Wired / Unwired: The Urban Geography of Digital Networks

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ABSTRACT

This dissertation examines the development of digital network infrastructure in the world's great cities at the turn of the 20th century. Drawing upon the concept of cities as information systems and techniques of communications geography, it analyzes how the physical components of digital networks were deployed in major urban areas during the 1990s. It finds that historical processes and pre-existing differences between places shaped the evolution of this infrastructure at multiple spatial scales; global, metropolitan, and neighborhood. As a result, rather than bringing about the "death of distance", digital network infrastructure actually reinforced many of the pre-existing differences between connected and disconnected places. With the telecom bust of 2000-2002, these differences were likely to persist for a decade or more.

Yet just as the development of wired digital network infrastructure slowed, wireless technologies emerged as a more flexible, intuitive, and efficient form of connecting users to networks in everyday urban settings. As a result, an untethered model for digital networks emerged which combining the capacity and security of wired networks over long distances with the flexibility and mobility of wireless networks over short distances. This new hybrid infrastructure provided the technology needed to begin widespread experimentation with the creation of digitally mediated spaces, such as New York City's Bryant Park Wireless Network.

Thesis supervisor: William J. Mitchell
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This thesis is dedicated to the people of New York City.

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INTRODUCTION

On June 25, 2002, midtown Manhattan's Bryant Park underwent an invisible change that would come to profoundly transform its relationship with the surrounding business district. That morning at 9am, the park's management and a group of volunteer geeks activated the world's largest outdoor local wireless network to the general public. This new service built upon the many other amenities provided by the park to its visitors, by offering free broadband wireless access to the Internet. From this day forward, instead of going to the park to disconnect from the hustle and bustle of daily life, now people would come to the park to connect to the global digital network.

By providing free, unrestricted broadband Internet access to park visitors, the management brought Bryant Park into the digital age and dramatically transformed our concept of what a park should be, and the nature of its relationship to the surrounding city. With a mobile phone and wireless-ready laptop computer, there were far fewer reasons to return to the office at the end of lunch. The vital network connections of the information economy could be provided by public space just as readily as private offices.

At the turn of the century, urban spaces throughout the world were undergoing changes similar to what happened in Bryant Park that summer morning. During the 1990s, a new digital communications infrastructure was deployed throughout the world's great metropolitan regions, the capacity and capability of which were unimaginable just a few years earlier. As people and organizations rushed to develop cyberspace, a corresponding physical infrastructure was in place to house these new virtual communities.

In contrast to most chronicles of the digital network revolution, however, this dissertation does not emphasize the distance-shrinking opportunities of digital networks. Quite the contrary, it argues that the construction of this new digital network infrastructure has actually reinforced existing geographic differences in connectivity at multiple spatial scales – global, metropolitan, and neighborhood. It will present evidence that the deployment of digital network infrastructure followed familiar paths, laid down along roads and rail lines (which themselves followed old footpaths and animal tracks). Instead of trailblazing into the wilderness, opening a path to new settlements, digital networks have been built to reinforce existing connections between centers of power and influence in the world's great cities and metropolitan areas.

The simple fact that telecommunications has not threatened the existence of cities, but rather subtly reinforced them, has led to a general neglect of telecommunications infrastructure in urban research. Aspiring city planners will not find a single volume dedicated to telecommunications infrastructure among the hundreds of titles published on urban infrastructure in the late years of the 20th century.

Yet digital network infrastructure has important implications for theories of urban development, as well as professional planning and design. These systems are reinforcing existing physical, social, and economic networks within the urban fabric, but in a highly uneven fashion. The deployment of digital network infrastructure has not been the egalitarian and universal process that many techno-utopians envisioned in the early 1990s. While dozens of redundant fiber optic networks now connect the downtowns of major cities in a global grid, they rarely extend beyond these highly concentrated markets. Digital networks, like all urban infrastructures, have the power to disconnect as well as connect.

With the transition from a fixed, wired infrastructure model in the 1990s to an untethered hybrid of wired and wireless systems in the early years of the 21st century, digital network infrastructure became even more capable of selectively linking places and people. Added to the dramatically increased usefulness of untethered technologies, the importance of connectivity began to differentiate urban spaces to an entirely new degree. It is no surprise that Bryant Park, generously supported by its corporate neighbors, was the first park to deploy its own wireless infrastructure. Instead of leading to the death of distance, digital connections are instead being used as a powerful tool for enhancing places.

Wired and Unwired

This dissertation chronicles the development of digital network infrastructure in the world's great cities during the 1990s and early 2000s. At the end of the 20th century, the world was rewired for a third time.[1] In the late 1800s, the telegraph had spurred the spread of wired communications grids across the globe. This "Victorian Internet" followed routes established in the preceding decades by the railroads and steamships.[2] Following the invention of the telephone, another wired network infrastructure would be built along these same paths, linking together existing centers of financial, political, and cultural power.

These networks, upgraded and expanded across the landscape, served the telecommunications needs of the world for a century. Their impact upon urban form, though greatly underappreciated in urban research, has been tremendous. The telegraph and the railroad have been called the "Siamese twins of commerce" of the 1850s.[3] The telephone "arrived at the exact period when it was needed for the organization of great cities and the unification of nations."[4] Without telephones, the centralized decision-making functions of the modern office building could never be brought together in one place, nor detached physically from the operation they oversaw.[5]

At the end of the 20th century, changes in global finance and commerce combined with scientific and engineering advances to jumpstart the deployment of a third global wired telecommunications infrastructure. With the global computer network called the Internet as its most well known use, this infrastructure quickly spread throughout the world's major cities in less than a decade.

Naturally, this new infrastructure differed dramatically from its century-old counterparts. Most importantly, it was designed to transmit signals in digital format that

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[1] Actually the world was rewired four times. The electric power grid could be considered a form of wired infrastructure but since it is not used for communications it is not included here.

[2] Standage T. 1998. The Victorian Internet. (Walker & Company, New York)

[3] Thompson R L. 1947. Wiring A Continent: The History of the Telegraph Industry in the United States: 1832-1866. (Princeton University Press, Princeton, New Jersey) p 203.

[4] Casson H. The History of the Telephone. (Project Gutenberg E-Text, http://www.guteberg.org)

[5] Gottman J. 1977. "Megalopolis and Antipolis: The Telephone and the Structure of the City", in Pool, 1. de S. (ed.). The Social Impact of the Telephone . (Boston, MIT Press)

permitted high capacity multimedia communications. Unlike the telephone network, which was designed for voice and later modified to support limit data communications capabilities, digital networks were solely for data. On a digital network, a telephone call was just another form of digital media that could be carried as easily as any other.

Fueled by the possibilities of digital networks, the 1990s were a time of great utopian prognostication. Digital networks brought remote regions into closer contact, and applications like the World Wide Web supported the growth of global communities based on interest rather than physical proximity. Technology companies marketed telecommunications products as a means to a convenient and cosmopolitan future free of the "unpleasantries" of urban density.[6] Why go downtown when you have the world's great performances at the click of button? Governments made bold policy pronouncements about their intention to ensure universal access to digital network infrastructure.

Unfortunately, as it usually works out, the future was anything but what the pundits had foretold. The Internet turned out to be a useful research tool but its broader impacts on the functions that cities had come to serve were minimal – things like shopping, entertainment, travel, and meetings. Added to that, digital network communications never evolved into an effective substitute for face-to-face meetings. Videoconferencing never replaced the business trip, and in fact business travel grew rapidly in the 1990s at just the same time digital networks were spreading rapidly. It turned out that global connectivity led to new international trade, which required more face-to-face meetings. Finally, the predictions and promises of universal access were never realized. Rather, digital network infrastructure remains the most restrictive and geographically concentrated of all major urban infrastructure systems.

As a result of these failures, and parallel technological development processes, towards the end of the 1990s a concerted effort began to transition towards a new model for building digital network infrastructure and providing access to telecommunications services. This new model was designed to support untethered communications; portable,

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[6] Campanella T. "Anti-urbanist city images and new media culture" in Imaging the City: Continuing Struggles and New Directions, L J Vale and S B Warner, eds. (Center for Urban Policy Research, New Brunswick, New Jersey)

wireless computers and phones that could connect back into global networks, providing freedom, flexibility, and mobility in all varieties of urban and suburban environments. Combining the strength of wired networks for cheap, high-capacity transmission over long distances with the advantages of wireless for building flexible and convenient last mile interfaces to the network, the untethered model emerged as the dominant over-arching logic for the integration of digital network infrastructure into urban environments.

The hybrid logic of untethered infrastructure could be seen at every urban scale, from the mobile telephone networks deployed along urban expressways to local wireless data networks installed in intimate urban locales like Bryant Park. For unlike wired technologies like fiber optic networks, which had almost exclusively been developed for very long-distance communications, wireless technology had evolved in symbiosis with cities over a half century. From the early car-mounted radiotelephone systems of the 1950s to the analog cellular network of the 1980s and the digital cellular systems of the 1990s, wireless network technology had steadily been improved to cope with the density of users in large cities.

Ironically, by the early years of the new century it seemed that instead of digital infrastructure eliminating the need for cities, those networks had been completely been reshaped by the realities of urban life. By 2003, in several nations the number of daily calls between mobile phones surpassed those between fixed ones.[7]

Structure and Main Findings

This dissertation is organized into seven chapters.

While the study of telecommunications infrastructure is not yet a well-established specialization within urban planning, a growing body of research and practice deals with the issues arising from the growth of this new urban network. Chapter 1 ("Communications Networks as Urban Infrastructure" surveys three bodies of research in urban studies, geography, and computer science to develop a theoretical and

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[7] 2001. "Mobile dynamics" *Telecommunications Policy.* Vol 25, No 1/2.

methodological framework for analyzing the growth of digital networks in contemporary cities.

Chapter 2 ("The Global Structure of the Internet") begins investigating of the structure of digital networks by charting the evolution of the most popular use of digital network infrastructure, the Internet, on a global scale. As the granddaddy of all digital networks, the experience of the Internet helped shaped the evolution of all succeeding digital network technologies. This chapter outlines three main periods of Internet development: as an experimental military technology, as a research and education network, and as a commercialized mass medium. It describes how the goals and objectives of driving organizations during each phase reshaped the global geographic scope of the network, with significant long-lasting impacts.

Chapter 3 ("The Rise of the Network Cities") looks deeper at the role of particular cities and classes of cities in the diffusion and development of the Internet. Contrary to the model proposed by a decade of research on global cities, while global cities did finally come to dominate the global geography of the Internet in the early part of the 21st century, they were relative latecomers to this position. Rather, for much of its early life, the Internet's hubs were in smaller, network cities like San Francisco, Singapore, and Stockholm. This chapter describes this brief but interesting early period in the last quarter of the 20th century, when the Internet and other digital network technologies were incubated in these technopoles, and later adopted for use in global city networks.

Shifting focus from the Internet's virtual architecture to the actual physical supporting network media, Chapter 4 ("The Wired Metropolis") describes the metropolitan infrastructure system that emerged within cities and regions to support digital communications. This system for moving bits is comprised of four components, analogous to their industrial city counterparts for moving goods; information highways, information ports, information factories, and information warehouses. This new metropolitan communications grid has emerged in a decentralized fashion, relying upon standards and cooperation instead of centrally driven monopoly planning.

Just as early industrial infrastructure like the railroads were zealously overbuilt in the late 19th century, the "irrational exuberance" of the 1990s led to irrational poorly planned deployments of digital network infrastructure. Chapter 5 ("The Fiber Boom and

Bust") describes the catastrophic collapse of the competitive telecommunications industry. It finds that poor planning and too much competition resulted in a highly uneven geographical distribution of digital network infrastructure that is likely to persist for many years.

Thus, at the start of the 21st century, routes between major cities were served by dozens of redundant fiber optic lines, many of which are barely utilized. Yet the collapse in the telecom industry means that building out the last mile of wires between bandwidth hubs and homes and offices will proceed slowly, if at all over the next decade. Coincidentally, however, the fall of the fiber barons came just as wireless digital network technologies reached an unprecedented level of maturity. Chapter 6 ("The Untethered City") analyzes the slow, incremental growth of wireless technologies since the 1950s, and the emergence of a new untethered model for communications infrastructure. Based on a hybrid of wired and wireless media, this new infrastructure model presents enormous challenges and opportunities to urban planners. On the one hand there is potential for creating mediated spaces like Manhattan's Bryant Park, where digital and physical spaces can intersect and add value to each other. But the cost of building new wired infrastructure will continue to rob disconnected places of the benefits of these new types of urban spaces.

Chapter 7 brings this analysis full circle by returning to the important questions that motivate this research. What implications does digital network infrastructure have for the formulation of urban policy, the planning of urban space, and the design of streets, neighborhoods, and cities? This thesis concludes that practitioners need to integrate digital network infrastructure into new plans and designs in ways that enhance place. Digital network infrastructure should not be seen as a panacea for urban problems, but as a new tool for increasing the quality and flexibility of urban space. For urban research, digital infrastructure poses many questions how we conceptualize the construction of space, place, and connectivity in the 21st century city.

CHAPTER 1

Communications Networks as Urban Infrastructure

In the early 21st century, cities were increasingly reliant upon digital network infrastructure for communications and coordination of nearly all human activities. Yet compared to the amount of research devoted to housing, transportation, or physical design, communications infrastructure had not received much attention in urban planning.[8] While research in economic geography had addressed the spatial aspects of communications networks since the late 1960s this work still had not been systematically integrated into the urban planning research community per se.[9] Even as postmodern urban thinkers offered Los Angeles as a new urban archetype in the 1990s, the role of communications in building the 100-mile city was mostly ignored as research focused on the transportation and land use dimensions of this new model.[10]

During the 1990s, private investment in digital network infrastructure represented one of the largest streams of funding for urban infrastructure in the United States and other developed countries. Yet far more research was published in that decade on almost any other topic in urban studies. The major database of social science research listed just a single peer-reviewed work on telecommunications infrastructure during the 1990s, while there were 151 on transportation infrastructure and well over 1,000 on housing policy. Even wastewater infrastructure was more widely studied during this period.[11]

However, the September 11, 2001 attacks dispelled any remaining doubts in the urban studies community about the pervasiveness of digital communications infrastructure in modern cities. From stock markets to the cockpits of hijacked airliners to cell phones buried under the rubble of World Trade Center, the world's digitally

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[8] Graham S and S Marvin. 196. Telecommunications in the City: Electronic Spaces, Urban Places. (Routledge, New York)

[9] Urban geographer Jean Gottman devoted an entire section of Megalopolis, his 1964 study of the Northeastern U.S. seaboard to telephone traffic linking its major cities. Others such as John Goddard and Andrew Gillespie at the University of Newcastle extensively developed this literature in the 1970s, 1980s, and 1990s. As we will see in later chapters, in the "global cities" theories of the 1980s and 1990s telecommunications infrastructure was often mentioned as an invisible agent of global urban change, but nonetheless poorly understood beyond this agency.

[10] Michael Dear, Ed Soja, and Mike Davis are among the proponents of the "Los Angeles school" of urban theory who have rarely touched on the role of telecommunications in the evolution of Southern California's urbanization.

[11] Author's query of peer-reviewed articles indexed in Social Sciences Abstracts database, 1990-2002.

networked urban nervous system quivered visibly under the strain of those events. While digital networks themselves proved highly resilient, and greatly improved the ability of cities to respond to catastrophe, they had also become new points of failure for increasingly inter-connected urban infrastructure systems.[12]

The question begs then, why was telecommunications infrastructure been so widely ignored in urban studies? There were three main causes for the lack of research on this topic:

- *Telecommunications infrastructure was invisible.* Digital networks were not visible in the urban landscape. Modern wired telecommunications networks were almost universally routed through subterranean or underwater conduit. Wireless networks used the electromagnetic spectrum to invisibly carry data, even through our very bodies. Direct, noxious physical impacts of telecommunications infrastructure were rare as well.[13]

- *Digital networks were highly complex.* The underlying technology of digital networks (both hardware and software) was extremely sophisticated. Extensive training was required to understand even the most basic properties of these systems such as packet-switching. Additionally, large digital networks like the Internet had very complex, decentralized structures that defied traditional, hierarchical organizational models so common in other areas of urban studies.

- *Building telecommunications networks was a private-sector activity.* The planning, financing, construction, and operation of telecommunications networks historically was a private sector activity in the United States. This was in sharp contrast to transportation infrastructure, which was exclusively a public-sector

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[12] For an in-depth analysis of how digital networks performed that day, see Mitchell W J and A M Townsend. 2003. "Trauma and Rebuilding in the Digital Era" in The Resilient City, L J Vale and T Campanella, eds. (Oxford University Press, Cambridge, England)

[13] The proliferation of cellular transmission towers in the late 1990s is one of the few exceptions. Ironically, cellular towers are one of the few components of telecommunications infrastructure that have been restricted extensively by land-use regulation. The proliferation of data centers that threatened some urban neighborhoods (and spurred some land use changes in particularly affected cities) was the result of speculative overbuilding and is no longer an immediate problem.

enterprise. Many other networked urban infrastructures – water, sewer, and power –also were frequently the domain of local governments. As a result, urban studies – which was often driven by the need for proscriptive recommendations for public policy –kept its distance from the telecommunications sector. The ongoing deregulation of telecommunications at the federal level in most developed economies pushed the project of telecommunications infrastructure building ever further from the traditional public realm of urban planning.

Recognizing that a significant knowledge gap existed in urban studies with respect to the nuts and bolts of digital networks, where then to begin developing an intellectual framework for looking at telecommunications systems within cities?

The most obvious point of departure was to approach digital network infrastructure like any other urban infrastructure system. This approach was effectively used in a major recent work on the inter-connectedness of modern urban infrastructure networks.[14] However useful though, this approach is limiting because its narrow scope fails to capture the long-term technological trends involved in the development of digital networks, nor the great potential for integrating digital networks into future cities.

Instead, this dissertation relies upon three main bodies of literature that offer useful tools for thinking about telecommunications in general, and digital networks in particular from a theoretical, empirical, practical, and speculative perspective.

The theoretical basis for launching this investigation into digital network infrastructure is based upon the rich body of work in urban studies that sought to explain *cities as information systems*. This work described the changing structural trends in society and economy, which were shaped by and helped shape the need for digital network infrastructure.

