advanced air transportation and telecommunications networks has emerged. Combining a highly skilled workforce with advanced information technology, these cities have achieved a high degree of efficiency in producing and transmitting nonstandard information, as well as disseminating it through branch offices and the media (Moss, 1987). As a result of their unique position at the crossroads of a rapidly growing flow of international exchange, so-called global cities have experienced dramatic internal transformations in economy, society, and politics over the past quarter-century (Friedmann & Wolff, 1982). New York, Tokyo, and London are the prototypical examples of this type of city.

However, the global cities concept has always been a dubious one. It is now clear that many commonly cited examples of global cities, such as Chicago or Paris, hardly compete with smaller cities in terms of global connectivity to new telecommunications networks like the Internet. This article presents evidence that new telecommunications networks reflect a more complex system of interurban information flows than that proposed by proponents of the global city hypothesis, connecting more cities in more varied ways.

This article challenges the assumption that global cities dominate all forms of international information exchange, specifically those conducted on new telecommunications networks such as the Internet. These findings corroborate earlier evidence that many large, dense metropolitan clusters of Internet activity exist outside the archetypical global cities of New York, London, and Tokyo (Townsend, 2001; Zook, 2000). Whereas past telecommunications networks did primarily converge in global financial centers, new telecommunications infrastructures are more dispersed, stitching together a network of network cities into a highly complex global urban economy. As will be seen, this also means global cities increasingly rely on indirect connectivity through other cities for international telecommunications.

This article presents this argument in the following manner. First, a description of the purpose and function of backbone networks, the trunk lines of the Internet, is presented. Next, an experiment using *traceroute*, a standard piece of network diagnostic software, illustrates the unique role of the United States as global hub for the Internet. To illustrate how global cities have fared in the rapid and massive deployment of Internet networks, a comprehensive map of New York City's international linkages through the Internet is examined. Finally, the basis for economic competitiveness and the challenges to city planning in this complex networked urban world are investigated.

Whereas other vital urban infrastructure networks are easily identified by the average citizen, telecommunications networks like the Internet are largely invisible, even to skilled planning professionals. This "soft transformation" of the urban landscape, best described by Mitchell (1999), threatens to shape an entire generation of new cities (and dramatically transform older ones) without the slightest pause for considerations of livability, sustainability, or civic life. This article argues that awareness of global telemediated connections permeating everyday physical places must influence every level of city design and planning. By developing plans and policies that encourage smart dependency on other urban areas, better and more equitable accessibility to telecommunications infrastructure, and proficiency in the use of information technology, local governments can dramatically improve conditions for long-term economic growth.

GLOBAL INTERNET BACKBONE NETWORKS

There is little need to review the phenomenal growth of the Internet in the latter half of the 1990s. The ubiquitous dot-com, printed on everything from soft drink cups to commercial airliners, was but the most visible symbol of the everyday acceptance of this new communications technology. Despite the onset of global warming and the emergence of human pathogens such as BSE (mad cow disease) that can survive incineration, hospital disinfectants, and irradiation, this decade is likely to be characterized by future historians as the Network Nineties.

However, the rapid development of the Internet has obscured understanding of its precise functioning and structure. The Internet is often portrayed and almost always perceived as a magical black box that invisibly and effortlessly produces documents on demand. Yet, many complex layers of computer hardware and software are necessary to perform even simple tasks such as sending an e-mail message, and these systems are linked together in networked structures of high complexity and interdependence. Even a basic dial-up connection to an Internet service provider involves the execution of dozens of codependent software programs on several computers at both ends of the link.

Backbone networks are a key layer of Internet technology, connecting a geographically scattered array of computers, fiber optic networks, and satellite relays into a navigable cyberspace. Traversing rights-of-way alongside highways or railroad lines, running under the sea and via satellite, they connect metropolitan areas throughout the world by linking together routers, the specialized high-performance computers that manage the flow of data where two or more network links meet. In essence, backbone networks are the trunk lines of the Internet.

Like much else on the Internet, a backbone is actually only virtual, a logical construct that defines how physical network components will interact to transport packets of data from point to point. Backbone networks represent a level of abstraction that separates the very real physical infrastructure of wires and fiber from the Transmission Control Protocol/Internet Protocol (TCP/IP) connections that they facilitate, which are completely ignorant of geography and are actually a service rather than a physical object. Often, backbone networks are operated via channels on high-speed data lines leased from long-distance or regional telephone companies. In many cases, the only physical infrastructures actually owned by backbone operators are routers, the powerful computers that manage the flow of data packets at junctions in the network (Rickard, 1997).

These networks have grown rapidly over the past 25 years. The first international connection on the Internet's predecessor, ARPANET, was established via satellite between a Washington, D.C.–area research facility and University College London during the 1970s (Salus, 1995). Foreshadowing the Internet's eventual commercial maturity, this link relied on commercial satellites owned by Intelsat rather than government or military satellites (Kristula, 1997). However, by mid-1999, more than 20 companies operated backbone links between London and New York alone, with a total data capacity tens of thousands of times greater than that first feeble satellite link on the ARPANET.

GLOBAL STRUCTURE: THE UNITED STATES AS THE CENTER OF THE INTERNET

The spread of the Internet among nations has been unequal, similar to the diffusion of earlier telecommunications technologies such as the telephone, television, and radio. To a large extent, the Internet connectivity of a country is related to its level of development, financial and technical resources, and culture (Hargittai, 1998). Comparing the level of development of more traditional infrastructure systems such as electricity and telephone networks to that of the Internet, Arnum and Conti (1998) found that nations with well-developed traditional network infrastructures such as roads and telephone systems also proceeded rapidly with deployment of Internet infrastructure. This is not surprising, for Internet infrastructure is often a retrofit on existing telephone networks and cable television systems. Also, new fiber optic cable is often buried in shallow trenches alongside railroad and highway rights-of-way.

The United States has a special role in the development of global computer networks. The basic technologies that underlie the Internet were first developed by research funded through the U.S. Department of Defense's Advanced Research Projects Agency (ARPA). Throughout the 1970s, ARPA expanded the geographic scope of its research network (ARPANET) to cover the entire continental United States. However, it was not until the 1980s that the Internet (as it had come to be known) began expanding internationally in a significant way. With the military portions of ARPANET spun off into MILNET in the early 1980s, the National Science Foundation (NSF) took over responsibility for funding computer network infrastructure in the United States. In 1991, NSFNet established links to scientific research centers in Sweden and southern France and, by 1995, had added several higher capacity links to London and Paris (Goldstein, 1995).

By the early 1990s, the United States possessed the most developed computer networks in the world, the most aggressive telecommunications companies, and the most widely visited sources of information on the Internet. As this technology began to take root overseas, it became increasingly urgent for other countries to link their national research networks to the Internet directly through the United States. Furthermore, Internet access providers in foreign countries had and continue to have powerful economic incentives to link to the United States rather than other networks in their own country or region.

For example, Cukier (1999) noted that it is often cheaper for national service providers to lease high-capacity Internet connections (from American companies) from any European capital to the United States than from one capital to another within the continent (from European telecommunications companies). Although this imbalance is rapidly disappearing, direct links to the United States also permit better access to the most popular Web servers, such as Yahoo! Thus, this arrangement often makes sense on purely technical grounds. Yet, even this situation is quickly changing, as new content-delivery networks such as Akamai's FreeFlow or Digital Island's FootPrint bring distribution points for Web content closer to end users by caching data files at servers on different networks throughout the world (Akamai Technologies, 2000; Digital Island, 2000).

Today, as a result, whereas every region and nearly every country has a direct Internet connection to the United States, direct connections between other countries are less common. Furthermore, direct connections between different major regions such as Asia and Europe are practically nonexistent. As Table 1 indicates, the United States still serves as a central switching facility for interregional data traffic.

This structure dictates that the U.S. Internet infrastructure functions as a massive switching station for traffic that originates and terminates in foreign countries.[1] Figure 1 demonstrates how the United States is used as a transit point for data packets traveling from one major region to another. Using a software tool called *traceroute* that diagnoses problems in Internet connections, it is possible to determine the pathway that data packets take from one computer on the Internet to another.[2]

The first example is a trace from University College London to the Web site of an Australian Internet service provider (see Figure 1). Unlike a telephone transmission, which sets up a dedicated circuit that remains open between caller and receiver, Internet data travel in discrete, destination-marked packets more similar to the way letters are transmitted through a postal system. After leaving the university, data packets cross the Atlantic on a dedicated link to New York leased by JANET, the United Kingdom's scientific research network, and transit the United States on the UUNet network. Arriving in Los Angeles, they leave for Sydney, where they will be offloaded onto the Australian Internet service provider's network. Although traceroute's output does not reflect the precise path-

TABLE 1: Interregional Internet Bandwidth, 1999 (in megabits per second)

	United States/Canada	*Europe*	*Asia/Australia*	*Latin America*
United States/Canada				
Europe	13,258			
Asia/Australia	5,916	152		
Latin America	949	63	0	
Africa	170	69	3	0

SOURCE: Data are from Telegeography, 2000.

way taken between any set of Internet computers for several obscure technical reasons, it does offer a reasonable approximation (Carl, 1999). The results are straightforward and useful in identifying the endpoints and operators of international backbone links to an area about as precise as a metropolitan area.[3] Finally, this example illustrates how nearly all Internet traffic that travels between major regions such as Asia, Europe, Latin America, and Africa is routed through the continental United States.

The second example illustrates how even traffic within a major region can transit through the United States, due to a lack of interconnection among networks outside America (Figure 1). Even the most networked countries of Europe often lack sufficient interconnections and rely on American networks to connect to each other. (Once again, however, this is rapidly improving.) This figure shows the path of a trace from London to Helsinki, Finland. Although Finland is consistently ranked among the top five most “wired” nations on the planet (Hutchison, 2000), its Internet connectivity to the outside world is largely through Stockholm, Sweden, and to a lesser extent, Frankfurt, Germany. There are much shorter routes that the trace might have taken through Europe, but a lack of interconnection agreements among national data network operators in individual countries forces traffic through the United States.

These inefficiencies have largely been eliminated within the United States, where a number of convenient peering points have been set up in major metropolitan areas. In Europe and Asia, however, national boundaries and the much higher expense of intraregional bandwidth versus overseas connections to the United States have resulted in a global network structure based on interconnection within the United States. This is both technically inefficient for data exchange between European countries and undesirable from a policy standpoint (Cukier, 1999).