The second set of literature consists of research in *communications geography* and addresses the empirical challenge of locating, identifying, classifying and quantifying telecommunications networks and the flows of information they carry. This task requires special techniques and methods significantly more sophisticated than are needed to

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[14] Graham S and S Marvin. 2001. Splintering Urbanism: Network Infrastructures, Technological Mobilities, and the Urban Condition. (Routledge, New York)

analyze other types of infrastructure networks that are more likely to be publicly owned, visible, and intensively regulated and monitored.

Finally, the importance of this research ultimately lies in how it can be practically applied towards the planning and design of future cities. What are the practical implications of emerging patterns of digital network infrastructure development? What are the opportunities for shaping more livable cities using digital networks? What ways can planners reshape digital networks to achieve their design goals? Drawing upon research in human-computer interaction and design experiments from around the world, this third (somewhat necessarily speculative) body of work on technologies for creating *mediated spaces* offers guideposts for practically applying an understanding of digital network infrastructure to real-world city-building problems.

Cities As Information Systems

Historically, urban studies and planning has approached the study of cities from a physical perspective. This is primarily due to the origins of city planning as an offshoot of architecture and civil engineering. During the 1960s, the widespread failure of Urban Renewal and other urban policies that ignored the social and economic realities of urban life drove planning to broaden its intellectual scope. Among the new ideas that emerged in this period was the concept that cities could be understood as systems.

In contrast to prevailing models of urban land use based on static equilibrium, these new models incorporated the concepts of systems dynamics to understand cities.[15] One of the essential aspects of systems dynamics is its focus on information and signals that are passed among the different components of a system. Instead of focusing on the individual components of the system – housing, transportation, etc – several theorists began to look at communications and communications networks as the all-important glue that tied cities together and passed information between these various components. It was clear that in urban systems signals are transmitted through social interaction, markets, and the media, often employing telecommunications infrastructure as a medium. Rapidly, a

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[15] Forrester J. 1969. Urban Dynamics. (Productivity Press, Portland)

"communications theory of urban growth" began to emerge.[16] The efficiency of cities for transmitting information among various firms, individuals, and institutions led Gottman to conceive of the *transactional city*.[17] As Deutsch eloquently summed it up, "it is the multiplicity of different facilities and of persons, and the wide choice of potential quick contacts among them, that makes the metropolis what it is."[18]

In this new framework, telecommunications infrastructure was the lynchpin of urban systems, tying together scattered groups, economies, and infrastructure systems into a smoothly functioning whole. Changes in the state-of-the-art of telecommunications thus could have a monumental impact on the spatial economics of cities, by rewriting the costs and delay of information propagation through urban system.

From this perspective, much of 20th century urban history could be rewritten in terms of changes in communications technology. For instance, the telephone was just as instrumental to the emergence of the postwar megalopolis as the automobile. It allowed factories to decentralize to cheap land at the metropolitan fringe while also permitting skyscrapers to centralize decision-making operations in urban business districts. Without the telephone, skyscrapers would require so many elevators for messengers they would be impractical.[19,20] In more recent years, the Internet has permitted the combination of massive regional logistics systems for overnight delivery with the highly decentralized desktop storefront.[21]

Digital networks merely represent the latest transformation of the spatial economics of information movement. Like cafes, office buildings, and sidewalks, digital networks are but one of the critical support systems that facilitate interaction within (and between) cities. But as urban economies and societies have become increasingly more mobile, complex, and fragmented in the late 20th century, digital networks have become

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[16] Meier R. 1962 A Communications Theory of Urban Growth (MIT Press, Cambridge, Massachusetts)

[17] Gottman J. 1983. The Coming of the Transactional City. (Institute for Urban Studies, University of Maryland)

[18] Deutch K W. 1977. "On social communications and the metropolis" in Urban Communication: Survival in the City. (Winthrop Publishers, Winthrop, Massachusetts)

[19] Gottman J. 1977. "Megalopolis and antipolis: The telephone and the structure of the city" in The Social Impact of the Telephone, Ithiel de Sola Pool, ed. (MIT Press, Cambridge, Massachusetts)

[20] Gottman J. 1983. "Urban settlements and telecommunications." *Ekistics*. 50(302):411-416.

[21] Mitchell W J. 1999. E-Topia: Urban life Jim, but Not As We Know It. (MIT Press, Cambridge, Massachusetts)

more and more important to the functioning of the metropolis.[22] Furthermore, digital networks are far less specialized than earlier systems because they can carry many different types of media – voice, video, images and text – encoded as digital data.

The role of cities as information systems has become firmly embedded in contemporary debates on global urbanization. They are the enabling medium for international capitalism, and they are largely structured to serve existing centers of power and influence. This pattern is evident at both global and local levels. The development of the "global cities" hypothesis has relied extensively upon the idea of cities as information systems to explain unfolding patterns of urbanization around the world. One of its primary tenets is that advanced information and communications technologies alter the fundamental spatial relationships that define urban form – between employers and labor, and between firms on a global scale.[23,24,25]

This approach to understanding technological development as a complex socio-technical process is deeply embedded within the writings on cities as information systems. Most observers describe technological innovation as if it randomly occurred or was passed down from the heavens. However, research and development into new technologies is always guided by prevailing social and economic needs. Thus, it might be argued that the emerging industrial society of the 19th century invented the telephone to meet its communications needs. This thesis will argue in Chapter 6 that the mobile telephone was developed in the 1990s largely in response to this type of widespread social need, not random technological breakthroughs.

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[22] Wright R. 2000. <u>Nonzero: The Login of Human Destiny</u>. (Pantheon, New York)

[23] Most scholars tend to argue that the balance of power is being shifted in favor of capital, though labor and anti-globalization groups have certainly made effective use of global digital networks to advance their own agenda.

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

[25] Sassen S. 1997. "The new centrality: The impact of telematics and globalization" in <u>Intelligent Environments</u>, Peter Droege, ed. (Elsevier Science, New York)

Communications Geography

With a firm set of concepts in place describing an urban model based on information flows and supporting structures, empiricists set out to prove the existence of the information city. Most of the relevant literature in this area was conducted by geographers in the specialized field of *communications geography.*

Throughout the 1960s, 1970s and 1980s there was a trickle of published research that offered glimpses into the emerging information society at an urban scale.[26] One of the first widely published surveys of inter-urban information flows was in the geographer Jean Gottman's study of the northeastern United States, *Megalopolis.* First published in 1962, *Megalopolis* was the first urban survey to include a substantial section on communications activities. The study included maps indicating the volume of telephone traffic in each major city, and the ratio of incoming to outgoing calls. Gottman used these data to illustrate how certain key cities exerted economic dominance by exporting more information than they imported (e.g. they talked more than they listened!).[27] (Figure 1.1)

After *Megalopolis*, at least in human geography research circles, communications was added to the list of fundamental demographic indicators that should be addressed in any survey of a region. The telecommunications monopolies of that era were both a boon and bane to research in this field. When researchers could obtain data, such as Moss[28] or Abler[29], it could be assumed to be comprehensive, accurate, and timely. These studies, published in the 1970s and 1980s, expanded the case first made in *Megalopolis* that there was an urban hierarchy of communications flows that reflected differences in population, influence, and wealth. These studies illustrated hidden linkages within urban systems by rendering invisible communications visible for the first time.

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[26] Because of the regulatory structure of the international telecommunications industry, a far greater body of work was published on information flows at the national level. These works will not directly be addressed here, though a useful survey can be found in Kellerman A and A Cohen. 1992. "International telecommunications as international movement. The case of Israel, 1951-1988." *Telecommunication Policy*, March, pp. 156-166.

[27] Gottman J. 1964. Megalopolis: The urbanized northeastern seaboard of the United States. (MIT Press, Cambridge, Massachusetts)

[28] Moss M L and J G Brion, "Face to face: Why foreign banks still love New York." *Portfolio*, Spring 1989, pp. 1-7.

[29] Abler R. 1970. "What makes cities important." *Bell Telephone Magazine*, 49(2):10-15.

More recently, the study of communications geography has taken two new directions that are relevant for this thesis. The first direction led researchers to begin studying all aspects of the geography of digital communications networks, in particular the Internet. The second direction has been an effort to catalog the actual physical properties of communications networks, including routes, hubs, junctions, and termini.

The branch of communications geography that deals with digital networks such as the Internet has been dubbed *cybergeography*. The name is derived from the word cyberspace, which literally means "navigable space". Cyberspace is itself derived from the Greek *kyber* - "to navigate".[30] The term cyberspace was first used in William Gibson's prophetic cyberpunk thriller *Neuromancer*[31], and was used to describe a complex digital network of computers that generated a virtual reality navigable through computer graphic representations of individual users called avatars.

Cybergeography is a rapidly developing field within geography, which has arisen in response to the extremely complex task of mapping and navigating digital networks and the information spaces that they contain. Cybergeography is an inter-disciplinary field, with important contributions from geography, computer science, sociology, and urban studies.[32] While this very young field has not yet generated cohesive theories about cyberspace, a number of widely held tenets are shared throughout much of the research. To date, three primary lessons have emerged from early research efforts in cybergeography:

- There is structure to the relationships between virtual and physical places.
- The internal structure of digital networks is complex and often chaotic but understandable
- Cybermaps, like maps of physical space, can provide useful metaphors for clarifying or obscuring our understanding of the structure of cyberspace.

While these findings may seem trivial, at the very least the extant work in cybergeography has established its viability as a specialization with many interesting researchable questions of significant value to a broader scholarly community.

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[30] Dodge M and R Kitchin. 2000. *Mapping Cyberspace.* (Routledge, New York)

[31] Gibson, W. 1984. *Neuromancer.* (Ace books, New York)

[32] A comprehensive list of research in cybergeography can be found at the Geography of Cyberspace Directory, maintained by Martin Dodge of the Centre for Advanced Spatial Analysis at University College London. [http://www.cybergeography.org/references.html]

More directly relevant to this thesis, the wide variety of disciplinary approaches has fostered much experimentation in research design and data collection and analysis.

- Automated data collection techniques can use the very infrastructure of digital networks to measure themselves.
- Accurate analysis requires understanding of both geographic techniques and the underlying technical structure of digital networks.
- The modern structure of the telecommunications industry is a powerful deterrent to comprehensive research, yet there are "chinks in the armor" that never previously existed, providing opportunities to gather data.

In summary, the most valuable lesson from early efforts in cybergeography is that it is possible to map digital communications activities. Furthermore, these maps are essential tools for understanding the structure of these systems. Of the three methodological areas of cybermapping (data collection, analysis, and representation), the least progress has been made on the challenges in representing cyberspaces. This is due to a lack of past cooperation between computer scientists and cartographers. Computer scientists tend to lack the visual communications skills to create clear information presentations, while geographers and cartographers tend to lack the ability to systematically collect and manage the large amounts of data on network structure and performance that need to be presented.

The second main direction of research in communications geography has been a focus on the actual underlying physical structure of telecommunications infrastructure. Urban planning concerns during the boom phase of Internet and fiber optic development in the late 1990s provided the original impetus for these studies. Local economic development corporations and business coalitions in cities as varied as Philadelphia, San Diego and Atlanta conducted studies to map various fiber optic networks being deployed in their central business districts.[33] Following the terrorist attacks of September 11, 2001 critical infrastructure assessments focused substantial resources on identifying choke

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[33] In Philadelphia by the Center City District; In Atlanta by the Metro Atlanta Chamber of Commerce; in San Diego by the Downtown San Diego Partnership.

points in the United States' digital network infrastructure, which had been haphazardly thrown together in the 1990s.[34]

The mapping of small-area communications infrastructure is a relatively new area. Earlier studies, like Abler's historical study of the evolution of the American telephone network[35] relied on AT&T corporate archives and focused on national and urban units. Current, neighborhood-level data on operations and infrastructure were closely guarded secrets considered vital to national security. With the proliferation of carriers, service providers, and networks following the deregulation of telecommunications in the 1980s and 1990s, the sheer volume of infrastructure development increased the amount of data available to researchers. In some instances, previously unavailable date on network routes and capacity were released in marketing materials to demonstrate the quality of a particular carrier's network.[36] In other cases, new types of communications infrastructure that had never previously existed, such as carrier hotels, were developed in a way that made it impossible to hide their existence.

Cybergeography research has thus applied many of the original concepts and techniques used in *Megalopolis* to the study of digital networks. Of particular interest to urban planning research was the developing focus on the form and evolution of physical communications infrastructure. However, beyond just gauging the impact of communications networks on the urban fabric, planners needed to assess how they could employ digital networks as a tool to transform the urban landscape.

Design and Planning of Mediated Spaces

For urban planners and urban designers, both the theoretical models of cities as information systems and the empirical and representational techniques of cybergeography offered useful tools for understanding the changing nature of cities in the age of digital

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[34] The most interesting work on assessing the nation's telecommunications infrastructure vulnerabilities was conducted at George Mason University's Critical Infrastructure Protection Project. [http://techcenter.gmu.edu/programs/cipp.html]

[35] Abler R. 1977. "The telephone and tehe evolution of the American metropolitan system" in The Social Impact of the Telephone, Ithiel de Sola pool, ed. (MIT Press, Cambridge, Massachusetts)

[36] This was a stated marketing strategy of Metromedia Fiber Networks, which published many detailed street-level maps of its central city and metropolitan fiber optic networks.

networks. However, they still lacked any practical body of knowledge upon which to base decisions and visions about building and managing the future evolution of cities.

The third and final guiding body of research for this thesis is a loosely connected body relevant to the construction of a new kind of urban space that can be called *mediated spaces*. In the urban design context, mediated spaces were urban environments such as New York's Times Square or Seoul's Myeong-dong district, in which traditional elements of architecture and urban design were supplemented or augmented with digital technologies that enhanced their existing purpose or provided new functionality. Some of the digital technologies employed included large-format Liquid Crystal Displays (LCD), wide- and local-area wireless networks, and environmental sensors.

The study and design of mediated spaces does not yet constitute a defined area in urban design or architecture, nor in computer science. However, an effort to develop a conceptual approach to mediated spaces are underway within the City Design and Development Group of MIT's School of Architecture and Planning, as part of the Seoul Digital Media Street project.[37] This project draws upon two main disciplinary fields – urban design and human-computer interaction (HCI).

Human-computer interaction is a specialization within computer science that introduced techniques of human psychology to help improve understanding of howpeople interact with computational devices. Since it first coalesced in the 1980s, it had grown rapidly and the HCI special interest group was one of the largest and most active within the Association for Computing Machinery, the premier international computer science association. HCI research has contributed such innovations to computing as the mouse, the desktop user interface and graphical icons, and speech recognition.

By the late 1990s and early years of the new century several strands of research in HCI were investigating ways to move computing off the desktop and into the surrounding environment. These investigations represented some of the first experiments aimed at the development of *ubiquitous computing*.

The term ubiquitous computing encompassed research aimed towards integrating computation into every element of the manufactured environment, from buildings and

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[37] "Up and Down the Avenue, 21st Cenutry Style: MIT Envisions a Street Scene for Seoul's New Digital Media City". *PLAN*. [http://loohooloo.mit.edu/plan/plan_issues/56/TheAvenue /article_bottom.html]

roads to consumer products and clothing. This area of work was pioneered by Mark Wieser at Xerox PARC, who described its genesis:

> Inspired by the social scientists, philosophers, and anthropologists at PARC, we have been trying to take a radical look at what computing and networking ought to be like. We believe that people live through their practices and tacit knowledge so that the most powerful things are those that are effectively invisible in use. This is a challenge that affects all of computer science. Our preliminary approach: Activate the world. Provide hundreds of wireless computing devices per person per office, of all scales (from 1" displays to wall sized). This has required new work in operating systems, user interfaces, networks, wireless, displays, and many other areas. We call our work "ubiquitous computing". This is different from PDA's, dynabooks, or information at your fingertips. It is invisible, everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere.[38]

In later work, with colleague John Seely Brown, Weiser expounded the idea of "calm" computing technology that integrated itself more transparently into the human-environment interaction.[39] By the end of the decade, playing the idea of ubiquitous computing out to its conclusion had carried the computer science full into the realm of environmental design. One scholar noted:

> When computation is part of the environment, it will be part of everyday physical space. This single shift radically changes the relationship between humans and computation--from a fairly static single-user location-independent world to a dynamic multi-person situated environment.[40]

Beyond this realization that computing had entered a new era of integration with the real world, however, ubiquitous computing research offered little guidance for architects and planners to anticipate or shape this comprehensive integration of computing into the built environment.

During the late 1990s, two research efforts at MIT sought to implement dramatically different visions of ubiquitous computing. Each vision held many lessons for how we might go about designing digitally mediated cities of the future.

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[38] Weiser M. 1996. "Ubiquitous Computing." [http://www.ubiq.com/hypertext/weiser/UbiHome.html]

[39] Weiser Mand J S Brown. "Designing Calm Technology", *PowerGrid Journal*, v 1.01, http://powergrid.electriciti.com/1.01 (July 1996).

[40] Mark W. 1999. "Turning pervasive computing into mediated spaces" *IBM Systems Journal: Pervasive computing*. 38:4. [http://www.research.ibm.com/journal/sj/384/mark.html]

At the Artificial Intelligence Lab, researchers developed tools for creating *intelligent environments*, which used gesture and speech to determine the user's intent rather than traditional input devices like the mouse and keyboard.[41] This hands-free approach was largely supported by DARPA, the Pentagon's research agency, as a technology intended for use in battlefield management systems aboard naval vessels and combat aircraft. However, the civilian applications for supported more natural, less obtrusive computing were clear.[42]

Meanwhile, across campus at the Media Lab, Hiroshi Ishii and his students were pursuing a very different philosophy for environmentally integrated computing. As conceived by Ishii and Ullman in 1997, *tangible media* relies upon sensing of changes of objects in the environment to interact with the computer. Rather than use gesture or speech to interact as in the *intelligent environment*, users manipulate non-computational objects to start, stop, and control computational simulations that are then projected through light or sound back to the user.[43] One prototypical example of tangible media was a set of bottles that played music when their corks were removed.

Both intelligent environment and tangible media research offer food for thought in thinking about issues of human-computer-environmental interaction. These interactions will be key to the design and sustainability of mediated spaces.

The final area of advanced computer science that provided new tools for building mediated environments was in geographic information systems (GIS) and geographic information systems (GPS). Geographic information systems (GIS) science were developing information architectures for geo-referencing many different kinds of archival information so that they can be readily accessed by mobile uses in mediated urban settings. These systems differed in that they relied on remote position-sensing and offsite databases, not an augmented local environment as for tangible media and intelligent environments.