For traffic between regions, it is unlikely that this pattern will change quickly. The United States is both geographically and culturally located at an ideal position as a mediator between Europe, Asia, Australia, and Latin America. Furthermore, for at least a decade, American companies have aggressively dominated

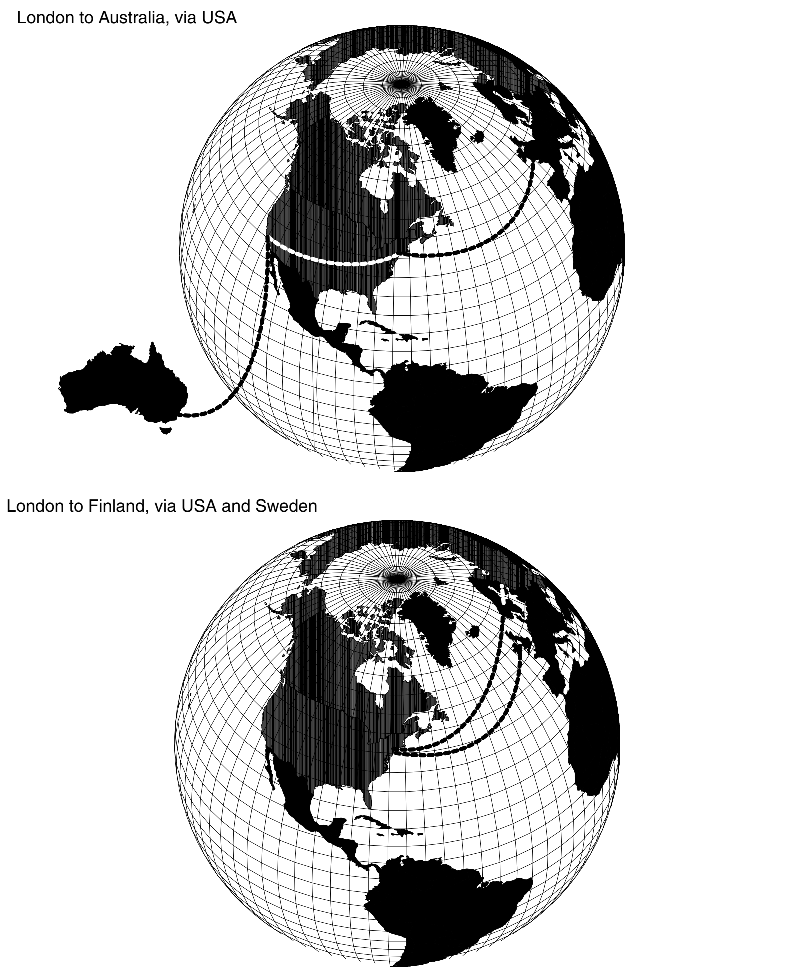

Figure 1: Global Structure: The United States as the Center of the Internet

the global telecommunications industry and constructed networks primarily designed to meet the connectivity needs of American businesses.

For Internet traffic within regions, such as Europe and Asia, there are signs that the situation is improving rapidly. The proliferation of panregional networks such as A-Bone and E-Bone (Asia and Europe, respectively), as well as regional Internet exchanges such as the London Internet Exchange (LINX) and Singapore Telecom Internet Exchange (STIX), should reduce the importance of the United States as a switchboard for intraregional traffic. As this article goes to press, quotes retrieved from online bandwidth exchanges indicate that price is rapidly being eliminated as a deterrent to intraregional interconnection. For example, the lowest quote for E1 (2048 kb/sec) service between New York and London is about $5,000, between London and Paris just $1,000. Yet, pricing inequities remain. The same service between London and Amsterdam can cost 2 to 3 times as much, even though the geographic distance is much shorter.[4] Furthermore, the one critical link for most overseas Internet service providers is the one to the United States (for Web content), and they will be much slower to invest in new links within their own region.

GLOBAL CITIES, INTERNATIONAL LINKAGES, AND THE INTERNET: THE CASE OF NEW YORK

Given the global structure of the Internet backbone described in the preceding section, the next question to ask is what are the roles of cities as nodes or hubs on these new communications grids?

First, direct international telecommunications has been extended to a broader set of cities and metropolitan areas than past technologies. This proliferation of international Internet links is diminishing the variations in access to telecommunications technology that have traditionally separated global cities from less important regional hubs. However, to accept this statement, one must understand a subtle difference between physical telecommunications infrastructure and the virtual nature of Internet backbone networks.

The submarine cable systems that carry most international communications follow a rigid hierarchy of national, regional, and interregional aggregation points (Zsalanky et al., 1995). In theory, Internet backbone networks ought to follow the same geography. However, backbone connections actually represent a service: a guaranteed data transmission rate between two TCP/IP routers. A backbone link can operate by any medium: fiber optic cable, satellite, even smoke signal. Therefore, it is not uncommon for backbone service between two cities to transit other cities transparently. What is of interest to urban scholars is not the physical pathway but the endpoints of the connectivity package being delivered.

In addition, the rapid and recent development of fiber optic networks and the ability to reconfigure backbone networks in near real-time to these infrastructure improvements have created the opportunity for shifts in the geography of international communications. Additional backbone capacity can be rapidly deployed on popular routes simply by installing new routers. Because of these developments, the global geography of information and capital flows that underlies the global cities concept is in a dramatic state of flux, and a new group of metropolitan areas is rising in importance in these new international communications networks.

Whereas global cities remain important and the ties between them are greater than ever, they no longer serve as the sole intermediaries for international communications networks but now are complemented by a competing set of international telecommunications links that are ushering in a less centralized global network. A note of caution is in order, however, lest this article overstate the degree of transformation. As Koffman and Odlyzko (1998) reported private data networks still have greater capacity than all public Internet backbones combined. It is very likely that these private networks are most highly concentrated near global cities and the financial institutions that have their headquarters there. However, the Internet is growing much faster than these private networks, especially since the development of Virtual Private Networking (VPN) technology, which uses sophisticated encryption techniques to create secure connections over public Internet backbone networks. Specifically, a much wider range of cities appears to be gaining importance in the rapidly evolving global structure of Internet backbone networks.

In Asia, Singapore and Hong Kong are engaged in intense competition to become one of the region's primary Internet hubs, although they both already play this role. And Seoul rivals Tokyo as a major consumer of international transmission capacity (see Table 2).

In Europe, London remains a critical hub for network links to the United States, yet, Amsterdam and Frankfurt are increasingly popular, more centrally located alternatives for interconnection and links to the United States and other European cities (see Table 3). Paris, on the list of Sir Peter Hall's original world cities in his 1961 book of the same name, ranks fourth among European cities. As the dominance of English on the World Wide Web inevitably fades in coming years, London may lose even more of its importance for transatlantic Internet links.

This shifting away from a single, dominant regional hub in Europe and Asia is also reflected in a number of recent corporate movements, such as Intel's strategic investment in international Internet providers based in Amsterdam and Singapore ("Intel Discloses," 1999). The online bandwidth exchange, RateXchange, also has identified this "hub dispersion effect." It has added Frankfurt and Hong Kong to its existing system for trading excess capacity on networks linking New York, Tokyo, and London.

In the United States (although New York is clearly an exception), Washington, D.C., San Francisco, and Seattle—never considered global cities—have emerged as major international Internet hubs. Each of these three regions has equal or better international Internet links than Chicago or Los Angeles, typically considered global cities by most urban scholars (see Table 4).

New York's dominance is better understood by looking more closely at the composition of its international linkages versus an emerging hub such as San Francisco. As Tables 5 and 6 clearly indicate, geographic proximity determines much of how international Internet backbone links are deployed. New York

TABLE 2: International Backbone Hubs in Asia

City	*International Backbone Capacity (Mbps)*
Tokyo	2,393
Seoul	1,106
Hong Kong	541
Singapore	497
Taipei	324
Kuala Lumpur	188

SOURCE: Data are from Telegeography, 2000.
NOTE: Mbps = megabits per second.

TABLE 3: International Backbone Hubs in Europe

City	*International Backbone Capacity (Mbps)*
London	17,969
Amsterdam	10,874
Frankfurt	10,516
Paris	9,687
Brussels	6,213
Geneva	5,947

SOURCE: Data are from Telegeography, 2000.

SOURCE: Data are from Telegeography, 2000.
NOTE: Mbps = megabits per second.

TABLE 4: U.S. International Internet Hub Cities

City	*International Backbone Capacity (Mbps)*
New York	13,205
Washington, D.C.	3,998
San Francisco	3,950
Chicago	2,666
Seattle	2,607
Los Angeles	740

SOURCE: Data are from Telegeography, 2000.
NOTE: Mbps = megabits per second.

primarily links the East Coast of the United States with Europe, whereas San Francisco primarily links the West Coast to Asia and the Pacific Rim. New York is not directly linked to Asia in a significant way, nor is San Francisco directly linked to Europe.

In addition, both cities show a similar distribution of link capacity across cities. Each is tightly linked to another dominant regional communications hub,

TABLE 5: New York's International Internet Connections

Destination	*Capacity*	*Percentage of Total*
London	5,212	39.5
Toronto	1,085	8.2
Frankfurt	936	7.1
Amsterdam	910	6.9
Montreal	820	6.2
Stockholm	668	5.1
Rest of world	3,574	27.1
All New York City international capacity	13,205	100.0

SOURCE: Data are from Telegeography, 2000.

TABLE 6: San Francisco's International Internet Connections

Destination	*Capacity*	*Percentage of Total*
Tokyo	1,487	37.6
Seoul	752.3	19.0
Sydney	541	13.7
Hong Kong	361	9.1
Singapore	229	5.8
Rest of world	579.7	14.7
All San Francisco capacity	3,950	100.0

SOURCE: Data are from Telegeography, 2000.

with lesser links to the emerging hubs identified earlier. Although precise data are not available, it is expected that the share of these emerging hubs should increase as their infrastructure and markets are further developed.

Further insight into how international backbone connections are used by Internet users in a particular city can be investigated experimentally. The case of New York City offers additional evidence on the diffusion of international connectivity across a wide array of cities. Exploiting the possibilities of traceroute for mapping the geography of backbone networks, a series of probes were run from New York University to create a map of Internet linkages between New York and the rest of the world. This survey used a list of 205 Internet sites in 78 different countries, which were accurately probed using the traceroute program. These measurements were double-checked from the Massachusetts Institute of Technology in the Boston metropolitan area, which is linked to international and even many domestic backbone networks through the New York metropolitan area.

Foreign countries are generally connected to the Internet in the United States through backbone connections to one or (often) two major metropolitan areas.