As these advances in HCI were taking place, urban designers, architects, and media companies were beginning to experiment with mediated spaces. Many of these

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[41] Coen M. 1998. "Design principles for intelligent environments" [http://www.ai.mit.edu /people/mhcoen/IEsymposium.ps]

[42] Author's conversation with Michael Coen, October 1999.

[43] Ishii H and B Ullman. 1997. "Tangible Bits: Towards Seamless Interfaces Between People, Bits, and Atoms" MIT Media Lab report.

experiments took place in Manhattan due to the rapidity with which its urban fabric was rebuilt during the 1990s as well as the large concentration of digital media firms located there.

Rojas documented many of these experiments in 2001, and identified three urban design goals that were particularly attractive to digital mediation strategies – connectivity, flexibility, and imageability.[44] Connectivity was in mind at the Seagram Building's Brasserie, a swanky bar redesigned by the firm Diller & Scofidio, where LCDs over the bar showed digital photos of the last 16 persons to enter. Bryant Park and Starbuck's both installed wireless Internet hotspots, the former providing unlimited free use. Bryant Park also addressed the issue of flexilibity, by blurring the boundaries between the office and the park. By providing vital network services in the park, it could be retasked as an office or study space in addition to passive recreation. (Chapter 6)) Imageability was enhanced through the use of large building-mounted digital displays. From Kohn Pedersen Fox's building for Lehman Brothers at 745 Seventh Avenue to the Reuters sign in Times Square, powered by software from the RG/A Media Group' these displays connected those in the immediate area with news and events occurring throughout the world.[45]

Aside from these early, cautious experiments there was little active investigation on mediated spaces in the urban design and planning research community. As a result, integrated approaches to designing mediated spaces are just beginning to emerge in experimental settings. One such experiment, which is described in detail in the concluding chapter of this dissertation (Chapter 6), is the development of a public wireless network in Manhattan's Bryant Park. This project has demonstrated the many dimensions along which the introduction of digital communications technologies can enhance and transform existing urban spaces.

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[44] Rojas F. 2001. "The Virtues of the Virtual: New Directions for Urban Design" *Projections: MIT Student Journal of Planning*

[45] Dunlap D W. 2001. "The Great Red, Green, and Blue Way" *The New York Times*. Dec 30.

Conclusions

The impact of digital networks within urban space is an increasingly important, yet under-researched topic. While a theoretical basis for investigation in this area existed since at least the early 1960s, and empirical and analytical techniques could be readily borrowed from communications geography, it was not until the 1990s that telecommunications infrastructure entered the public mind on a level anywhere near to that of roads, water, and electrical power. With such as late start, the fruits of research are only stating to be born. Complicating matters, advances in technology and theories of human-computer interaction are rapidly reshaping the possibilities for bringing digital networks into urban environments. Clearly urban planners and designers face a number of challenges that range from understanding and visualizing the scope of digital networks within the city, to learning how and why to reshape those networks to achieve design goals.

The following chapters seek to address both of these challenges by providing describing the structure and evolution of digital network infrastructure in a vocabulary understandable to urbanists. With this base of knowledge established, this thesis concludes with a discussion of the challenges and opportunities presented by this new infrastructure for designing and planning more livable cities.

Chapters 2 through 4 describe digital network infrastructure at three scales - global, metropolitan, and local – with the goal of providing urban designers a basic mental vocabulary for their components and overall structure. This analysis begins by looking at the most familiar manifestation of digital network technology, the Internet, but then delves into the actual physical components that provide the means of support for this cyberspace. Chapter 5 focuses on the organizational and economic processes that halted digital network development during the period 2000-2002 and connect them to trends in urban development. Finally, Chapter 6 describes the transition from wired networks to a new, untethered infrastructure model. It presents the example of Bryant Park as one urban space coping with the promise and pitfalls of this new model for urban communications.

CHAPTER 2

The Global Spread of the Internet

At the turn of the 21st century, the Internet was by far the most important and extensive digital network ever developed. Through the adoption of standards for data transmission, Internet technology had enabled the interconnection of hundreds of thousands of individual computer networks in a single global whole.

This chapter begins exploring the spatial structure of wired digital networks by surveying and analyzing the global structure of the Internet backbone. Internet backbone networks are a virtual network that have been overlaid upon an underlying network of fiber optic cables, in much the same way that the air transportation network is overlain upon an underlying network of airports and flight paths.[46]

In contrast to common knowledge, the Internet is not placeless but has a distinct geography that can be mapped, analyzed, and understood. Over the last three decades that geography has been shaped through three phases of growth, each defined by a unique purpose: defense, education, or commerce.

While American interests dominated these three phases, that influence is waning as the Internet becomes a truly global network. However, the impact of early American dominance is still visible in the overall structure of Internet infrastructure.

This chapter begins this discussion by analyzing these patterns at a national level throughout the world. The important role of individual cities and metropolitan regions in the shaping of the Internet is picked up Chapter 3.

Internet Engineering: A Primer

The rapid development of the Internet has made understanding of its precise functioning and structure difficult. The Internet is often portrayed (and almost always perceived) as a magical black box that invisibly and effortlessly produces documents on demand.

In reality, the Internet is one of the most complex networked infrastructure

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[46] This underlying physical infrastructure layer is the subject of Chapters 4 and 5.

systems created by mankind, and approaches the complexity of the city itself. Multiple layers of computer hardware and software are necessary to perform basic tasks such as sending an email message, and these systems are linked together in networked structures of high complexity and interdependence. A basic dial-up connection to an Internet Service Provider involves the execution of dozens of co-dependent software programs on several computers at both ends of the link. Even before considering the geographic scope of infrastructure and activity, modeling the Internet is a daunting task.

Backbone networks are a key layer of Internet technology, and serve to connect servers and clients into a seamless global communications network. Backbones are the trunk lines of the Internet, spanning the distance between clusters of activity much like the highways that connect large cities. At junction points, several backbone routes may converge, and there routers are stationed. Routers are specialized high-performance computers that forward data packets along to their final destination.

In the early days of the Internet, there was just a single backbone operated by the Defense Department's Advanced Research Projects Agency (ARPA) and later transferred to the National Science Foundation (NSF). Following the commercialization of the Internet in the mid-1990s an array of over thirty companies deployed nationwide IP backbone networks in the United States.

It is important to understand that Internet backbones are not physical networks in geographic space, but logical networks in Internet address space. They 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. In a sense, an Internet or TCP/IP backbone is encapsulated within, or stacked on top of a physical communications network.

The Open System Interconnection (OSI) model illustrates this separation of network layers works in practice. This generic model defines a multi-layered structure that describes how applications running on computer networks relate to each other and interact.[47] The seven layers of the OSI model are shown in table 2.1.

The layered nature of the Internet lends itself to vertical disintegration, and thus two different sets of companies are responsible for the physical transport of voice and

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[47] 2000. "Understanding the OSI 7-layer model" Briscoe, Neil. *PC Network Advisor*. July.

data ("carriers") and the logical routing of data ("backbone operators"). Most backbone operators lease physical transport services from carriers, who have built extensive national and global fiber optic networks. Typically, the only physical infrastructure actually owned by backbone operators are routers, the powerful computers that manage the flow of data packets at junctions in the network.[48] These routers are strung together into a network through the fiber stands leased from carriers.

This chapter and Chapter 3 focus on the geography of TCP/IP networks, which operate at level 3 and 4 independent of the underlying hardware. Chapters 4 and 5 delve deeper to look at the structure of underlying physical networks. Obviously, the geography of TCP/IP networks follows that of the underlying infrastructure – it cannot travel without a physical medium. However, TCP/IP networks are far more selective than physical networks. There are many physical paths they do not follow.

The Historical Evolution of Internet Backbone Networks

The global Internet did not emerge fully formed from the laboratories of network engineers and computer scientists. Rather, over its roughly thirty-year lifespan, the Internet has undergone three main periods of growth and development. First, as a prototype for future military communications networks, second as a research and educational network, and finally as a commercial mass medium.

During each of these three periods the Internet's development reflected the goals and objectives of the over-riding authority. During the first period, in the 1970s and 1980s, the Defense Department's Advanced Research Projects Agency (ARPA) used the Internet to experiment with packet-switched networks for military communications. The second period, from the late 1980s until the mid 1990s, was an era of rapid expansion as the National Science Foundation sought to transform the network into a far-researching scientific and educational medium. Finally, during the third period, deregulation led to full commercial exploitation of the Internet as a mass communications system. During this period, there were many infrastructure, technology, and policy changes that reflected

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[48] Rickard, Jack. "The Internet - What Is I*t?"*. *Boardwatch Magazine - Internet Service Providers Quarterly Directory*. (Littleton, Colorado, Fall 1997).

these new commercial priorities.

The Military Research Network (1969-1987)

In response to Sputnik and other early feats of Soviet technological prowess, the ARPA commissioned a prototype packet-switched computer network in the early 1960's, which became known as ARPANET. In 1969, the first node was connected at UCLA, and by 1976 there were 63 computers connected to the network. The technologies developed for ARPANET, such as the Network Control Protocol and email, would lay the seeds for the Internet of today.

The ARPANET was an experimental network that linked together defense researchers at a number of computing facilities throughout the United States, in order to test the viability of packet-switched computer networks. From an initial network of just four sites (two in California, two on the East Coast), throughout the 1970's ARPA expanded the geographic scope of the fledgling network to cover the entire continental United States. At first, APRANET sites were concentrated in just a few metropolitan areas. Throughout the 1970's, however, it evolved into a highly de-urbanized and de-centralized communications network, linking remote research centers and military bases throughout the United States.

Through frequently discredited in the technology press, one urban myth holds that the ARPANET was designed to withstand a nuclear attack. As Winston has noted, the connection between RAND and the Pentagon's military interest in packet-switched networks and the subsequent evolution of ARPANET (largely under the nurture of the computer science community) is obscure.[49] Yet, the geography of the early Internet was suspiciously decentralized, as if the Pentagon were following the philosophy first laid down by RAND researcher Paul Baran in an influential series of monographs in the mid 1960s.[50] Envisioning a command and control network that would ensure the ability to respond to a first strike, Baran computed the ability of varying network structures

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[49] Winston B. 1998. Media, Society, and Technology: A History from the Telegraph to the Internet. (Routledge, 1998)

[50] For instance, Baran P. 1964. "On Distributed communications: Introduction to distributed communications network" RAND Corporation (Santa Monica, CA) [http://www.rand.org/publications/RM/baran.list.html]

(centralized, decentralized, and distributed) survive targeted attack. Informative diagrams illustrated the topology and points of failure of each network structure. (Figure 2.1)

Baran concluded that distributed networks were highly survivable, even when nodes and links were targeted for attack. He concluded that "there are reasons to suspect that we may not wish to build future digital communication networks exactly the same way the nation has built its analog telephone plant."[51]

It seems too coincidental that the ARPANET project was begun just a few years later. Throughout the 1970s funds and human resources were poured into ARPANET as the network expanded and an array of supporting technologies were invented, tested, and refined.

ARPANET stopped growing and began to decline in the early 1980s. By 1983, the Defense Communications Agency determined that ARPANET had grown large enough to raise serious security issues, and moved all non-classified military traffic over to a separate network called MILNET.[52] Stripped of its military purpose, ARPANET was replaced in 1987 by NSFNET, an education and research network funded by the National Science Foundation. This transition marked the start of the second great phase of Internet development. ARPANET had served the purpose of demonstrating that packet-switched networks were practical, and many of the underlying technologies developed in that period – TCP/IP, email, and ftp – are still widely used today.

The Educational Network (1987-1995)

The National Science Foundation had very different priorities for the Internet than ARPA. Rather than restricting access, NSF's main goal was to expand access throughout the American higher education system, and to expand the reach of TCP/IP networks worldwide. To further this goal, NSF embarked on an ambitious program of expansion, establishing a national backbone in 1987 and subsidizing the development of regional feeder networks like NYSERnet and JvNCnet. NSF also actively sought opportunities to interconnect the American Internet to research and educational networks in other

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[51] Ibid. Baran, 1964.

[52] 1983 was also the year that TCP/IP replaced the less versatile Network Control Protocol (NCP) as the Internet's core standard.

countries. NSFNET expanded on earlier efforts to interconnect the resources of university computer science departments, called CSNET.

The NSF also established a national backbone to link together the regional feeder networks. A non-profit corporation named Merit, Inc. (a consortium of IBM, MCI, and the University of Michigan) managed this network. In comparison to the benefit that would ultimately result, the initial $57.9 million contract NSF awarded to develop the NSFNET backbone seems trivial. NSFNET was one of the fastest growing programs at NSF in terms of percentage increase in annual budget throughout its duration.[53]

The result of NSF's networking push was enormous growth in the number of sites and host computers connected to the Internet. Between 1987 and 1990, the number of hosts doubled nearly five times from 10,000 to over 300,000.[54] By April 1995, over 50,766 networks had been connected to what had started being called the Internet.[55]

The meteoric growth of NSFNET quickly congested the national backbone, particularly as new applications such as Gopher became widely available.[56] Network congestion became a persistent problem requiring periodic capacity upgrades. In July 1988, the national 56kpbs backbone was replaced with a T1 network (1.544 kpbs). In November 1992, a new T3 backbone (45 Mbps) offered thirty times the capacity for key transcontinental routes.[57] By the time NSF was decommissioned, its capacity of key backbone routes was nearly 1,000 times greater than the early ARPANET.

It was during the latter half of the NSFNET program that the first attempts at mapping flows of information across the global network were conducted, such as Steven Eick's visualization of international data flows shown in Figure 2.2. Such maps represent the earliest forms of *cybergeography*.[58]

By the early 1990s, the growing base of personal computers and the rapid expansion of the Internet presented many commercial applications for the new network.

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[53] Merit Networks, Inc. 1995. NSFNET: A Partnership for High-Speed Networking: Final Report, 1987-1995. (University of Michigan)

[54] PBS. 2002. "Life on the Internet: Internet Timeline" [http://www.pbs.org/internet/timeline/]

[55] Merit, Inc. Ibid.

[56] Gopher was a text-based predecessor to today's web browsers that implemented some of the hyperlink functionality of the World Wide Web.

[57] National Laboratory for Applied Network Research. 1995. "NSFNET – The National Science Foundation Network" [http://moat.nlanr.net/INFRA/NSFNET.html]

[58] Dodge, M & Kitchin, R., 2001, Atlas of Cyberspace, Addison-Wesley, London.

New applications like *Mosaic*, the first graphical web browser fueled an enormous surge in demand for network services both inside and outside the research communities NSFNET was trying to serve. On the infrastructure side, NSF simply could not build new capacity fast enough to keep up with demand. It was clear that the Internet would have to be privatized; the only question was how it would be implemented.

NSF moved quickly and effectively to implement Internet privatization. In March 1991, NSFNET revised its acceptable use policy to permit commercial traffic.[59] Then in 1994-5, it implemented a plan for transition to a new framework for interconnecting commercial data networks that influences the structure of the Internet to this day.

The Commercial Network (1995-present)

The start of the third and largest phase of Internet development was marked by the commercialization of the Internet in 1995.

Private firms such as Sprint had built commercial IP networks as early as 1992.[60] Yet it was NSF's ingenious architecture for transitioning from a single, centrally-planned backbone (NSFNET) to an inter-connected, competitive structure that truly opened the floodgates for private investment in network infrastructure.

The reengineering of the Internet's topology that was implemented in 1995 was the culmination of a long-term trend away from the idealized distributed network Baran had envisioned in the 1960s. While ARPANET was quite distributed, the economics of expansion during the NSFNET era had led to a far more decentralized approach, with regional feeder networks converging on a dozen hubs spread across the United States. These hubs were inter-connected through the NSFNET backbone, forming a two-tiered hierarchy that departed substantially from the distributed ideal model. (Figure 2.1)

In order to maintain the integrity of a privatized Internet, NSFNET choose to centralize the Internet topology even further. The transition plan called for the establishment of four regional inter-connection points, shown in Table 2.2.

The purpose of the NAPs was to ensure that the Internet would remain whole, and not be segmented into isolated, private networks. By establishing a presence at one or

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[59] National Science Foundation. 2002. "Nifty 50: The Internet" [http://www.nsf.gov]

[60] Sprint. 2002. "IP Network History" [http://www.sprintesolutions.com/network/history.jsp]

more of the NAPs, anyone could connect to the global Internet. Further down the chain, second- and third-tier networks could connect to any network connected to the NAPs.

This strategy was soon to become the victim of its own success. In just a few years, the rapid growth of Internet usage had led to massive congestion at the NAPs – in essence, an Internet traffic jam. At the world's busiest Internet exchange point of the day, MAE-East, congestion was so bad that as many as 40 percent of packets were being lost.[61] In a vicious cycle, TCP/IP's internal control mechanisms would cause these lost packets to be retransmitted from their source, further congesting MAE-East.

The NAP congestion problem was eventually solved by the proliferation of new NAPs in other cities, improvements in the internal networks at the NAPs, and the growth of private inter-connection agreements between large ISPs. The result was unfettered growth in IP network capacity. Between 1995 and 1999, a flurry of construction by over two dozen companies created a vast web of regional and national Internet backbone networks. By early 1999, key inter-metropolitan routes such as New York-Washington and Los Angeles-San Francisco had over 5,000 Megabits per second transmission capacity more than 100 times that of the last NSFNET backbone constructed in 1991.

Global Diffusion

Early its early development, it was clear the Internet would become a global network as its reach quickly spread from its birthplace in the United States to other countries. The first international connection on the Internet's predecessor, ARPANET, was established via satellite between a Washington, DC area research facility and University College London during the 1970's.[62] Foreshadowing the Internet's eventual commercial maturity, this link relied on commercial satellites owned by Intelsat (a private company) rather than government or military satellites.[63]

Under NSFNET, the US Internet was rapidly connected to scientific and education networks in dozens of other countries between 1991 and 1996. It actively

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[61] Gitlen, Sandra and Denise Pappalardo, "Even a $10 million upgrade won't fix congested Internet exchange points" *Network World Fusion* [http://www.nwfusion.com/news/1997/1107mae.html] Nov. 7, 1997.