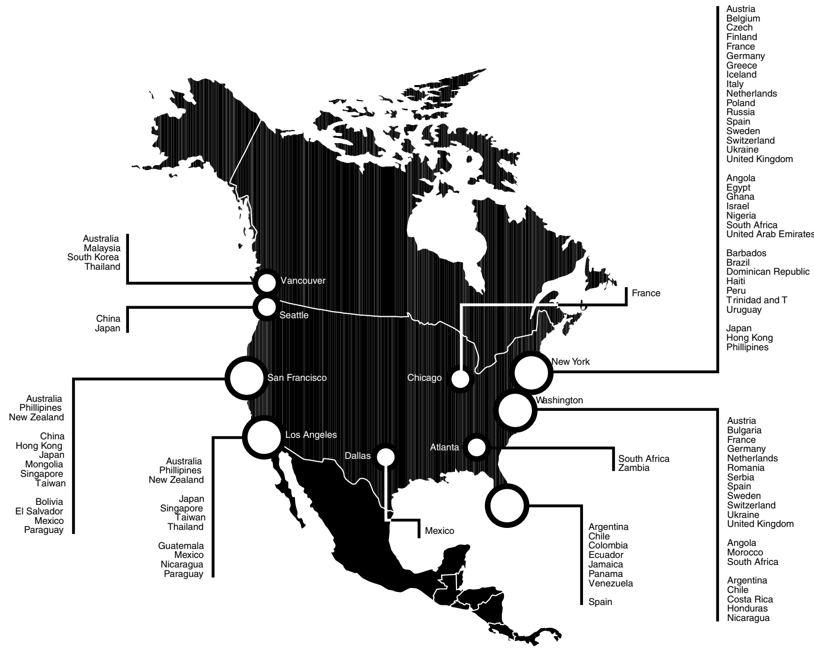

Figure 2: Gateway Cities for International Internet Connections

Thus, data traveling to these countries are routed through continental U.S. networks to the gateway city, where it is transferred to an international link for delivery to the foreign country. Figure 2 shows how links from New York City to 75 countries in five major regions are structured. This map should not be mistaken for a comprehensive picture of international Internet connections coming into the United States, as it only shows how these connections are accessed by one service provider (NYUNET) located in the New York area.

The most important evidence from Figure 2 is that a highly diverse set of metropolitan areas participates in connecting New York's Internet users with the rest of the world. Despite New York's overwhelming dominance of U.S. international backbone capacity (it has more than 3 times that of Washington, the second largest hub), Internet users in New York rely heavily on other metropolitan regions for international connectivity. Four cities (Los Angeles, San Francisco, Seattle, and Vancouver) facilitate 15 links to Asia in addition to the 2 direct links that were identified from New York to Japan and Hong Kong. Sites in Europe are highly likely to be connected to New York indirectly through the Washington area, the primary hub for backbone networks on the East Coast of the United States. Both Miami and Washington play a key role in facilitating connections to

Latin America and the Caribbean. Finally, for only a single region, Africa and the Middle East, does New York not rely heavily on other cities for connectivity.

It is tempting to argue that the structure of international Internet links suggested by this map reduces many of the traditional advantages for global cities like New York. Rather than serving as a hub for highly centralized, private communications networks as it has since the 1960s, are New York and other global cities now merely nodes on a vast decentralized global communications grid, where no one city is truly important?

Unfortunately, there is not enough information to provide an answer to this question. First, it is clear that the physical role of New York as a place for international connections is no longer unique. Although it is still America's leading telecommunications hub, the Washington metropolitan area plays a major role in connecting New York to Europe and offers competitive connectivity to local firms seeking to do business internationally. Furthermore, far greater domestic connectivity (Moss & Townsend, 2000), Washington, D.C., is certainly an alternative rival gateway to Europe.

Furthermore, as Figure 3 shows, the time required for data to travel domestically across the Internet is small in comparison to the much larger times required to reach foreign cities. Although Boston has very few international backbone connections of its own, the time delay (or latency) between Boston and New York is a small fraction of the total time involved in international Internet communications.[5] When communicating with sites in London, Boston is at a 12.5% time disadvantage to New York (80 ms from Boston versus 70 ms from New York). However, this disadvantage generally decreases as the distance to the destination increases. When communicating with Tokyo (5.5%) or Sydney (2.5%), the differential is much less, and for locations such as Sao Paulo (1.8%) or Cape Town (1.6%), it is almost undetectable.

These delays are usually insignificant to the average Internet user, beneath the threshold of detectability. However, for large Internet or other intensive users, these types of delays quickly accumulate and become a major technical obstacle. It is just such content-delivery problems that have led to the development of highly sophisticated networks for caching synchronized Web content throughout the world, rather than at a single information provider's corporate headquarters. A number of firms, such as Akamai Technologies, Digital Island, and Metromedia Fiber Networks, have parlayed these solutions into a combined market valuation of more than $25 billion.

Finally, if we consider cities further inland, the delay becomes even more significant. The clustering of large facilities for Web site servers at major international exchange points in the San Francisco and Washington, D.C., metropolitan areas—called "server farms," Internet data centers, or "telehouses"—indicates that certain geographic locations do, indeed, have advantages in the temporal space of the Internet. In fact, these few urban nodes represent the most highly connected points in the network, critical to maintaining interconnectivity (Albert, Jeong, & Barabasi, 2000). This pattern is linked to the convergence of

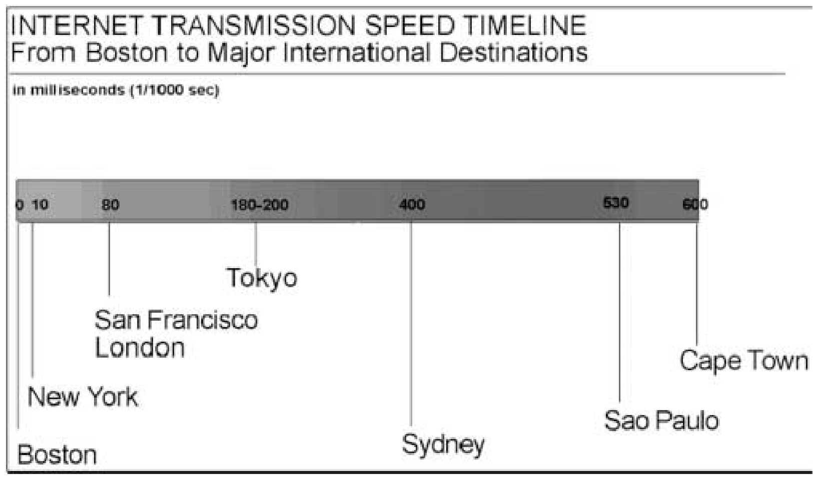

Figure 3: Internet Transmission Speed Time Lines

networks in a handful of important metropolitan areas, where mutual benefits are reaped through interconnection. Coastal cities, due to their proximity to undersea fiber optic cables, are particularly favored (Gorman, 1998).

THE NETWORK OF NETWORKED CITIES: IMPLICATIONS FOR URBAN PLANNING

This article has questioned some of the myths regarding globalization and cities. It has attempted to illustrate how new telecommunications technologies are being deployed to permit international linkages between cities that are dramatically different than those supported by earlier systems. As a result, although it finds that global cities do not dominate the global geography of the Internet, they are important nodes. More of interest are the new communications hubs such as San Francisco, Frankfurt, and Hong Kong that are emerging from the shadows of the great financial centers such as New York, London, and Tokyo.

As the Internet supersedes, supplants, and enhances existing urban infrastructure networks for commerce and communications, it is dramatically transforming the structure of relationships among metropolitan areas. Rather than the clear hierarchy of interurban information flows between cities that typifies other means of communications (Abler, 1970; Mitchelson & Wheeler, 1994), these new networks are facilitating commerce, information exchange, and communications in ways that challenge urban theories based on a hierarchical division of labor and capital flows. The long-lasting impact of these new patterns should not be underestimated. Most of the world's major cities are still located on coast-lines or major rivers, an artifact of the shipping networks that once connected nations. It remains to be seen what effect the economics of packet-switched computer networks will have on the location of activities and development. This article merely seeks to establish that these networks, like any others, have a defined spatial structure that privileges some locations over others.

This experiment demonstrates that even global cities such as New York are highly dependent on a broad group of other metropolitan areas for international Internet connectivity. Extended to a global scale, it is clear that the Internet is both driving and reflecting broader trends toward far more complex webs of interurban economic and communications flows. This emerging network of network cities defies traditional geographic barriers on a global scale, greatly increasing the accessibility of each particular locale's specialized labor force to global markets. This has certainly been the case in cities such as Bangalore, India, where Western firms such as Microsoft and Oracle can capitalize on lower wages and time zones to cut production cost and time.

We should not be surprised to see the international urban system evolving in such a fashion. Ernst (1997) has shown that for the computer industry in Asia, telecommunications have been used increasingly to organize regionwide production networks that completely bypass traditional nodes of control. Groups of firms, linked in a dense web of contractual agreements and partnerships, can thus capitalize on the coordination of specialized local industrial clusters. Without the capabilities of new information and communications technology, these networks would be unmanageable.

Knowing this, what challenges await urban planners as they grapple with the implications of these new technologies? How can cities plan to take advantage of the growth of interurban communications or mitigate its negative consequences? This study suggests three primary interrelated areas of concern that need to be addressed immediately: dependency on other cities and urban areas, accessibility to global Internet backbone networks, and proficiency with communications technology.

DEPENDENCY

Dependency poses a very new set of challenges for the city builders of tomorrow. In the past, cities depended on their hinterlands for the raw materials and natural resources that fueled factories. Over the past two decades, most city boosters and urban critics have rallied around the idea of urban competitiveness, in which cities compete to attract footloose corporations. Yet, cities that are plugged in to new communications networks face a very different set of questions dealing with the antithesis of competitiveness, dependency. In the late 1990s, the air transportation system in the United States has reached a previously unthought-of level of efficiency and operates at record capacity. But the same real-time information management capabilities that make this possible have bound cities together in tightly coupled networks that are incapable of adjusting to disruptions at one point in the system (Gleick, 1999). Although prophecies of an Internet meltdown, most notoriously by technology columnist John Dvorak, have gone largely unfulfilled, outages in MCI's frame-relay network during the summer of 1999 had major effects on Internet traffic throughout the country. We still know little about how vulnerable new telecommunications networks are to these types of disruptions. For now, fierce competition and the redundancy and diversity of linkages that it encourages offer the best insurance policy for cities to avoid being vulnerable to these types of disruptions. Yet, the clear lesson is that when a network system fails or becomes congested in one city, that failure can spread very rapidly to other cities.

However, the vulnerabilities of dependency also offer opportunities for prosperity. In fact, it is likely that the cities with the most dependencies have and will continue to thrive the most. New strategies for capitalizing on dependencies and internetworking of urban economies are needed. The old competitive zero-sum game of economic development is no longer adequate, as the meager benefits and massive public expenditures on sports facilities in the 1980s and 1990s in American cities have shown. On a national scale, the United States has benefited by linking to other nations through the Internet, creating an entire new global industry in less than a decade. There are opportunities for local industries in the world's cities to employ the same strategies.

It is clear that urban planners and policy makers must now develop an increasingly complex conceptual model of their region's telemediated connections to the rest of the world. Just as technologies like the cell phone are blurring the boundary between the home, the automobile, the street, and the workplace, the Internet is blurring the boundary between cities, nations, regions, and the world. While architects are busy reconceptualizing the role of the home and office in an information-based economy, a parallel reassessment of city and regional planning has not occurred.

More information is needed before a thorough reconsideration of the role of cities in a global information- and communications-based economy can take place. This article offers a start at identifying the kinds of data that are necessary to measure urban performance on key measures such as accessibility and dependency. Without further development of these types of indicators, public officials and urban analysts in the cities of tomorrow will be incapable of fulfilling their roles as leaders and advisers.