[62] Salus P. 1995 Casting the Net

[63] Kristula d. 1997. "The history of the Internet" [http://www.davesite.com/webstation/net-history.shtml]

engaged equivalent institutions overseas to interconnect US research networks with those of other countries. In 1991, NSF issued a five-year contract to Sprint for international connections management (ICM) to NSFNET. By 1996, the ICM program had linked over 25 countries to the US Internet through NSFNET. With some 22,296 of NSFNET's 50,766 member networks located outside the United States by 1995, NSF had presided over the globalization of the Internet.[64]

Initially, the ICM program consisted of just two 128kbps links to London and Stockholm. By 1995, the expanded network consisted of dual T1 links each to London, Stockholm, and Paris. By 1995, the London link was upgraded, and the first-ever trans-Atlantic T3 (45 Mbps) service was established. The link continued on at 34 Mbps to Stockholm.[65]

By mid-1999 more than twenty companies operated IP backbone links between London and New York with a total data capacity tens of thousands of times greater than that first feeble Internet satellite link on the ARPANET.

The Internet has evolved to connect every major city on earth. Yet not all nations or cities are endowed with the same level of connectivity. On the Internet, like all other networks, there are central hubs and there are backwaters. Not surprisingly, the spread of the Internet among nations has been highly unequal, similar to the diffusion of earlier telecommunications technologies such as the telephone, television, and radio.

Research has found that "the Internet connectivity of a country depends… on its development level, its financial and technical resources, and its 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. Internet infrastructure is often a retrofit upon existing telephone networks and cable television systems, or in new fiber optic cable buried in shallow trenches alongside railroad and highway right-of-way.

Numerous other studies have documented the advantage of early-movers in the

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[64] Merit, Inc. Ibid.

[65] National Science Foundation. "International Networking – Historical" Directorate for Computer and Information Science and Engineering. [http://www.nsf.gov]

international diffusion of telecommunications technologies.[66,67,68] There is also the obvious assumption that Internet development is related to national wealth or GDP. To illustrate this fact, Table 2.3 lists the number of Internet hosts per capita by country in 2000.

The United States as the Center of the Global Internet

By the middle of the 1990s, the United States had become the dominant hub of the global digital computer network that had come to be known as the Internet. NSFNET's aggressive policy of funding international connections to other national research networks was unique, and early on established the United States as the primary hub of the global Internet. In addition, the US boasted the largest population of Internet users, and a wide array of telecommunications firms operating in the almost completely unregulated Internet service provider (ISP) market. These early mover advantages, combined with the establishment of the regional NAPs as the Internet's primary interconnection points, the US emerged as the de facto global switching center of the Internet by the mid 1990s. As Figure 2.3 shows, by 2000 the United States dominated the global distribution of Internet infrastructure.

As the commercial Internet spread throughout the developed world in the late 1990s, the nascent role of the United States as a central site for network interconnection was reinforced. There were powerful technical and financial incentives for non-US ISP powerful economic incentives to link to the United States rather than other networks in their own country or region.

For example, Cukier notes that it was 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

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[66] Arnold E, Guy K, and N Hanna. 1995. "The Diffusion of Information Technology: Experience of Industrial Countries and Lessons for Developing Countries" (Washington, DC, World Bank)

[67] Zook, M.A. (2001). "Old Hierarchies or New Networks of Centrality? The Global Geography of the Internet Content Market" *American Behavioral Scientist.* (June). Vol 44. No. 10 .

[68] Kellerman A. 2002. The Internet on Earth: A Geography of Information. (London, John Wiley)

continent (from European telecommunications companies).[69] As a result, by 1999 nearly every country had direct Internet links to the United States, but direct connections between non-US countries were far less extensive. Direct connections between continental regions were practically non-existent – nearly all inter-continental traffic was routed through the United States. As Table 2.4 indicates, nearly all inter-continental bandwidth terminated in the United States. As a result of this structure, the United States' domestic Internet infrastructure functions as a massive switching station for traffic that originates and terminates in foreign countries.

Consider for example, data traveling from the United Kingdom to Australia. Using a widely available network diagnostic tool known as *traceroute*, it is possible to map the approximate geographic pathway that data packets take from one computer on the Internet to another.[70] Figure 2.4 illustrates the path taken by data between a server at University College London and the web server of an ISP in Australia.[71]

Unlike a telephone transmission, which sets up a dedicated circuit that remains open between caller and receiver, Internet data travels in discrete, destination-marked packets more similar to the way letters are transmitted through a postal system. After leaving the university, data packets crossed the Atlantic on a dedicated link to New York leased by JANET, the UK's scientific research network, and transited the United States on the UUNet network, owned by MCI/Worldcom. Arriving in Los Angeles, they left for Sydney where they will be offloaded onto the Australian ISP's network. While *traceroute*'s output does not reflect the precise pathway taken between any set of Internet computers for several obscure technical reasons, it does offer a reasonable approximation at the city level.[72] 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. Remarkably, the geopolitical structure of the Internet

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[69] Cukier K. 1999. "Bandwidth Colonialism? The implications of Internet infrastructure on international e-commerce". January 1999 Proceedings of the 9th Annual Conference of the Internet Society, San Jose, California, USA [http://www.isoc.org/inet99/proceedings/1e/1e_2.htm]

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

[71] Martin Dodge of University College London's Centre for Advanced Spatial Analysis assisted in collecting the data used in this example.

[72] Carl J. 1999. "Nailing Down Your Backbone: The Imprecise Art of Tracerouting". *Boardwatch Magazine - Internet Service Providers Quarterly Directory.* (Littleton, Colorado). [http://boardwatch.internet.com/isp /summer99/tracerouting.html]

ignores centuries of direct network linkages between England and her former colony in the southern hemisphere.[73]

Even for Internet communications between countries *on the same continent*, data packets were often routed through the US. This phenomenon illustrates the real-world outcome of the financial and technical incentives for inter-connection of IP networks at US NAPs. Even the most networked countries of Europe often lack sufficient interconnections and rely on American networks to connect to each other. Figure 2-5 shows the path of data packets from London to Helsinki, Finland. While Finland is consistently ranked among the most "wired" nations on the planet, (Hutchison, 2000), its Internet connectivity to the outside world is largely through links to Stockholm and Frankfurt.[74] In this example, because of a shortage of direct connections between Scandinavia and England, the quickest path between these two cities was through the east coast of the United States, in this case New York City.

These examples of Internet packet traces illustrate how technical and financial incentives for interconnecting in the United States can have negative impacts on usability. One critic even described the evolving pattern as "bandwidth colonialism."[75] These technical and financial incentives have waned in recent years, as ongoing deregulation has brought the cost if intra-regional bandwidth more in line with cheap US-bound bandwidth. The development of domestic, native-language content has eased the need to connect to overseas servers. Nonetheless, the United States's early dominance of Internet structure remains imprinted upon the global structure of the Internet. While it is less of a hub today than in 1999, the United States is still the de facto center of the Internet.

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[73] By ship, telegraph, and telephone.

[74] Hutchison S. 2000. "The IDC/World Times Information Society Index: A Glimpse into the Future of the Information Society." [http://www.itresearch.com].

[75] Cukier. Ibid.

Loosening America's Grip on the Internet

However, three forces have combined to loosen America's grip on the Internet's core infrastructure. The first force is a change in the telecommunications industry, towards more interconnection outside the US through regional Internet exchanges. The second force is the emergence of more sophisticated content distribution systems. The third force is the rapid growth of the Internet user base outside the United States and a corresponding demand for non-US and native-language content. While things are changing, nonetheless, the centrality of the United States in the Internet's global structure seems likely to persist in some form for many years.

One of the main purposes of establishing multiple NAPs during the privatization of NSFNET was to provide for more efficient routing of data packets. For example, traffic between hosts in different parts of California could transit through the PacBell NAP in San Francisco, without having to travel great distances. Thus, the routing scheme put in place through the establishment of the NAPs was very similar to the hub and spoke systems used in the airline industry. As the commercial Internet developed in the late 1990s in the United States, new public NAPs (also referred to as "Internet exchanges" or IXs) sprung up in every major US city. This greatly improved routing efficiency within the domestic US Internet.

Outside the US, however, there were few IXs since most large ISPs interconnected at US-based exchanges. This situation was both technically inefficient for data exchange between European countries and undesirable from a policy standpoint.

To remedy this situation, there was considerable action to initiate regional Internet exchanges in Europe and Asia, and to develop pan-regional networks that would interconnect the exchanges. The strategy appears to be working. Internet traffic analysts noted that "the percentage of traffic that stays local in Asia and Europe is increasing."[76] By 2000, hundreds of Internet exchanges were in operation around the world. In fact, the development of neutral, third party Internet exchanges became a lucrative business in its own right.

The second force transforming the Internet's global structure had to do with the

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[76] Telegeography, Inc. 2000. "Hubs and Spokes: A Telegeography Internet Reader" (Washington, DC)

logistical problem of moving data from producers to consumers. From a user standpoint, routing data through the United States had a substantial negative impact on Internet performance. Two trips across congested trans-oceanic backbones and through busy exchange points could lead to detectable latency. This was mildly annoying for web browsing or file transfers, and unnoticeable for email. However, such delays rendered impossible latency-sensitive applications such as streaming media or Internet telephony (VoIP).

This problem led to the development of content distribution networks. Content distribution networks (CDN) operated on a simple principle – they seek to minimize the network distance between users of content and distribution points. The fewer the number of nodes that must be transited between a content user and a content provider, the less delay and less chance there is of encountering a congested bottleneck.

Figure 2.6 illustrates how CDNs decreased the physical distance between content producers and content users. Akamai, the largest and most successful CDN, operated 6000 servers on 335 networks in 54 countries.[77] Shown on the left is the old distribution model for Internet data from a single, central server (or set of load-balanced servers at a single location). In practice, this server would take requests for web pages from around the world and return HTML source and any accompanying graphics or multimedia files to the requesting client. This model worked well for the vast majority of websites to date.

Yet as the World Wide Web and streaming media industries evolved in the late 1990s, it soon became clear that a small number of content providers were responsible for a large share of the data moving across the Internet. (Table 2.5) For example, AOL and Yahoo! were frequented by greater than 50 percent of Internet users.

Bottlenecks appeared because of the mismatch between the location of production of Internet content (a handful of metropolitan areas) and the location of consumption (globally distributed). Yahoo! needed to move data from its production studios in Silicon Valley to satisfy their customers. AOL had to route huge amounts of data to its proxy/firewall in Northern Virginia. Added to this logistical problem was the rise of “hotspotting”. As Akamai co-founder Tom Leighton, a professor at MIT’s Laboratory for Computer Science explained it, “That’s where a lot of people go to one site at one time

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[77] Akamai. 2000. [http://www.akamai.com].

and swamp the site and bring down the network around it—and make everyone unhappy."[78]

The solution was to develop a more sophisticated two-tier data distribution system utilizing a network of cache servers scattered throughout the world's ISP networks. From these strategic cache locations, content could be delivered much more rapidly and less wastefully since its journey would be much shorter, both geographically as well as by the number of network hops. Typcially it would be within the same city as the person requesting the content. This is illustrated in Figure 2.6. Geography was clearly a factor in the improved efficiency of content distribution networks for the reasons previously discussed in this chapter – namely the inefficiency of US-based interconnection. However, as Akamai Technologies' co-founder Tom Leighton explained, "Close is something that changes dynamically, based on network conditions, server performance, and load."[79]

Content delivery networks such as Akamai had a major impact on Internet infrastructure. Most importantly, distribution points for multimedia content were pushed to the "edge" of the Internet. CDN technology helped relieve congestion on major backbones by significantly reducing the amount of data that needed to be shuttled back and forth between content providers and users. The result was a more efficient use of Internet infrastructure. As Leighton remarked, "Before you typically got your interactions with a central web site. And typically that was far away. Now you typically have a lot of your interactions – not all, but a lot – with an Akamai server that is near you and selected in real time."[80]

The final force driving the diffusion of US dominance over international Internet traffic was the rise of a large user base outside the United States in the late 1990s. As Table 2.6 shows, by 2002 less than 1/3 (30.2 percent) of Internet users were from the United States and Canada, down from 72.7 percent in 1996. As a result by 2002, only 36.5 percent of all Internet users were English-speakers.[81] Their demand for native-language content dramatically reduced the amount of content requested US servers.

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[78] *Technology Review*. 2000. "Akamai's Algorithms" Sept/Oct

[79] Technology Review. Ibid.

[80] Technology review. Ibid.

[81] Global Reach, Inc. "Global Internet Statistics by Language" [http://www.glreach.com/globstats/index.php3]

Conclusions

This chapter has shown that contrary to rhetoric about the "death of distance" popular during the dot-com era, the Internet possesses a distinct geography. This geography is heavily influenced by global economic patterns and historical events. However, there are also powerful technological imperatives that have influenced Internet geography as well.

From a social and organizational perspective, the Internet's geography was shaped primarily by the shifting priorities and resources of the three main governing regimes. During the first era, under the Pentagon's guidance through ARPA, the core technologies of TCP/IP networking were developed and network nodes were widely scattered at a variety of urban and rural sites. Network infrastructure was disseminated over a wide geographic area presumably to test the military potential of packet-switched networks in strategic command and control operations. During the second era, NSF created a global research and educational network through an aggressive period of development and diffusion but domestically and abroad. In the third phase, the Internet was readied for commercial development and exploded into a truly global network linking over one half billion people representing nearly every nation on earth.

While America played a key role in creating Internet technology and the critical early components of network infrastructure, several economic, social, and technological forces combined to greatly weaken US dominance of the Internet. Non-US ISPs teamed to create regional Internet exchanges, eliminating the need for costly transoceanic bandwidth to the US. Content Distribution Networks retooled the way in which networks were used to move data from producer to consumer, reducing the total bit-miles of travel needed to deliver data to end-users. Finally, the diffusion of Internet technology dramatically reduced the share of English-speaking Internet users, resulting in much greater demand for locally produced native language content.

This chapter has chronicled the history of the Internet's geographic evolution at a global scale. Chapter 3 will examine the important role of key cities and metropolitan regions in that unfolding process.

CHAPTER 3

The Rise of the Network Cities

As the previous chapter has shown, the structure of the Internet is highly uneven when viewed on a global scale. This chapter expands on the spatial analysis of the Internet's structure begun in Chapter 2 by looking more closely at the role of individual cities and metropolitan regions in this process of uneven global diffusion.

To date, most studies of the Internet's diffusion have focused on nations. Yet within nations, the gap between wired enclaves and disconnected ghettos is even greater. Furthermore, the real economic might of nations rests in their cities, where economic networks of all types converge – shipping, air transport, and telecommunications. Thus, a city-level analysis is needed to truly understand the spatial dynamics of the Internet's diffusion.

While national differences were clearly a determining factor in the race to get wired, as the goals of the Internet changed during successive periods of evolution, the cities which were chosen to serve as its main hubs changed accordingly. Just a few key places served as hubs during all three periods of Internet growth; the military, educational, and commercial eras. As a result they are extremely important to the network's current overall structure.

As a result of this historical evolution process, the Internet's current structure left behind the ideal distributed, redundant topology that was envisioned by its creators. Instead, just a handful of cities around the world serve as dominant hubs for the network, reflecting their importance as global cities - world centers for communications.

Yet it is not only traditional global cities that form the core of this global urban network, because of the special role played by those cities that adopted these technologies early on. In the United States, San Francisco and Washington, DC were both heavy centers of investment throughout all three phases of Internet development. Correspondingly, they retained their role as key hubs long even after global cities caught up in the late 1990s.

This chapter seeks to reconcile the spatial development of the Internet in network cities like San Francisco and Washington with the urban studies literature on global cities like New York and Los Angeles. According to global cities theorists, cities like New York ought to have dominated the geography of the Internet from the outset, since they dominate the financial, cultural, and administrative functions of the global economy.

Yet the evidence presented in this chapter shows that global cities did not play an important role in the Internet's development until well into the third period of growth, in the era of the commercial Internet. During its long incubation, Internet growth happened far more extensively in a network of network cities – more dispersed medium sized cities such as San Francisco, Boston, or Bangalore. Instead of being developed by the large institutions of global cities, Internet technologies were developed in a far more decentralized way, in the universities of the network cities. And as the students and researchers exposed to these technologies entered the workforce and started new companies, these cities got an early lead over global cities in commercial use of Internet technology.

First, it is useful to review the global cities literature and its main tenets, as well as the popular utopian discourse to which it stands opposed. For purposes of this overview, we will refer to this body of literature as the urban dissolution theory.

Urban Dissolution: The Death of Distance

During the technology boom of the late 1990s, numerous pundits, scholars, and pop intellectuals alike resurrected a long-standing tradition of utopian thought to justify the enormous investments being made in information and communications technologies.

Proponents of the urban dissolution framework argued that engineering breakthroughs (most notably the development of fiber optics) were fundamentally rewriting the economics of telecommunications in such a way that they were becoming suitable substitutes for face-to-face contact. One respected journalist proposed that "the death of distance" was at hand, as high-capacity digital networks would rewrite the economic geography of the planet.[82] One of the most popular scenarios of this vision involved the replacement of the city's role as a meeting place with telepresence, projected through advanced videoconferencing. As radical as it was, this view gained widespread acceptance in academic, political, and media discourse due to its direct appeal to a long

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[82] Cairncross F. 1997. The Death of Distance (Harvard Business School Press, Cambridge, Massachusetts)

tradition of American anti-urbanism and, as Campanella notes, its usefulness in marketing a wide variety of "liberating" communications products and services.[83]

The idea that new distance-shrinking technologies would rewrite the landscape was a fundamentally American idea with a long cultural history. The automobile spurred fantasies of bucolic, yet cosmopolitan suburbanization like GM's Futurama (Figure 3.1) at the 1939 World's Fair in New York, or Frank Lloyd Wright's Broadacre City.

In the 1960's, as the power of television delivered graphic images of urban riots into new suburban tract homes, media scholar Marshall McLuhan "repeatedly announced the obsolescence of the built city in the electronically-mediated future."[84] Gaining credence in the wake of the ascendant Republican conservatism of the 1980's, Toffler's bestseller The Third Wave proscribed a future in which the tele-mediation of social and economic activities in the "electronic cottage", the advanced home of the future, would usher in a radical decentralization of population and production.[85]

While telecommunications-based visions of urban dissolution were not as well articulated visually as the automobile-based fantasies of the 1930s, it was nonetheless persuasive and optimistic enough that even respected urbanists could not resist its simple and compelling logic. It was argued that telecommunications would bring the conveniences of metropolitan life to remote mountaintops.[86] While this has certainly happened in international resorts like Aspen or Sun Valley, only a fraction of the world's wealthiest persons have been able to completely sever their physical tethers to metropolitan areas.

As the Internet gained widespread attention in the United States following the privatization of NSFNet in 1995, a new generation of anti-urban utopians rallied to proclaim the end of urbanism. Foremost among them was investment guru George Gilder, who proudly wrote in 1995 from his rural aerie in western Massachusetts that we are "headed for the death of cities." He described downtown business districts as

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[83] Campanella T. 2001. "Anti-urbanist city images and new media culture" in Imaging the City: Continuin Struggles and New Directions. L J Vale and S B Warner (Center for Urban Policy Research, New Brunswick, New Jersey)

[84] Campanella, Ibid.

[85] Toffler A. 1980. The Third Wave. (Morrow, New York)

[86] Webber M, 1964. "Urban Place and Non-urban Realm", in Explorations into urban structure. (University of Pennsylvania Press, Philadelphia)

"leftover baggage from the industrial age."[87] The fact that most of the content for new corporate World Wide Web sites was being developed by startups operating out of the loft districts of New York and San Francisco was apparently lost in Gilder's analysis.

Ironically too, even those who were contributing to the vitality of cities in the telecommunications age succumbed to the urban dissolution idea. Nicholas Negroponte, director of the influential Media Lab at the Massachusetts Institute of Technology had gathered talent from around the world in a multi-million dollar building on MIT's Cambridge, Massachusetts campus, creating a rich nexus for face-to-face interaction. Yet at the same time, in his bestselling book Being Digital, Negroponte wrote:

> The post-information age will remove the limitations of geography. Digital living will include less and less dependence upon being in a specific place at a specific time, and the transmission of place itself will start to become possible.[88]

Negroponte was not the only critic who wrote about urban dissolution from a busy urban office, humming with colleagues, protégés, and assistants. From *The Economist's* central London office, editor Frances Cairncross resurrected Toffler's vision of the "electronic cottage", forecasting a drop in crime and revitalization of bedroom communities as tele-connected suburban homes emerge as the center of economic activity. Cities would survive, but only as havens for bohemians and living museums for tourists.[89]

Beyond anecdote, however, little evidence supported the urban dissolution framework. While in the United Sates there were some documented population shifts towards suburban and non-metropolitan communities, there was not a concurrent shrinking of urban centers. In fact, the telecom boom of the 1990s coincided with the largest urban population explosion in American cities since the 1960s.[90]

Furthermore, the validity of this argument has been called into question by the bursting of the telecommunications investment bubble in 2001-2002. George Gilder, whose stock picks were once powerful enough to sway the market, ended up penniless

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[87] Gilder G. 1995. *Forbes ASAP*. February 27, p.56.
[88] Negroponte N. 1995 Being Digital. (Knopf, New York)
[89] Carincross, Ibid.
[90] Hampson R. "1990s Boom Reminiscent of 1890s." *USA Today*. April 4, 2001.

and largely forgotten.[91] However, even before that, the global cities literature posed serious challenges to the legitimacy of the urban dissolution argument, although it was largely aimed at an academic audience.

Global Cities and the Internet

A more nuanced perspective on telecommunications and urban development can be found within the scholarly literature on global cities. The global cities hypothesis is predicated on the idea that a handful of cities function as the financial and cultural capitals of the world, and as such as key agents in the process of globalization.

The idea that just a few great cities were steering global economic and cultural destiny seems to have first emerged in Peter Hall's seminal work on what he called "world cities".[92] Yet it was not until the early 1980s that a rigorous formulation of the hypothesis was proposed in the research community, and a set of research questions laid out to test the hypothesis. This analysis tied together Hall's ideas about urban development with ongoing debates in political science and economics.[93]

The central thesis of the global cities literature published in the 1980s and 1990s was the fact 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. In particular, the rapid transformation of global city economies from manufacturing and goods processing into producer services and finance was seen as a spatial manifestation of these global processes. This approach led to sweeping reconceptualizations of local urban problems in global cities as impacts of these supra-national processes, particularly the increasingly rapid and unregulated movement of capital across national borders. For example, the housing shortage in New York was not merely a result of strict rent control laws, but was largely caused by international immigration and the booming financial sector.

But just as they were impacted by global problems, global cities' economic and cultural influence was the driving force of global economic transformation. Since the

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[91] Rivlin G. 2002. "The Madness of King George". *Wired 10.07.*

[92] Hall P. 1966. The World Cities. (McGraw-Hill, New York)

[93] Friedmann J and G Wolff. 1982. "World City Formation," *International Journal of Urban and Regional Research*, 6, pp. 306-344.

globalization of economic activity had greatly increased the complexity of business transactions, a centralization of corporate command and control functions was necessary even as primary production was scattered to the corners of the earth.[94] Telecommunications networks provided the means by which global city decision-makers could exert power and influence around the world.

Thus, advanced information and communications technologies played a vital role in the global cities view of contemporary urbanization. They provide the means for centralized corporate decision-making through control and coordination of far-flung production networks. They were also the distribution channels for the cultural products of global city economies - news, fashion, and entertainment.

In contrast, then, with the proponents of urban dissolution, the global cities literature argued that telecommunications network infrastructures were in fact dominated and centered upon this handful of powerful cities. The influential urbanist and sociologist Manuel Castells underscored the global city dominance of advanced telecommunications networks, stating:

> [Megacities] are the connecting points to global networks of every kind. Internet cannot bypass megacities: it depends on the telecommunications and on the "telecommunicators" located in these centers.[95]

In Castells' social constructivist view, digital network infrastructure owed its existence to intensive users of telecommunications in global cities. Earlier evidence on the intensive use of the telegraph, telephone, and overnight express delivery in global cities like New York suggested this was a likely reality.[96,97,98]

Unfortunately, little evidence was presented to support these claims with respect to the Internet. Were digital networks like any other communications network, and bound to follow existing patterns of trade and commerce, or did they truly have the potential to eliminate the "tyranny of geography"? The literature on global cities was long on

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[94] Sassen S. 1991. The Global City: New York, London, Tokyo. (Princeton University Press, Princeton, New Jersey)

[95] Castells M, 1996. The Rise of the Network Society. (Blackwell, Cambridge, Massachusetts)

[96] Standage T. 1998. The Victorian Internet. (Walker & Co., New York)

[97] Gottman J. 1964. Megalopolis: The Urbanized Northeastern Seaboard of the United States. (MIT Press, Cambridge, Massachusetts)

[98] Mitchelson R and J O Wheeler. 1994. "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).

speculation and short on specification when addressing advances in telecommunications during the 1990s.

A notable exception to the shortage of quantitative evaluation of the telecommunications functions of global cities was the work of Mitchell Moss. One analysis by Moss showed that New York City alone was responsible for nearly 20 percent of the nation's annual overseas telephone calls during 1982 despite having less than 5 percent of its population at the time.[99] As Table 3.1 shows, New York was indubitably the nation's international gateway. This expanded upon an earlier analysis of overseas telephone traffic in New York City.

Despite Moss' work, there was little data to support the idea of a global city monopoly on international communications activity and infrastructure, especially on new networks like the Internet. Some attention was focused on this knowledge gap, and a set of measures was proposed that could be used to rank cities by their share of global flows of information, money, and power. Peter Hall tentatively offered the usual triumvirate of New York, London, and Tokyo as the dominant global cities by these measures, yet left open the possibility that "changes in political, economic, and technological" frameworks might affect positions in such a hierarchy. [100]

The Inadequacy of Existing Views

The conflict between these two visions of the future of cities remained badly neglected by urban researchers at the time that that the Internet was growing rapidly. This chapter presents evidence on the geographic diffusion of Internet infrastructure between 1998 and 2002 that supports a more sophisticated theoretical framework needed to understand the ongoing co-evolution of settlement patterns and digital telecommunications networks.

While the global cities hypothesis offered a number of useful concepts and predictions for understanding the emerging structure of digital networks like the Internet, it was too rigid to account for the potentially dramatic shifts in economic and cultural geographies made possible by telecommunications systems. While global cities are the

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[99] Moss M. 1986. "Telecommunications and the future of Cities". *Land Development Studies*. 3.

[100] Hall P. 1997. "Modeling the Post -Industrial City", *Futures* v29, n4/5, pp.311-322.

largest clusters of advanced network infrastructure in terms of size, many other second-tier cities had dramatically higher overall rates of network adoption. In short, new centers of communications activity outside global cities appeared to be gaining significance. The global cities hypothesis did not adequately explain this phenomenon.

Secondly, for the first time in history, technological innovation is no longer the monopoly of global city institutions. Historically, global city institutions (mainly banks) were the driving force behind innovation and diffusion of new communications technologies. Allen Pred described how in the American colonies, New York-based "packet lines" were early innovators in accelerating the flow of communications between the U.S. and Europe.[101] The early development of the telephone network was characterized by inter-city connections radiating from New York to Boston (1880), Washington (1890), Chicago (1892), San Francisco (1914), and Miami (1916).[102]

The Internet and other digital network technologies had emerged in a far different geography of innovation. Unlike the days of Bell and Edison, when research and development was largely concentrated in a few major industrial cities, the post-war American landscape was characterized by a dispersed system of university-based research networks and "technopoles", such as Silicon Valley and the Route 128 corridor in Massachusetts.[103] The invention of the personal computer was another classic example of tinkering in suburban garages that also typified the geography of technological innovation in late 20th century America. The open source movement, an important force in software development, consisted of groups of independent programmers scattered throughout the world.

The most compelling evidence on the minimized role of global cities in technological innovation was Mathew Zook's analysis of venture capital funding in the 1990s in the United States.[104] He found that the networks of investors, entrepreneurs, and workers in places like Silicon Valley and Boston's Route 128 were the driving forces in the rapid product cycles of the telecommunications and high-technology sector. Jump-

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[101] Pred A R. 1973. Urban Growth and the Circulation of Information. (Cambridge, Massachusetts: Harvard University Press)

[102] Abler R. 1970. "What Makes Cities Important," *Bell Telephone Magazine*.

[103] Saxenian A. 1994. Regional Advantage: Culture and Competition in Silicon Valley and Route 128. (Cambridge, Massachusetts: Harvard University Press)

[104] Zook, M. 2002. Hubs, nodes, and bypassed places : A typology of E-commerce regions in the United States. *Tijdschrift voor economische en sociale geografie* .

started by defense contracts in the 1960s and 1970s, and fed by a self-reinforcing flow of graduates from the region's universities and capital from earlier successful entrepreneurs, technopoles had clearly usurped the global city role of technology incubator in the United States.

So while the flow of information and related technologies remained vitally important to the economic well being of global cities, they had become importers of technological innovation rather than producers. The Internet and its most compelling applications were developed in far-flung, specialized information cities and only began to be adopted by global city institutions when its commercial usefulness was established with the release of the graphical web browser Mosaic in 1993.

The urban dissolution framework was seriously flawed as well. First, the financial districts of cities like London and New York persisted precisely because highly-skilled workers in close physical proximity provided the most efficient means of interpreting, in real-time, the massive amounts of information generated by the international financial system.[105] Advances in telecommunications and information technology actually increased the need for institutions, people, and districts that can extract meaningful knowledge from the rapidly increasing glut of undifferentiated information. This reasoning, while typically used to support the global cities hypothesis, however, was not limited only to the financial industry. It could also be applied to any emerging specialized industrial cluster, such as the technology firms surrounding Austin, Texas or the special effects industry in Southern California.

Second, urban dissolution naively assumed that telecommunications and transportation were substitutes. The "electronic cottage" obviated the need to travel to a central area for shopping, work, or entertainment. On the contrary, there was strong evidence of a complementary relationship between business travel and spending on telecommunications during the 1980s and 1990s.[106] Telecommunications created more demand for travel, as it made it easier to manage global alliances and enterprises.

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[105] Thrift N. 1996. "New Urban Eras and Old Technological Fears: reconfiguring the goodwill of electronic things" *Urban Studies* 33(8): p1463-1494.

[106] Gaspar J and E Glaeser. 1998. "Information Technology and the Future of Cities" *Journal of Urban Economics* 43(1): 136-156.

Third, the deployed digital network infrastructure described in this chapter and the following chapter overwhelmingly pointed towards a metropolitan dominance in telecommunications assets. In fact, the urban-rural divide in telecommunications capabilities was far worse after deregulation than before, when most rural towns in developed countries had achieved parity with urban centers in telephone and television services.

Finally, prophecies of wholesale urban dissolution must be reconciled with the fact that cities are clearly prosperous in the "digital economy". A mass exodus of firms and population from cities has simply not occurred, and in fact by 2000 most cities in the developed world were more vibrant than they had been in decades.

The Network of Networked Cities

There were useful concepts in both the global cities and urban dissolution frameworks. The global cities literature offered useful arguments for explaining the distribution of telecommunications infrastructure among the world's cities, and the urban dissolution argument suggested that there were circumstances where technological innovation could disrupt this hierarchy. A more nuanced model for digital network diffusion that combines aspects of both approaches was clearly needed.

Drawing upon historical maps of Internet backbone network architecture published in trade magazines, program reports, and secondary sources, the remainder of this chapter first describes the structure of the commercial Internet at the metropolitan level of aggregation, and then looks at the lasting impacts of earlier waves of network building during the ARPANET and NSFNET eras.

This analysis shows that while the structure of the Internet mimicked the existing geography of inter-urban economic networks, the distributed nature of its early structure remained imprinted deeply, challenging the notion that global cities would naturally dominate the new digital network infrastructure. Instead, the global structure of the Internet was a flatter, less hierarchical network of networked cities. While major cities were its basic building blocks, this mesh of high-capacity, densely interconnected nodes was far more widespread and less hierarchical than would be predicted by the global cities hypothesis.

Mapping the Internet's Metropolitan Connections

Because of the lack of regulation on Internet service providers during the commercial boom of the 1990s, detailed data on their operations and network assets was notoriously difficult to obtain. As a result, only a handful of studies were conducted to investigate the international urban geography of the Internet.

Most studies relied upon national IP backbone maps published by *Boardwatch Magazine* during the late 1990s. Aimed at network administrators, these maps were intended to help customers better understand the internal architecture of service provider networks when shopping for wholesale bandwidth. For example, a regional ISP might have favored one backbone over another because its network had better connections to key cities.

The *Boardwatch* maps did not provide specific information on the actual physical routing of the backbones – as explained in Chapter 2, IP backbones are a layer 3 network carried over a variety of underlying physical media. Geographic IP network maps simply indicate the nodes and topology of links in-between, much in the way air transportation networks are schematic diagrams of city pairs between which service is provided, rather than showing the actual flight path. In addition to the topology of inter-city connections, the *Boardwatch* maps provided basic information about capacity deployed on those links. While the exact locations of network nodes were not provided for a variety of competitive concerns, the published maps did indicate the metropolitan area in which the hubs were located.

From these maps, a database of nodes (cities) and links (backbone segments) could be developed and aggregated to create a matrix of metropolitan areas and the total deployed Internet capacity linking them together. Townsend was among the first to publish such an aggregate analysis of Internet backbone capacity at the metropolitan level. That study compared backbone diffusion between 1997 and 1999, focusing on the United States and found that seven metropolitan areas (New York, San Francisco, Los Angeles, Atlanta, Dallas, Chicago, and Washington) had emerged as the dominant hubs of the nation's Internet infrastructure.[107] While other studies that employed more rigorous geographical analysis later followed[108], this was the first multi-city look at the evolution of Internet infrastructure over time. Furthermore, this study was distinguished by its historical perspective, and tied the shape of the commercial Internet to its non-commercial predecessors.

This chapter presents the results of that study in the overall context of this dissertation, which seeks to place the unfolding story of Internet development within a framework of changing urban telecommunications infrastructure. When applicable, updated data from parallel research conducted by other scholars is used to supplement and confirm this analysis.

A Hub and Spoke Network for Data Transport

As excitement about the commercial Internet began to build in the mid 1990s, there was a rapid increase in the deployment of backbone capacity to serve the rapidly growing number of businesses, institutions, and individuals using the Internet for communication. The new backbone network companies evolved from a variety of origins. Some, like PSINet[109] and UUNET[110], were the descendants of regional networks that had been formed under the NSFNET program to provide Tier 2 transport from the NSFNET backbone hubs to participating universities. Many backbones were new divisions or subsidiaries or large telecom firms, such as SprintNet and AT&T. Still others

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[107] Townsend A M. 2001. "The Internet and the Rise of the New Network Cities: 1969-1999" *Environment and Planning B.*

[108] Wheeler D C and M E O'Kelly. 1999. "Network topology and city accessibility of the commercial Internet"; Grubesic T H and M E O'Kelly. 2002. "Using Points of Presence to Measure City Accessibility to the Commercial Internet." *Professional Geographer*, 54(2): 259-27; Gorman S.P. and Malecki E.J., 2002, "Fixed and fluid: stability and change in the geography of the Internet" ,*Telecommunications Policy*, Vol. 26, No. 7-8, pages 389-413.

[109] PSINet was started by the founders of NYSERNET (New York State Education and Research Network).

[110] "By 1988, it was becoming apparent, however, that the Internet's growth and use in the business sector might be seriously inhibited by this restriction. That year, CNRI requested permission from the Federal Networking Council to interconnect the commercial MCI Mail electronic mail system to the Internet as part of a general electronic mail interconnection experiment. Permission was given and the interconnection was completed by CNRI, under Cerf's direction, in the summer of 1989. Shortly thereafter, two of the then non-profit Internet Service Providers (UUNET and NYSERNET) produced new for-profit companies (UUNET and PSINET respectively). In 1991, they were interconnected with each other and CERFNET. Commercial pressure to alleviate restrictions on interconnections with the NSFNET began to mount." From [http://www.worldcom.com/uunet/be/resources/cerfs_up/internet_history/whatIs.xml]

were entirely new venture-backed speculative builders. This category included firms like Qwest and Level 3. One large backbone operator (BBN) even traced its origins back to the very first node of ARPANET. Bolt, Beranek, and Newman (BB&N) had been the Massachusetts-based engineering firm that designed the original Interface Message processor (IMP) that connected ARPANET nodes together via leased phone lines. With Internet traffic doubling annually there was ample room for a proliferation of backbones.[111]

However, due to the increasingly fragmented and secretive nature of IP backbones caused by intense competition in a rapidly growing market, the overall structure of the Internet backbone (if it could even be referred to in the singular) looked nothing like the last published map of the NSFNet backbone in 1995.