ACCESSIBILITY

This article has shown that defining and representing accessibility to international Internet connections is challenging. However, it is clear that a divide is emerging between cities and regions that are well connected to the global Internet, and those that are not. But what can cities that are left off of new telecommunications networks do to change this?

There is a compelling argument for public subsidy and even operation of backbone links from disconnected cities to international backbone hubs. Much of this infrastructure could be overlaid on the existing telephone network and would offer one-hop global connectivity to many cities. At tens of thousands of dollars per month, the cost of a T-3 connection is insignificant compared with what is often spent on transportation or housing projects. Similar accessibility could be achieved by arranging for the Web sites of local businesses to be mirrored at server farms with better connectivity, perhaps under the aegis of a local economic development agency.

Finally, local governments can promote development of backbone connections by gathering and publishing information about local users of Internet services. The pace of growth and innovation in the Internet backbone industry has helped some cities where markets are large, dense, and easily identified. However, the sector has not stabilized for a sufficiently long period of time for companies to seek the slimmer margins of second- and third-tier markets.

PROFICIENCY

Although this study has focused on the infrastructural components of Internet diffusion, it must be remembered that the spread of Internet backbone networks primarily reflects broad variations in the acceptance of this technology among regions. Access to telecommunications infrastructure is a critical prerequisite for widespread use of Internet technologies to develop and market services on a global scale; however, it is seldom more than 10% to 15% of the total cost of deploying Internet technology (NYSERNET, 1996). The real cost lies in the training and ongoing maintenance required to use and sustain these incredibly complex technologies. Thus, although Singapore's "Intelligent Island" initiative brought fiber optic networks into nearly every home and business, the system is still underused. It is likely that a more selective process of deployment, coupled with extensive investment in skills and education, would have been more effective.

Approaching the development of networked cities with a focus on physical infrastructure, as is often done, will only lead to more failures. Telecommunications and information technologies are incredibly cheap, invisible, and nearly ubiquitous. However, at the same time, they are becoming increasingly sophisticated and complex. It is this very fact that lies at the heart of the information revolution that looms as the greatest challenge for planners. The virtual city of Web sites, e-mails, and intellectual property is just as important as the physical city of streets, bridges, and sewers. Cities need to invest in developing the navigational tools and workforce skills needed to traverse this new urban landscape.

APPENDIX

NOTES ON METHODOLOGY: MAPPING INTERNET BACKBONE NETWORKS WITH TRACEROUTE

Geographic information is often included in the names of host computers, particularly routers that arbitrate the flow of packets along major national and international backbone networks operated by companies such as TeleGlobe, Sprint, and AT&T, for example. Some firms use highly descriptive names:

Moscow12-FE2-0.RoSprint.net

This router, apparently operated by a Russian subsidiary of Sprint, is clearly located in the Moscow area. Other firms use more cryptic systems for nomenclature. AlterNet (operated by MCI Worldcom) prefers the use of airport codes:

290.ATM2-0.TR2.*EWR*1.ALTER.NET	Newark, New Jersey
222.ATM1-0.CR2.*AMS*.ALTER.NET	Amsterdam, Netherlands

AT&T uses a strange combination of city and state initials:

br1-p380. *cgcil*.ip.att.net	Chicago, Illinois
br1-p320. *sffca*.ip.att.net	San Francisco, California

Still others refer to the names of common network exchange points, such as:

icm-bb1-*pen*-6-0.icp.net	Sprint NAP, Pennsauken, New Jersey
p0-0-0. *maeeast*.bbnplanet.net	MAE-East, Washington, D.C. Metro Area

However, most firms are fairly consistent in applying these naming systems throughout their networks. In addition, the limited geographic database that accompanies a commercially available visual version of the traceroute program, GeoBoy,[6] is often useful in determining the location of hosts.

Finally, several additional tools exist for determining more information about backbone networks. Bing (Bortzmeyer, 1995) and pathchar (Jacobson, 1997) are both tools that attempt to measure the capacity of links on backbone networks, although they remain in the earliest stages of development. Prtraceroute (Policy-Based Routing Implementation Deploymnet in Europe, 1996) is capable of unambiguously identifying which network company owns the routers identified along a given trace. A number of geographical versions of traceroute exist, employing localization methods very similar to those described above. A useful overview can be found at Martin Dodge's *Atlas of Cyberspaces*, http://www.cybergeography.org/atlas/routes.html.

NOTES

1. Coastal Canadian cities such as Vancouver and Halifax also play an important role in international Internet networks due to their geographic proximity to Asia and Europe.

2. Several traceroute gateways exist on the Internet and are available for public use. A useful index is maintained at http://www.traceroute.org.

3. For a thorough discussion on extracting geographic information about networks from traceroute output, please see the note on methodology in the appendix.

4. Due to confidentiality agreements required to obtain access to this service, neither the name of the service nor the providers offering these rates for bandwidth can be disclosed.

5. Excluding Canada, the only international links discovered from the Boston metropolitan area were to Israel and the former Soviet Republic of Georgia, and there remains some doubt as to whether these are direct or pass through an intervening location.

6. Published by NDG Software, http://www.ndg.com.au.

REFERENCES

Abler, R. (1970). What makes cities important. *Bell Telephone Magazine*, pp. 10-15.

Akamai Technologies, Inc. (2000). *Our network* [Online]. Available: http://www.akamai.com/service /network.html

Albert, R., Jeong, H., & Barabasi, A.-L. (2000). Error and attack tolerance of complex networks. *Nature*, *406*, 378-381.