By late 1997, total backbone capacity deployed on key inter-metropolitan routes like New York-Washington and San Francisco-Los Angeles had increased by several orders of magnitude. As Figure 3.2 shows, the emerging structure of the Internet backbone had begun forming a hub and spoke pattern centered around seven major metropolitan hubs. These seven hubs (Washington, Dallas, San Francisco, Atlanta, Chicago, New York and Los Angeles) were vitally important to the structure of the network. Some two-thirds of all Internet backbone capacity deployed in the United States passed through these seven cities.

By early 1999, just 18 months later, backbone capacity had expanded five-fold amidst an unprecedented explosion in network deployment. Diffusion theory would suggest that access would have diffused to smaller metro areas. Indeed, this did occur, by 1999 most metropolitan areas were connected to the Internet backbone. However, much of the capacity growth occurred along routes linking hub cities together. Thus, despite an exponential expansion in network capacity, the hub and spoke pattern that was in place by 1997 was largely reinforced. (Figure 3.3)[112]

Despite the five-fold expansion in capacity since 1997, by 1999 the seven hubs had only lost a tiny share of the nation's total backbone capacity. While their share of

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[111] Odlyzko A. 2000. "Internet Growth: Myth and Reality, Use and Abuse" *IMP: Information Impacts Magazine* [http://www.cisp.org/imp/november_2000/odlyzko/11_00odlyzko.htm]

[112] These maps only indicate 80 percent of inter-city capacity. The remaining 20 percent of capacity connects city pairs that are not adjacent. Representing these links would render the map illegible.

national capacity fell from 60.4 percent to 41.5 percent between 1997 and 1999, the seven big metropolitan hubs added capacity at 60-90 percent of the rate of the nation as a whole, despite their enormous existing lead in 1997. (Table 3.2) Furthermore as Figure 3.3 clearly shows, much of this "diffusion" was actually devoted to new routes between the seven major hubs. As a result, by 1999 most of the major metropolitan hubs were linked by direct high-capacity "express" links as well as high-capacity "local" links that served intermediate cities. For example, the Atlanta-Washington route was served by a direct connection as well as a secondary connection passing through intermediate locations in North Carolina and Virginia.

Contrary to what might have been predicted based on the global cities hypothesis, none of America's most global cities were the dominant hubs for the emergent Internet backbone during the late 1990s. In fact, New York, Chicago, and Los Angeles were generally outpaced by the other four hubs (Washington, Dallas, San Francisco, and Atlanta) during the 1997-1999 period.

Even more surprising than the lack of global city dominance of Internet backbone topology was the absolute dominance of the seven metropolitan hubs over all other cities. If one measures the number of links emanating from each metropolitan area, the special role of these seven hubs in facilitating the inter-connectedness of the entire network becomes starkly clear.

Figure 3.4 plots metropolitan areas' total number of backbone links in rank-order, a standard rank-size distribution. This analysis is analogous to looking at the number of destinations that can be reached by direct airline flights from a given city, as is common in economic development practice. Compared to the fitted exponential regression line, the top seven metropolitan areas clearly formed a separate group. Beyond this group, there was a fairly stable distribution of network nodes.

More significantly, however, between 1997 and 1999, a period of intense deployment of new networks and capacity, the gap between the top seven metropolitan areas and the rest remained. In 1997, Washington, DC had 2.17 times more links than the 8th ranked metropolitan area (Phoenix). By 1999, the Washington area still had 2.15 as many links as the 8th ranked metropolitan area (Seattle).

Supply and Demand:
Domain Registrations as an Indicator of Internet Activity

As the preceding section has shown, even after nearly a decade of rapid growth, commercial Internet backbone capacity was more widely dispersed across American areas than the global cities hypothesis would suggest. According to that thesis, one should expect to find great concentrations of capacity serving New York, Los Angeles, and Chicago, the three U.S. cities most frequently identified as global in the urban studies literature.[113] But rather than being evenly dispersed across the American metropolitan system, the bulk of backbone capacity served just seven metropolitan areas, the new "network cities".

Looking beyond backbone infrastructure, the prominence of these network cities during the early phase of commercial Internet development (1995-1999) can be seen in the distribution of firms and organizations using the Internet as well. One method of measuring Internet activity in a given city or region is to count the number of Internet domain names registered by firms and individuals in that area. While this measure has several limitations, it has been studied extensively and shown to be a reliable indicator of trends in Internet adoption among firms and organizations across broad geographic areas.[114]

Just as Internet backbone network capacity was more diffused than the global cities hypothesis would suggest, domain name registrations tended to be more highly concentrated in the new network cities. As Table 3.3 shows, global cities simply did not exhibit the high levels of Internet adoption seen in the network cities such as San Francisco, Boston, or Washington. The global cities of New York (7.9 domains per 1,000 persons) and Chicago (7.9 domains per 1,000 persons) did not appear on this list, and Los Angeles barely registered.

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[113] Abu-Lughod J L. 2001. New York, Chicago, Los Angeles: America's Global Cities. (University of Minnesota Press)

[114] Moss M and Townsend, A. 1997. "Tracking the Net: Using Domain Names to Measure the Growth of the Internet in U.S. Cities". *Journal of Urban Technology*, 4(3), 47-60.; Kolko, J. 1999. "The Death of Cities? The Death of Distance? Evidence from the Geography of Commercial Internet Usage". Paper presented at the Cities in the Global Information Society: An International Perspective, Newcastle upon Tyne, UK.

Contrary to what would be predicted by the global cities hypothesis, the Internet was mushrooming elsewhere than global cities. What was going on? To answer this, one must look back at the metropolitan geography of earlier digital networks like ARPANET and NSFNET. The siting of early nodes on these networks laid the seeds of supply and demand for IP networking which drove the creation of commercial Internet hubs.

The Legacy of Early Networks

The adoption of Internet technology in the network cities was clearly far more rapid and widespread than global cities. But why were these (by global standards) relatively small cities so much further along the Internet adoption curve than the movers and shakers of the national and global economy like New York, Chicago, and Los Angeles?

The most important factor was their role as hubs in the earlier packet-switched networks ARPANET and NSFNet.[115] The structure of early packet-switched networks had an enormous impact on the later role of cities and metropolitan regions in the development of commercial Internet backbones. During each phase of network development, new cities were linked to the evolving Internet, a process of connection that continued to permeate these regions from the initial seedbeds at university computer labs and defense contractors.

Most of the important Internet hubs during the commercial expansion in the late 1990s were part of ARPANET in the 1970s. The early years of ARPANET were characterized by three main clusters of sites, in the Boston, San Francisco, and Los Angeles metropolitan areas. (Figure 3.5) These regions were the nation's primary clusters of information technology and electronics for the defense industry.

During the 1970s, growth was rapid and by 1980 ARPANET had a fourth major metropolitan cluster in the Washington, DC area, a region densely populated by military bases, defense contractors, and government information technology contractors.

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[115] To a lesser extent, the more homogeneous population of the networks cities helped speed diffusion within their regions. Lacking the extremes of wealth and poverty, and less fragmented through international immigration, network cities had an advantage to quickly spread Internet technology throughout their social and business cultures.

Additional sites were scattered throughout the interior of the nation, almost universally at universities and military installations far from urban cores. (Figure 3.6)

Throughout its two-decade lifespan, ARPANET largely bypassed the nation's largest cities, focusing instead upon dense concentrations of research and development institutions like Silicon Valley and Boston's Route 128 corridor. New York, the nation's largest city only had a single node at New York University. Of America's three global cities, only Los Angeles was an important hub on ARPANET. Rather, more modestly sized regions were the dominant hubs of ARPANET and NSFNET as well. (Table 3.4)

As described in Chapter 2, part of ARPANET's attraction to a more diverse set of metropolitan hubs was its goal of building a distributed architecture as an experiment in nuclear-proof communications grids. By the early 1980s, this had largely been achieved, and ARPANET's backbone architecture provided at least four redundant transcontinental routes.

The distributed nature of ARPANET was fine for the small community of users involved in that research project. However, priorities changed quickly as ARPA devolved responsibility for the Internet to the NSF. The aggressive agenda set by NSF for expanding the Internet necessitated a dramatic change in backbone architecture, and the end of Pentagon funding dictated a new set of cost constraints. While distributed networks like ARPANET were highly redundant and invulnerable to attack, they were costly to build and of limited additional value for a civilian network.

The Internet was expanded exponentially during the NSFNet years, surpassing first 10,000 hosts (1987), then 100,000 hosts (1989), and 1,000,000 hosts (1992) within the span of just five years.[116] In order to accommodate the rapid growth of traffic on the network and the expanding number of connected institutions, the NSF adopted a two-tiered service model that saved money by moving to a more centralized network topology.

The first national backbone that went into service in 1989 clearly illustrated NSF's new vision of network economics. (Figure 3.7) In this design, high speed T1 lines (1.544 Mbps) interconnected hubs at major computer science research centers around the country. Many of these had been involved in ARPANET, but NSF cast a wider net and

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[116] Hobbes Internet Timeline [http://www.zakon.org/robert/internet/timeline/]

included major research institutions that had not been connected to ARPANET. For the first time, the Internet's backbone topology started resembling its current form, rather than the distributed grid it had been until then.

At the same time it was funding the construction of the national backbone, NSF was funding regional consortia to build the second tier of the new network infrastructure to link member institutions to the regional backbone hubs. For example, NYSERNET connected New York State's highed educational institutions into the backbone through New York City. Much like the hub and spoke feeder network of airlines, NSF was establishing a decentralized (but not distributed) network for efficiently moving data around the country.

In the early NSFNET era, global cities began participating in the overall network structure. At the core of this emerging national digital backbone were major cities such as Chicago, Los Angeles, and New York. Yet they were no more important, in terms of capacity, than the hubs located in San Francisco or Washington. A T3 upgrade to the NSF backbone in 1991 that boosted its capacity some 30 times, featured new routing that favored large cities even more.

Even as NSFNET rapidly expanded, by the early 1990s, it was clear that the Internet would eventually need to be linked to commercial email networks like MCIMail which had quickly sprung up to serve the email needs of corporations. In March 1991, NSF revised the acceptable use policy for NSFNET to allow commercial traffic; in a recent cover story, *Business Week* pointed to this as a seminal moment for the Internet economy, which not altogether coincidentally began its record expansion in that very month.[117] Under the newly elected Clinton-Gore administration, the NSF moved quickly to privatize the provision of Internet infrastructure by designating a series of regional interconnection sites around the nation – the Network Access Points (NAPs) described in Chapter 2.

The location chosen for the NAPs were heavily influenced by the geography of the four ARPANET and NSFNET backbones that had preceded it. And the choice of these locations exerted a tremendous force on the evolution of commercial backbone

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[117] National Science Foundation "Nifty 50: The Internet" [http://www.nsf.gov/od/lpa/nsf50/nsfoutreach/htm/n50_z2/pages_z3/28_pg.htm

networks in the latter half of the 1990s. With the exception of Atlanta, every one of the seven major metropolitan backbone hubs described above was the site of a NAP following the privatization of NSFNET.

Thus, the deployment decisions made in the early days of ARPANET and NSFNET had clear impacts upon which regions were able to quickly adopt Internet technology become the first hubs of the early commercial Internet. These early advantages attracted further network investment during the intense infrastructure development of the late 1990s, further reinforcing their importance in overall U.S. Internet structure.

Once set in place, the hierarchy of network cities as the core hubs of the US domestic backbone (and in the case of San Francisco and Washington DC, the global backbone) was remarkably stable until an even larger second wave of network expansion that occurred in 2000-2001.

Regional Advantage:
Network Cities' Socioeconomic Advantage

These new network cities experienced faster, earlier growth in Internet activity and infrastructure than America's global cities. Much of this can be attributed to the decisions on backbone architecture made during the 1970s and 1980s under ARPANET and NSFNET. But why were these cities chosen to be hubs on these early networks?

Primarily, the network cities early advantage stems from their early lead in the technology industry and university-based technology research. Early ARPANET sites were deployed at leading computer science research departments in Boston (MIT, Harvard) and San Francisco (Stanford, Berkeley) and Los Angeles (Caltech, UCLA). While NSFNET broadened the scope of networked institutions, it was still mainly higher educational institutions that were connected to the Internet during the 1970s and 1980s.

As a result, the network cities had at least a decade in which familiarity with Internet technology could percolate out from the university into the private sector. Since Boston and San Francisco in particular were technology centers, the leap from computer lab to office was quickly made. In contrast, global city institutions like banks kept away from the Internet in favor of more secure, less experimental proprietary technologies. Thus for the decades that it took Internet technology to become commercialized, it had been slowly spreading throughout these network cities.

Turning the argument around, its clear that global city institutions (banks again offer a good example) were not developing the kind of regional innovation systems seen in network cities, where rapid product cycles, high employee turnover, and university-industry partnerships created a very fluid flow of ideas throughout the economy. In contrast, financial companies were the early adopters of information technology in global city economies but they generally purchased single-purpose systems and made every effort to prevent its diffusion outside the company.

Finally, the network cities did not possess the socioeconomic extremes of global cities, where rich and poor cohabited the same urban space but were disconnected socially. As a result of this disconnection, the free flow of ideas and technologies was further retarded. In contrast, the network cities all shared a very similar profile; a population of several million people, an economic base built upon diverse business services, and a degree of geographic centrality. Put simply, a network city was a nice place to be a geek. These places offered a reasonable commute, a place to get outdoors once in a while, and good places to study. One observer dubbed them 'Nerdistans'.[118]

Resurgent Global Cities:
The Second Wave of Commercial Internet Expansion

While network cities clearly were first out of the gate in the race to develop inter-metropolitan Internet connections, it was inevitable that global cities would reassert themselves on this new global system of trade and exchange. As IP backbone deployments accelerated even faster after 1999, global cities finally began to claim their position at the top of the Internet's global structure.

Despite the tremendous rate of growth in backbone capacity that had persisted throughout the 1990s, a second wave of backbone network deployment occurred in late 1999 and 2000. While total intercity Internet backbone capacity in the top metropolitan

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[118] Kotkin J. 2000. The New Geography: How the Digital Revolution is Reshaping the American Landscape. (Random House, New York)

hubs expanded five-fold between 1997 and 1999, in just one year (2000) the growth rate doubled again. Between 1999 and 2000, total inter-metropolitan backbone capacity in the United States expanded by a factor of 10. (Table 3.5)

Once again, during a major period of Internet development, a shift occurred in the location of major hubs. By the end of 2000, global city businesses and institutions had become more adept at adopting Internet technology. As a result they appear to be reassuming their "rightful" role as core hubs of global digital telecommunications networks.[119] Global cities are now core hubs of the Internet, not merely in terms of capacity, but also ease of accessibility.[120]

Yet global cities are far from dominating the topology of the Internet. The importance of network city hubs has not been erased, as Table 3.6 indicates. The domestic US backbone has shifted towards a more centralized global-city based topology, but with remnants of the old network of network cities.

Outside the United States, global cities are more dominant nodes of Internet infrastructure, yet are still challenged more forcefully as Internet hubs than they are as centers for finance, trade, or transportation. As Table 3.6 indicates, there are a number of Internet hub rivalries in various world regions that depart from the realities of other economic competition.

For example, Amsterdam is a relatively small city and not usually considered "global", yet as a major terminus of both transatlantic and continental backbone routes, it is a serious challenger to London's hub position. In Asia, relatively backwater Seoul, South Korea is on the same level of Tokyo as an international Internet hub. Also of note are the cities that fare poorly. Paris, one of Sir Peter Hall's original "world cities" in his 1961 book of the same name, ranks fourth among European cities.

Future Evolution of the Internet Backbone

In 2001-2002 the rapidly deteriorating condition of the telecommunications industry put a halt to Internet backbone expansion in the United States. While domestic

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[119] Gorman and Malecki, Ibid.

[120] O'Kelly M E and Grubesic T H. "Backbone topology, access, and the commercial Internet, 1997-2000" *Enviroment and Planning B* 29:533-552

Internet backbone capacity in the United States expanded 25-fold on major intercity routes between 1999 and 2002, by the end of 2002 the backbone market was in the doldrums. As network analysts at Telegeography, Inc. described the market in early 2003:

> IP transit prices have dropped 40 to 50 percent in each of the past two years. Prices for fiber-optic capacity, the building blocks for IP networks, have plummeted by more than 70 percent per year… It appears unlikely that falling prices for IP transit will appreciably stimulate demand in the short-term. Thus, backbone providers that do not already have a solid customer base may find it difficult to build their revenue streams.[121]

With such overbuilt capacity, intense completion and little future profit, the Internet backbone business was forecast to remain stagnant for much of the first decade of the 21st century. (Chapter 5)

Conclusions

Three main conclusions can be drawn from the evidence presented in this analysis of Internet topology at the metropolitan scale.

First, while only a limited amount of research has addressed the geography of the Internet at a city level, contrary to popular belief, these geographic differences are substantial and persistent. The analysis of the Internet's global evolution during the 1970s-1990s in Chapter 2 identified three major periods of investment, expansion, and diffusion. This chapter has showed how during each phase, investors' goals and changes in the user base were key determinants of geographic differences in Internet development.

Secondly, cities have thrived rather than being obsolesced by the advent of plentiful long-haul telecommunications as was predicted by utopian futurists. In fact, this analysis has shown that cities were the cradles of innovation for the early Internet in both its educational and commercial phases. Without the research complex of Boston's

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[121] Telegeography, Inc. 2003. "U.S. Internet Geography 2003"

universities or the industrial agglomeration of the San Francisco Bay Area, it is unlikely that Internet technology could have developed and spread so rapidly.

Third, this evidence about changes in the structure of the Internet's geography at a metropolitan level challenges some contemporary theories about global patterns of urbanization. The metropolitan regions that incubated Internet technology and developed it to the point where it was ready for mass diffusion rarely ranked highly in any of the major efforts to categorize the world's global cities.[122] While financial and cultural centers like New York, London, and Tokyo eventually became the world's largest Internet hubs (as predicted by the global cities hypothesis), for most of the Internet's 30+ year history they trailed "technopoles" like San Francisco, Washington, and Los Angeles in intensity and magnitude of Internet infrastructure development.

One result of this evolutionary process is that the Internet's geographical hierarchy was much flatter than other inter-urban network flows such as telephone traffic, air transportation, or trade. One interesting possibility was that this allocation of Internet infrastructure would level the playing field and permit firms in smaller cities to compete more effectively for access to global markets, rather than using global city institutions as intermediaries. If this becomes true, it would undermine much of the rationale for global cities. While the Internet may not be ungluing the metropolis in the way urban dissolutionists foresaw, it could be contributing to a flattening of the urban hierarchy in a way that decentralizes the global economy away from the rigid hub and spoke global city hierarchy.

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[122] Globalization and World Cities (GaWC) Research Center, Loughborough University. [http://www.lboro.ac.uk/gawc/]

CHAPTER 4

The Wired Metropolis

To this point, this thesis has focused on Internet backbones, which are the layer 3 networks superimposed upon the world's telecommunications grids to create the global Internet. This chapter delves beneath the *virtual* layer of the Internet backbone to examine the *physical* telecommunications systems upon which the Internet is built. These infrastructure systems provide the means to create, transport, store, and process bits as they flow from place to place. Well-known components of this new digital communications infrastructure include fiber optic networks, telephone, and cable television networks. Less obvious components include the interconnection facilities that stitch these networks together, the server farms and data depots that cluster around key distribution points, and the wired homes and offices where digital information is produced and consumed. For digital networks require more than just wires, but also components to create, consume, store and exchange bits.

This chapter describes the evolution of the four vital components of the urban digital infrastructure:

- Information factories: the office buildings and homes where digital data are produced and consumed
- Information highways: the physical transmission media which link other components together over long and short distances
- Information ports: the neutral inter-connection sites where competing carriers stitch their systems together to create a seamless global network
- Information warehouses: massive data centers or server farms where digital data is stored locally for rapid distribution

Combined, these four components comprise a radically new urban telecommunications infrastructure. Unlike the monopolies of the past, this new infrastructure is characterized by a multitude of overlapping and competing networks. Yet despite their competitive nature, the benefits of inter-connection have sewn these components together in a seamless mesh. This new network infrastructure operates largely without respect to regulatory or political structures and boundaries. Its geography therefore, reflects economic realities and is metropolitan in scope.

This chapter compares the development of metropolitan telecommunications infrastructure development during the 1980's and the 1990's, focusing primarily on the United States' experience. While access to advanced telecommunications infrastructures in the 1980's were typified by centralized satellite earth stations (the "teleport"), the new metropolitan communications grid is characterized by a more decentralized distribution of facilities. Similar to the global structure of the Internet (Chapter 2), the geography of the Internet at a local scale has tended to follow existing pathways of commerce and communications. Yet just as less dominant cities have emerged as important hubs on the global Internet grid (Chapter 3), the same is true with telecommunications infrastructure. Competition has helped spur a diversification of telecommunications infrastructure assets far greater than has ever existed before.

Yet while the structure of new telecommunications infrastructure is less centralized than before, it is by no means distributed equally within regions. In fact, the spread of advanced digital networks was highly uneven and selective, as telecommunications carriers cherry-picked their way through affluent neighborhoods and business districts. As a result, Fortune 500 companies could choose between dozens of competing fiber providers who offered them diverse and redundant network connections, but smaller businesses and less affluent residents were often served only by the incumbent carrier. While the cost of moving information long distances between cities dropped dramatically, even after the fiber boom a lack of "last mile" infrastructure remained the greatest obstacle to widespread broadband adoption.[123] This broadband digital divide, and continuing obstacles and strategies for overcoming it are discussed in Chapter 5.

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[123] "Last mile" is a commonly used term in the telecommunications industry which refers to the network segment linking homes and office buildings to neighborhood-level switching stations. It is the most capital-intensive portion of the network, and was largely overlooked by telecom startups during the massive telecommunications building boom of the 1990s. In most American cities, cable television and incumbent local telephone companies still overwhelmingly dominate this segment.

21st Century Technology, 19th Century Thinking: The Teleport

Before the sweeping transformations of the 1980s telecommunications infrastructure was typically planned, designed, and financed by publicly regulated monopolies making incremental improvements to highly centralized, bureaucratized, and capital-intensive physical plant. However, the surge in demand for telecommunications services in the 1980s and the development of many new and complex technologies presented challenges to this model.

The teleport concept emerged in the early 1980's as one strategy for developing new telecommunications capacity within a city or metropolitan region. The teleport concept was to aggregating telecommunications traffic for an entire city or metropolitan area, and route that flow through centralized transmission facilities. The teleports would then connect to satellite systems and serve as a global gateway for regional and metropolitan telecommunications networks.

The economic model for teleports drew upon traditional financing schemes for large centralized infrastructure networks such as air transportation or railroads. As one teleport developer explained:

> A teleport is analogous to an airport in many respects. Airports function as air travel centers where costly resources, such as runways and control towers, are shared among all of the air carriers within a given geographic region. Airports are surrounded by a protected airspace, which is kept free of obstructions that could disrupt operations. Travelers have access to multiple carriers at one central location. Aside from efficiently serving the needs of both providers and users of services, land use is maximized for the purpose of air travel.[124]

Teleports were typically financed in a similar fashion as undersea communications cables, utilizing joint ventures to distribute risk.

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[124] Hanneman, G J. (1985.) "Teleports: An Overview," in A. Lipman, A. Sugarman, and R. Cushman (eds) Teleports and the Intelligent City, New York.

The teleport was envisioned as a regional gateway to a network of global satellite telecommunications, in the same way that an international airport both enables and symbolizes a region's connections with the global system of air transportation. The World Teleport Association still promotes the view of the teleport as a central metropolitan gateway today:

> Teleports are the "intermodal hubs" of the broadband world – gateways that connect satellite circuits with terrestrial fiber optic and microwave circuits. Bridging the gap between land and sky.... they have pioneered in the export and import of the weightless cargo of information.[125]

Teleports attracted the attention of regional planning organizations, economic development agencies, and local governments around the world. They were seen as both a necessary amenity for international business, and a symbol of local technological sophistication. By 2000, approximately one thousand teleports were in operation around the world, with more than one hundred new teleports becoming operational each year.[126]

One of the first teleports, which became a model for similar projects around the world was New York City's Teleport, located on 350 acres in Staten Island. A joint venture of the Port Authority of New York and New Jersey, Merrill Lynch, and Western Union, the Teleport featured both satellite uplinks as well as co-located office space, primarily for use as back office and data processing centers. Construction began in 1983, with 17 satellite earth stations, 200,000 square feet of office space, and regional fiber optic connections to Manhattan, Brooklyn, Queens, and New Jersey.[127]

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[125] World Teleport Association. (2000) "What Is A Teleport?" Online document, viewed June 8, 2000. http://www.worldteleport.org/Whatis/whatisatele.html

[126] World Teleport Association. Ibid

[127] Moss, M L. (1988) "Teleports, Cities, and Regions," in K. A. Duncan and J. R. Avers (eds) Teleports and Regional Economic Development, New York: Elsevier Science

Dispersing the Hub:
Regulatory Reform and the Proliferation of Telecommunications Infrastructure

As cable networks drove a dramatic increase in television production during the 1980's, teleports became very successful enterprises. Always the mainstay of teleport use, broadcast video still accounts for 80-90% of commercial teleport revenues throughout the world.[128]

Despite the success of teleports in the broadcast market, they were ill positioned for the next cycle of innovation in the telecommunications sector. The commercialization of fiber optic technology in the late 1980s set the stage for an upheaval in the long haul telecommunications market, which had previously been dominated by satellites. Furthermore, growth in other areas of telecommunications (long-distance telephony, personal mobile communications, and the Internet) outstripped even the rapidly growing use of satellite for video uplinks. Thus, while teleports continued to play a crucial role in supporting broadcast video, and this important function has sustained their existence, they no longer dominate the vision or reality of metropolitan telecommunications infrastructure as they did in the mid 1980s.

Instead, teleports were relegated to a niche market (and a relatively slow growing one) in an increasingly varied telecommunications sector. As the World Teleport Association reported, Intelsat's satellite traffic has grown at an average annual rate of just 3-10% for decades. Compare this to growth rate of Internet data traffic, which doubled annually for several years during the 1990s.[129]

The centralized, teleport-based regional communications infrastructure that planners envisioned in the mid 1980s could not last. Technological change combined with rapid deregulation of the telecommunications industry to diffuse world-class telecommunications infrastructure throughout metropolitan areas.

Urban telecommunications infrastructure became characterized by a much more widely diffused set of access points to global networks. An equally varied array of new infrastructure systems were developed and deployed to support these activities. Unlike

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[128] World Telecom Association, Ibid.

[129] Coffman K G and A M Odlyzko. 2002. "Internet growth: Is there a Moore's Law for data traffic?" in Handbook of Massive Data Sets. (Kluwer)

the teleport model, which linked a single dominant metropolitan gateway to regional distribution systems affordable only to large businesses and institutions, this new infrastructure provided cheap and reliable high-speed data communications to a broad variety of customers. Furthermore, while competition fostered much duplication of infrastructure, this resulted in decentralization and redundancy, creating a more flexible, resilient communications infrastructure.

A useful way to categorize the components of this new information economy infrastructure is through analogies to the earlier infrastructure of the industrial economy. In this framework, the digital telecommunications infrastructure consisted of four main components. *Information highways* included the fiber optic lines and wireless networks that provided local, national, and global linkages between rapidly growing numbers of urban telecommunications sites. These *information factories* ranged in size from an individual using a wireless laptop to the New York Stock Exchange. The largest information producers often housed their data distribution in dedicated spaces, termed here *information warehouses*, also known as data centers or server farms. Finally, the entire grid was stitched together at centrally located *information ports*, where competing carriers met on an equal basis to gain the economic benefits of interconnecting their networks and users.

Information Highways

The first component of the new metropolitan telecommunications, and the one that received the most public attention during the late 1990s were the wires and cables that carried digital data from city to city, and from neighborhood to neighborhood.

These information highways increasingly resembled the nation's road network and often followed the same paths to connect distant cities to one another. Within urban neighborhoods and metropolitan areas, fiber optic networks were built along existing corridors of transportation and economic activity. Furthermore, new broadband services such as Digital Subscriber Lines and digital cable were piggybacked upon existing copper cable networks.

In the 1990s new information highways were deployed at three distinct scales –

long haul (inter-city), metropolitan, and neighborhood.

Long-haul networks

Historically, long-haul routes were the first deployment of new telecommunications technologies. This is largely because innovations in telecommunications have been driven by the needs of banks (and the military) to move large amounts of information quickly across great distances. Dating to the telegraph, as new telecommunications technologies have been developed, their first long-distance deployment was to connect major financial centers.

Fiber optic networks developed similarly. The first networks based on this new technology used undersea cables to link London, New York, and Tokyo into a 24-hour global financial system. Rather than destroying distance, the paths of this new data infrastructure closely followed age-old routes between major centers of financial power.

The 1990s saw an unprecedented increase in the capacity of long-haul telecommunications networks, thanks to the widespread deployment of fiber optic technology. Worldwide capacity on international undersea cables increased some 225 times between 1990 and 2000.[130] Global financial centers like New York were the primary landing points for these undersea cables, where telecommunications carriers concentrated their investments to serve large corporate customers. These locations were also used to patch undersea cable systems into domestic communications grids.

Long-haul networks were also deployed extensively overland in North America, Europe, and Asia. Long distance fiber networks in the United States built by AT&T, MCI-Worldcom, Sprint, Qwest, Williams Communications and others grew from 2.1 to over 3.5 million fiber strand miles between 1990 and 1998.[131,132] An estimated $17 billion was spent on long-haul network capacity in FY 2000, at the height of the telecom bubble.

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[130] Telegeography, Inc. 2000. International Bandwidth 2000. (Washington, DC)

[131] Federal Communications Commission. 2000. Fiber Deployment Update, End of Year 1998. Federal Communications Commission, Common Carrier Bureau, Washington DC

[132] A fiber-strand file indicates a single optical fiber running for one mile. Other commonly used measures of fiber deployment are the sheath mile and route mile, which offer no indication of potential transmission capacity.

Estimating capacity growth on domestic long-haul fiber networks during this period is difficult since there was no regulatory requirement to report this information, and rapid advances in signaling equipment have greatly increased the capacity of existing fiber networks. Based on extensive surveys, however the Federal Communications Commission estimated that domestic fiber capacity grew at roughly 15 percent per year during the 1996-1998 period.[133]

Development of domestic long-haul fiber optic networks was not limited to the United States alone. Europe was criss-crossed by at least 25 competing fiber optic networks in the late 1990s.[134] Even developing and newly industrialized nations like China invested heavily in long-haul network development. China Netcom's 6,000 mile, 40 Gbps national backbone served 15 cities, and cost an estimated $600 million. The Chinese government claimed to be investing about $2.5 billion annually on broadband infrastructure in 2000.[135] Figure 4.1 shows how this investment resulted in the deployment of a nationwide long-haul fiber backbone infrastructure.

In the 1990s, rapid expansion of capacity in long-haul fiber optic networks raised the hope that bandwidth would drop in cost so sharply that distance would cease to be a price consideration. Previously, intense competition and increased capacity in the United States' long-distance telephone market had led to the introduction of flat-rate long-distance calling, long a hallmark of local service in the United States.

Yet contrary to the claims of many 1990s telecom evangelists about the "death of distance", bandwidth rates remained sensitive to distance. Table 4.1 shows the mid-2000 per unit price for one megabit per second data transmission capacity for one year from New York City to destinations throughout the world.[136] Domestic rates were the lowest due to extensive competition along domestic routes and a lack of international tariffs. To the United Kingdom and Ireland, where telecom markets had been widely deregulated, prices were slightly higher. To the European continent and Asia, prices rise dramatically as regulatory barriers and large geographic distances came into play.

Rather than destroying the significance of distance, information highways

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[133] FCC, Fiber Deployment Update 1997, 1998.

[134] Telegeography, ibid.

[135] [http://www.telecom.globalsources.com/MAGAZINE/BB/0108/BROAD.HTM]

[136] One Mbps is approximately the amount of bandwidth used by 16 voice circuits.

increased the importance of central places by reinforcing their role as hubs in the global economy. Indeed, new information highways closely followed earlier telecommunications and transportation networks. Undersea cables connected port cities that first thrived when the seas were the primary means of communications. In a way, the TAT transatlantic cables that link the eastern seaboard of the United States with the British Isles were the great-grandchildren of the clipper ships. Continental long-haul networks followed another earlier urban infrastructure, the Interstate Highway System, which itself followed the inter-urban routes first pioneered by railroads in the 19th century.

In linking places already connected by a dense mesh of networked urban infrastructure, information highways reinforced existing geographical patterns of economic activity. Qwest's national optical network was primarily laid along train tracks, and rail-mounted vehicles were used to install the cable. In the densely settled Northeast, the bulk of long-haul fiber was laid down along Interstate highways and toll roads. Metropolitan Fiber Systems, an early builder of metropolitan networks, had its roots in Able Telecom, a contractor for data networking on the Northeast Corridor's EZPass automated highway toll collection system in the 1980s.

Metropolitan Networks

Long haul networks served the needs of financial services firms, governments, and other globalizing firms to communicate quickly and cheaply over great distances between cities. Yet, as historically happened with other innovations, the demand for digital networks to communicate locally soon outstripped that for long-haul networks.

As a result, extensive metropolitan fiber optic networks were built during the 1990s by local telephone companies to interconnect neighborhood-level switching centers for rapidly growing flows of digital data. Between 1985 and 1998, local telephone companies deployed over 15,000,000 miles of fiber strands, far greater than that laid for long-haul networks. More than half of this capacity was deployed in just five years between 1993 and 1998, to accommodate explosive growth in demand for additional phone, Internet, and fax lines.[137] By 2003, industry analysts projected that most of this metropolitan fiber was operating close to maximum capacity.[138]

Alternatives to the Bell's regional networks were non-existent before the emergence of competitive Metropolitan Area Networks (MANs) in the late 1980's. This sector developed as businesses seeking data transport among branch offices discovered that Local Area Networks were too small and long-haul networks were too large for "a modest community of users within a 50-kilometer diameter".[139] In the 1990s, significant venture investment flowed to firms like Metromedia Fiber Networks, greatly increasing the amount of fiber capacity linking the far-flung corners of major metropolitan areas. These firms easily leapfrogged the Bell networks, employing the newest technology. Not surprisingly, Verizon eventually became one of Metromedia's largest customers, and later a major shareholder.

Long-haul networks, like the Interstates before them, were inexpensive and easy to build, since right of way in the wide-open spaces between cities is inexpensive. For metropolitan area networks, this was never the case. The very logic of these networks dictated the need to deploy them near major clusters of office buildings, where land prices were high. Further complicating their deployment were the scores of local jurisdictions that a typical metropolitan network bisected as it works its way around the region.

These difficulties suggested that completing the buildout of metropolitan digital infrastructure would take decades to complete. One CEO's analysis was particularly illuminating:

> Unlike the long-haul networks that are [going to be] built in just a few years, the infrastructure that controls 80 percent of the data market worldwide is within the [metropolitan] loop. Many of these metropolitan areas of major cities will take 15-20 years to build out by the time it is completed.[140]

A typical metropolitan area network, such as Metromedia Fiber Networks' New York

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[137] FCC, Fiber Deployment Update 1998

[138] *BusinessWeekOnline*. 2003. "UBS Warburg Upgrades Corning to Buy" March 14. [http://www.businessweek.com/]

[139] Morreale P and Campbell G. (1990) "Metropolitan Area Networks", *IEEE Spectrum*, Vol. 27, No. 5.

[140] Global Telecoms Business. 1999. "MFN building on first-to-market advantage"

area network, extended throughout a region in rings of up to 100 miles in diameter. These networks serviced the Central Business District and "edge city" office clusters in suburban areas. The MAN was often a critical component of the carrier's long-haul global network.

Neighborhood Networks

The third component of the information highway were the neighborhood level networks that serviced commercial and residential neighborhoods in major cities and suburbs.

Commercial districts in major cities throughout the developed world were wired by a varying menu of fiber optic networks, depending on the type of commercial activity and the country. In Western countries such as the United States where telecommunications was rapidly deregulated, most central business districts in large cities saw the construction of at least 20 overlapping, competing public and private fiber optic networks. In the global cities of New York, Chicago, and Los Angeles and the network cities of San Francisco and Washington there are over thirty competing fiber optic networks. Even medium-sized cities such as Portland and Cincinnati gained two-dozen or more fiber optic networks tracing their downtowns. Even Philadelphia, long one of the east coast's laggard economies, saw the deployment of at least a dozen competing fiber grids.