Arnum, E., & Conti, S. (1998, July 21-24). *Internet deployment worldwide: The new superhighway follows the old wires, rails, and roads.* Paper presented at INET '98, Geneva, Switzerland. Available: http://www.isoc.org/inet98/proceedings /5c /5c_5.htm

Bortzmeyer, S. (1995, August 4). *Bandwidth pING* [Online]. Available http://web.cnam.fr/reseau/bing.html

Carl, J. (1999). Nailing down your backbone: The imprecise art of tracerouting. *Boardwatch Magazine—Internet Service Providers Quarterly Directory* [Online]. Available: http://boardwatch.internet.com/isp/summer99/tracerouting.html

Cukier, K. N. (1999, June 22-25). *Bandwidth colonialism? The implications of Internet infrastructure on international e-commerce*. Paper presented at INET '99, San Jose, CA. Available: http://www.isoc.org/inet99/proceedings /1e/1e_2.htm

Digital Island, Inc. (2000). *Content delivery services: Footprint* [Online]. Available: http://www.digisle.net/services /cd/footprint.shtml

Ernst, D. (1997). *From partial to systemic globalization: International production networks in the electronics industry* (Working paper). Berkeley, CA: Berkeley Roundtable on the International Economy. Available: http://brie.berkeley.edu/~briewww/pubs/wp /wp98.html

Friedmann, J., & Wolff, G. (1982). World city formation: An agenda for research and action. *International Journal of Urban and Regional Research*, *6*, 309-344.

Gleick, J. (1999). *Faster: The acceleration of just about everything*. New York: Pantheon.

Goldstein, S. N. (1995, May 3). *Future prospects for NSF's international connections program activities* [Online]. Available: http://www.isoc.org/HMP/PAPER/ 178/html/paper.html

Gorman, S. (1998, October 29). *The death of distance but not the end of geography: The Internet as a network*. Paper given to Regional Science Association, Santa Fe, NM. Available: http://web.geog.ufl.edu/grad_students/seanspaper.pdf

Graham, S., & Marvin, S. (1996). *Telecommunications and the city: Electronic spaces, urban places*. New York: Routledge.

Hargittai, E. (1998, July 21-24). *Holes in the Net: The Internet and international stratification*. Paper presented at INET '98, Geneva, Switzerland. Available: http://www.isoc.org /inet98/proceedings/5d/5d_1.htm

Hutchison, S. (2000). *The IDC/world times information society index: A glimpse into the future of the information society* [Online]. Available: http://www.itresearch.com/alfatst4.nsf/UNITTOCX/W22327-01?OpenDocument

Intel discloses European investment. (1999, June 25). New York: Associated Press.

Jacobson, V. (1997, April). *Pathchar: A tool to infer characteristics of Internet paths* [Online]. Available: ftp://ftp.ee.lbl.gov/pathchar/msri-talk.pdf

Kaplan, K. (1999, May 31). The Internet's at home almost everywhere. *Los Angeles Times*, pp. C3.

Koffman, K. G., & Odlyzko, A. (1998, October 5). The size and growth rate of the Internet. *First Monday: Peer-Reviewed Journal on the Internet* [Online serial], *3*(10). Available: http://www.firstmonday.org/issues/issue3_10/coffman/index.html

Kristula, D. (1997, March). *The history of the Internet* [Online]. Available: http://www.davesite.com /webstation/net-history.shtml

Mitchell, W. J. (1999). *E-topia: Urban life, Jim, but not as we know it*. Cambridge: MIT Press.

Mitchelson, R. L., & Wheeler, J. O. (1994, March). The flow of information in a global economy: The role of the American urban system in 1990. *Annals of the Association of American Geographers*, *84*(1), 87-107.

Moss, M. (1987). Telecommunications, world cities, and urban policy. *Urban Studies*, *24*(6).

Moss, M. L., & Townsend, A. M. (2000). The Internet backbone and the American metropolis. *The Information Society Journal*, *16*(1), 35-47.

NYSERNET, Inc. (1996). *Network access use and costs in K-12 schools and libraries*. Syracuse: New York State Science and Technology Foundation.

Policy-Based Routing Implementation, Deployment in Europe. (1996, March 18). PRIDE Tools 2 is now available. *RIPE (Réseaux IP Européens)* [Online]. Available: ftp://ftp.ripe.net/pride /tools/README

Rickard, J. (1997). The Internet—What is it? *Boardwatch Magazine—Internet Service Providers Quarterly Directory* [Online serial]. Available: http://www.boardwatch.com/isp/Architecture.htm

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

Sassen, S. (1997). The new centrality: The impact of telematics and globalization. In P. Droege (Ed.), *Intelligent environments*. New York: Elsevier Science.

Telegeography, Inc. (2000). *Hubs and spokes: A telegeography Internet reader.* Washington, DC: Author.

Townsend, A. M. (2001). The Internet and the rise of the new network cities: 1969-1999. *Environment and Planning B*, *28*(1), 39-58.

Williams, D. O. (1999, March). *An oversimplified overview of undersea cable systems*. Geneva, Switzerland: European Laboratory for Particle Physics. Available: http://nicewww.cern.ch/~davidw/public/SubCables.html

Zook, M. (2000). The web of production: The economic geography of commercial Internet content production in the United States. *Environment and Planning A*, *32*(3), 411-426.

Zsalanky, J. C., Marshall, N. W., Roberts, J. M., & Ross, D. G. (1995, January/February). The applications of undersea cable systems in global networking. *AT&T Technical Journal*, pp. 8-15.