The specific routing of these networks was highly protected, proprietary information. One study in San Francisco in 1996 attempted to map fiber optic networks by analyzing street cut permits. That effort was thwarted when a group of telecom companies working in the study area sued for an injunction to prevent public access to the permit information.[141]

Towards the end of the 1990s local economic development organizations began to take an interest in their community's endowment of telecommunications infrastructure and have attempted a number of fiber mapping projects. The Center City District in Philadelphia took a creative approach to mapping that city's telecommunications

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[141] Personal interview with Cheryl Parker, South of Market Association, July, 1997.

infrastructure. According to Executive Director Paul Levy, when telecommunications companies refused to share information on routes, he relied on building permits and city council ordinances authorizing related construction and street cuts to reconstruct the routes. The result was one of the few insights available into the aggregate impact of these competing infrastructures on urban cores. (Figure 4.2)

City fiber networks had short, highly selective routes that are designed to access the most lucrative corporate customers in a given city. MCI-Worldcom carried some 20 percent of the United Kingdom's international telecommunications traffic using a fiber optic ring through central London just 125 km in length.[142] The situation in New York City was similar, with a large concentration of fiber optic infrastructure in the central business districts of Midtown and Lower Manhattan, and little deployment elsewhere. (Figure 4.3) Hudson County, New Jersey's fiber optic infrastructure was concentrated near its large office buildings on the waterfront and along its many transportation corridors connecting Manhattan to points south and west. (Figure 4.4)

Residential Broadband Networks

Homes were also rapidly connected into America's digital infrastructure through new high-capacity technologies such as Digital Subscriber Lines (DSL) and bi-directional cable data networks. Inside the home, multi-computer households increasingly were integrated through Local Area Networks. Although it was not clear whether local networking within the home would best be achieved through wired or wireless technology, the home's main broadband data connection to the larger world – just like the office – would inevitably be a high-bandwidth wire.

The so-called "last mile" of the Information Superhighway – from neighborhood switching centers to consumers' homes had been the greatest obstacle to broad-based broadband deployment during the 1990s. However, surveys by the Federal Communications Commission indicated, broadband service was beginning to reach a significant number of homes by the end of the decade. According to one study, by the end

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[142] Graham S. (1999) "Global grids of glass: On global cities, telecommunications and planetary urban networks" Urban Studies, 36 (5-6):929-949

of 1999 nearly one million American homes subscribed to cable or DSL service, a three-fold increase from the end of 1998.[143] While delays in deployment remained in many areas of the country, subscriber growth rates were expected to remain very high over the 2000-2010 period.

Internationally there were wide variations in residential broadband deployment. As Table 4.2 indicates, by 2003 Asia was home to the world's largest broadband population, mainly due to the phenomenal growth of broadband households in South Korea, Japan, Taiwan, Hong Kong, and Singapore (Table 4.3).

As with every other digital network infrastructure, within nations there were great differences in the diffusion of residential broadband technologies. Within the United States, large global cities (New York and Los Angeles) and smaller network cities (San Francisco and Boston) had high and rapidly growing numbers of broadband households. (Table 4.4)

The slow deployment of residential broadband in United States relative to other nations became an important policy issue in 2002 as it was widely recognized that the United States was losing the edge in Internet infrastructure and diffusion when compared to Korea, Singapore, Canada and other nations. A 2002 report by National Research Council summarized the issue neatly:

> Following roughly a decade of deployment and experimentation and a recent period of rapid growth, first-generation broadband services, using primarily cable modems and digital subscriber line (DSL), are available in many markets. This progress is offset by recent business failures and uncertainty about the pace of future investment – factors that in part reflect slow growth in subscriptions for broadband services.[144]

This report went on to recommend that a comprehensive policy approach to broadband diffusion focused on light regulation and facilities-based competition. While a noble goal, at the time of this report nearly every market, judicial and regulatory trend appeared to be

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[143] FCC. 1999, 2000, 2002. Section 706 Reports. [http://www.fcc.gov/broadband/706.html[

[144] *Broadband: Bringing Home the Bits.* Computer Science and Telecommunications Board, National Research Council (National Academy Press, Washington, DC). 2002. p1

headed in the opposite direction. Cable and DSL providers were making significant headway on rolling back provisions of the Telecommunications Act of 1996 requiring them to provide at-cost access to their physical plant.

Regardless of the strategy pursued for residential broadband, progress in this area was hampered by a lack of accurate data on broadband deployment. Under Section 706 of the 1996 Telecom Act, the FCC was required to issue reports roughly every 18-months on the state of broadband deployment. However, the agency's method of considering a ZIP code area to have broadband available was based on the presence of a single broadband subscriber. No distinction was made between business and residential broadband access, nor between costly leased lines and more affordable DSL services. Not surprisingly, the FCC declared that "advanced telecommunications [was] being deployed to all Americans in a reasonable and timely manner" in each of its three Section 706 reports released between 1996 and 1998![145] However, the prohibitive cost of building fiber networks directly to homes ($2000-$5000 per home) suggested that residential broadband deployment will continue to rely upon the aging copper infrastructure of telephone and cable TV networks.[146]

Information Factories

The Interstate Highway System was developed to meet the need to move raw materials and finished goods to and from industrial factories. The need for information highways was driven by the production and consumption of information in the information age factories – the wired office buildings and homes where the bulk of data sent over telecommunications networks began and ended its journey.

Wired Office Buildings

Economic shifts into information industries had driven changes in building infrastructure to support communications services. Changing needs of firms for digital

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[145] FCC Section 706 Reports, Ibid.

[146] Tseng E. "Social and economic consequences of the new Internet infrastructure". *Projections, MIT Student Journal of Planning.* 2:12-23

connectivity led to the retrofitting of office buildings and commercial properties with digital network infrastructure. Most common was been the installation of Local Area Network (LAN) technology such as Ethernet, which supported broadband data speeds over short distances indoors.

The scope of this infrastructure building effort was far smaller in dollar amounts than the building of long haul and metropolitan networks. In 2000, the market for communications equipment and service in multi-tenant office buildings was just $371 million.[147] However, unlike the larger-scale networks, LAN infrastructure was deployed not by a few dozen competitors but by tens of thousands of property owners, tenant firms, and individuals.

In New York City in the late 1990s, many commercial property owners retrofitted their office buildings with both copper and fiber LAN infrastructure in order to attract the rapidly growing Internet services firms that were located along Manhattan's Silicon Alley. Subcontractors such as Intellispace typically performed this work. Intellispace wired hundreds of buildings in Manhattan and the surrounding metropolitan area. Figure 4.5 shows the location buildings in Manhattan that were wired for broadband Internet access by Intellispace. Using a high-speed fiber optic infrastructure, the firm offered clients broadband Internet for slightly under $1,000 per megabit per second (Mbps). Clients purchased Internet connections at speeds of up to 1,000 Mbps (1 gigabit per second). Intellispace and competitors such as Allied Riser Communications, Urban Media, and Eureka Broadband became known in the telecommunications industry as building local exchange carriers. (BLECs)

Not surprisingly, the concentration of metropolitan and neighborhood fiber optic infrastructure within the central business districts of major metropolitan areas both limited and responded to existing demand for fiber connections. As Figure 4.6 clearly shows, in New York City fiber-lit office buildings were overwhelmingly concentrated in the high-rent business districts in Midtown and Lower Manhattan.

The impacts of this geographic distribution are clear. Connectivity to local fiber infrastructure became a pre-requisite for premium office space. In major metropolitan areas, office buildings could no longer attract the best tenants without offering

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[147] Unpublished manuscript, Taub Urban Research Center, New York University.

sophisticated telecommunications facilities. For example, Jennifer Zeller, Research Manager for the Metro Atlanta Chamber of Commerce, noted "Up to half of all office prospects we talk to express a need to have fiber service. It's almost a given these days that office operations have access to fiber service."[148]

Wired Homes

Wiring the inside of homes proved a more difficult task than office buildings. First, the demand for internal network infrastructure was more limited. Throughout the 1990s most home network use of digital communications was limited to a single PC connected to the Internet through a dialup modem. Most families only owned one computing device, obviating the need for a LAN.

In the United States during the early first decade of the 21st century, residential broadband Internet connections became far more widespread. Additional computers and network devices were introduced into homes, driving a need to interconnect them, and to share the broadband Internet connection. One research group estimated that 29 percent of all US households had two or more PCs by 2002, and expected that to grow to 39 percent in 2006. The 7 million home LANs used to connect these PCs together was projected to grow to 21 million in 2006. By this estimate nearly half of all multi-PC households would have a LAN.[149]

As a result of the booming demand for LAN solutions, equipment manufacturers quickly brought to market a variety of alternative technologies. However, as homes usually lacked the modular drop ceilings and pre-installed conduits for network infrastructure found in office buildings, wiring them was a costly and disruptive process.

As a result, several technologies emerged which piggybacked LAN transmissions on existing wiring systems within homes. The HomePNA standard used existing phone wiring inside a home to provide LAN speeds comparable to Ethernet.[150] Another alternative, HomePlug, called for up to 14 Mbps throughput using existing electrical wiring in homes. However, the structure of residential power distribution systems in the

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[148] Personal interview, May 2000.

[149] Parks T. 2002. *Trends and Outlooks for Wireless Home Networks: A White Paper.* (Parks Associates, Dallas Texas)

[150] [http://www.homepna.org]

United States raised security issues, as signals generated by networking applications in one house could bleed over into neighboring homes.[151] The most successful alternative to traditional Ethernet LANs, however, used no wires at all. The 802.11b or 'Wi-Fi' standard, used unlicensed spectrum in the 2.4 GHz band to provide short-range wireless LAN access at speeds up to 11 Mbps. Because of the added value of untethered communications offered by wireless technology, by 2002 home wireless network equipment was selling at an annual rate of 6.8 million units.[152]

Information Warehouses

Information that circulated in the 21st century city's economic and social life was created and consumed in information factories, but just as in the industrial economy intermediate points of storage and distribution were required. Also known as "Internet data centers" or just "data centers", information warehouses were secure, climate-controlled environments that housed computer equipment such as web servers and remote data archives.

Like industrial warehouses, information warehouses tended to concentrate where major distribution routes converge. In the case of industrial warehouses, this was usually at railheads or highway interchanges. For information warehouses, it was where information highways converge to inter-connect at information ports. (Discussed in the next section)

Data warehouses connected to high-capacity Internet backbone networks through two service models. In the first model, the warehouse operator used a hands-off approach, inviting one or more carriers to build information highways that serve the information warehouse and market their services to tenants. In the second model, the information warehouse served as the ISP by reselling national or global backbone services to the tenant. In this model, the information warehouse operated much like a shipping company by providing door-to-door storage and distribution services to its clients. Under this

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[151] *CommsDesig.n.* [http://www.commsdesign.com/main/2000/12/0012feat5.htm] HomePlug Standard Brings Networking to the Home. By Steve Gardner, Brian Markwalter, and Larry Yonge. Accesssed 14 Oct 2002.

[152] Instat/MDR. 2003. "Ethernet Today, Wireless Tomorrow"

model, the firm was actively involved in the transcontinental transport of data among its clients' servers, which would be located inside one or more of their information warehouses.

Information warehouses typically served an entire metropolitan area, and their location was only loosely tied to urban centers. A location within important metropolitan markets was key to information warehouses, both to be close to producers and consumers of digital data. On the consumer side, information warehouses needed to be able to connect directly to metropolitan and neighborhood networks. On the producer side, tenant companies needed to have physical access to maintain their equipment. As one information warehouse company executive put it:

> You need to be in the proximity of those who own and use the servers, preferably within about 20 minutes to a half-hour, so that if there's a problem, the user will be able to reach the [information warehouse] very quickly.[153]

Thus, being centrally located inside the metropolitan area was not critical. Rather, land costs were the primary driver for locating information warehouses, with secondary considerations of access to telecommunications networks and electrical power.

In the late 1990s, the Internet's three main global hubs (San Francisco, New York, and Washington) led in information warehouse development. Los Angeles and Boston formed a second tier, followed by Chicago, Dallas, Atlanta and others. Figure 4.7 shows the distribution of information warehouses by metropolitan area in the United States and worldwide. (Table 4.5 shows the top twenty foreign and domestic metropolitan markets, which accounted for over 90 percent of all data centers in the world during the summer of 2000.)

Notably, few information warehouses existed outside the largest metropolitan areas in the United States. The collapse of the telecommunications industry in 2000-2002 seriously affected the development of information warehouses. As a result, the diffusion of information warehouses beyond these global city markets was unlikely to occur,

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[153] Martin W E. 2001. "Down on the Server Farm" *Government Technology*. September 6.

suggesting that the pattern evident in Figure 4.6 was likely to persist for a decade or more.

Information Ports

The most important components of the new metropolitan communications grid were the carrier-neutral collocation facilities, or information ports. Direct descendants of the Network Access Points (NAPs) setup to facilitate the privatization of NSFNet, these buildings were third-party locations that provided a centralized meeting point for telecommunications carriers and their clients. Commonly known as “telecom hotels”, “carrier hotels”, or “telehouses”, they were the hubs of metropolitan, national, and global information infrastructures.

The information port was a very new concept in the nation’s telecommunications infrastructure. In the past, upstart telecommunications carriers typically leased space in a facility owned and operated by AT&T or a local Bell Telephone company. Following the explosion of competition in the telecommunications sector after deregulation in 1996, this arrangement fell apart for two reasons. First, the incumbents’ facilities were notoriously small, substandard, and unsecured, and could not meet the huge demand for collocation space. Secondly, there was a serious conflict of interest for startup carriers in co-locating in their main competitor’s facilities. Incumbents could frustrate the new startups by limiting access to equipment to odd hours or refusing access to additional electrical power.

To meet the demand for secure, modern venues for housing telecommunications equipment, a number of real estate developers began converting old factory space in many central cities for use as information ports. These facilities offered state-of-the-art infrastructure systems for mission-critical telecommunications and computing equipment. Telecommunications tenants required very high standards of security (24 hrs/7 days), electric supply (grid plus diesel backup with on-site fuel storage), air-conditioning, and fire-suppression. Premium facilities even included Kevlar-lined walls, a response to the 1996 IRA bombing of London Docklands that caused millions of dollars in damage to computer systems and lost data. Additionally, in earthquake-prone regions along the Pacific Rim, seismic reinforcement was a critical requirement. To avoid disconnection from the communications grid due to accident or sabotage, multiple routes into the building for fiber optic lines also were typically provided. Figure 4.8 shows the many building components that supported the unique demands of Internet servers. Co-location also offered the advantage of allowing carriers and tenants to outsource facilities management, relieving rapidly growing telecommunications firms of the burden and liquidity problems of real property ownership.

Demand for information ports was primarily driven by the need for private carriers to inter-connect their IP networks. As argued earlier, the value of large inter-connected networks like the Internet comes from the huge number of potential contacts that can be reached. But carriers needed to physically interconnect their networks in at least one point in order to realize these gains, and to do it efficiently they needed to connect in many places. (i.e. East Coast, West Coast, etc.) The neutral status of information ports made them an ideal place for major carriers to interconnect their networks. In this role, information ports served a similar role in the information city that ports and railroad terminals served in the industrial city.

As of summer 2000, over 20 million square feet of information port space had been built throughout the world.[154] Most of this was speculative, and by the time the tenant companies had begun folding in the wake of the telecom bust, many information ports stood nearly empty.

Throughout the 1980s and 1990s, information ports were almost exclusively concentrated in the world's financial capitals – New York, London, and Tokyo. There, they supported the early growth of competitive telecommunications carriers targeting the concentrated markets of their great financial districts. However, the rapid growth of the Internet and the evolution of content distribution networks greatly increased demand for information ports in many other metropolitan areas.

The vast majority of information ports are located close to downtown central business districts. For example in New York City, the three main information ports – 111 8th Avenue, 60 Hudson St, and 25 Broadway – were all located along a 1.5 mile stretch of downtown Manhattan's West Side.

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[154] Cobb J. 2000. "Checking into Telecom Hotels" CNBC, August 30,

This was in contrast to the network interconnection points set up by the National Science Foundation when the Internet was privatized in the early 1990s. Of the four original interconnection sites designated by the NSF in the early 1990s, only one (the Ameritech NAP in Chicago) was located in a central city. Most were at the far fringes of their respective metropolitan areas.[155]

Not surprisingly, local real estate markets, rather than trends in the technology industry determine rates for leasing space inside an information port. High demand combined with already low vacancy rates for commercial real estate drove rates higher in the United States, even while they are falling in Europe. In the late 1990s, as the real estate industry struggled to catch up with demand for information ports, leasing rates rose rapidly. In Europe where suppliers generally outpaced the demand for Internet content and co-location space, there was less of a squeeze.[156] As Table 4.6 shows, by 2001, New York had less information port space than Frankfurt, London, or Paris.[157]

The New Metropolitan Grid

This chapter has outlined the evolution of a new telecommunications infrastructure that supports digital communications throughout metropolitan areas. This new metropolitan communications grid became an essential component part of urban infrastructure in cities throughout the world that depend upon it for the production, transport, and storage of digital information. Unlike earlier communications networks, which were built and operated by large state-regulated monopolies, the digital metropolitan grid was built and operated by thousands of competing private firms. Rather than rely upon centralized command and an overarching rational network design, this grid was coordinated by economics and technologies that encouraged widespread

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[155] Of the four Network Access Points (NAPs) designated by the National Science Foundation in 1992, only one, the Ameritech NAP in Chicago, was located inside the boundaries of a central city. The other three – MAE-East (Vienna, VA), Sprint NY NAP (Pennsauken, NJ), and PacBell NAP (San Ramon, CA) – were all located well away from central cities in suburban office areas, so-called "edge cities".

[156] Band-X. 2000. "Band-X survey shows US co-lo prices up 40 percent in six months", London, Band-X Inc. June 29; Band-X. 2000. "U.S. Continues to Suffer From Co-lo Cramp", London, Band-X Inc. October 31.

[157] Telegeography, Inc. Accesssed 14 Oct 2002. [http://www.telegeography.com/resources/statistics/bandwidth/co02_colo_space.html]

interconnection. The overall meshed, redundant form that emerged is a highly complex and robust natural design.

Figure 4.9 is a simplified diagram of this new digital infrastructure. In this framework, information ports formed the core of a meshed, redundant fiber-optics infrastructure that provided connectivity both within the region as well as long-haul inter-city service. From this centrally located interconnection complex, located near the largest information factories (corporate office buildings), smaller information highways distributed information to exurban information warehouses and clusters of residential neighborhoods using broadband or dial-up Internet access.

In contrast to the teleport model discussed at the beginning of this chapter, the metropolitan grid distributed access to broadband networks more widely throughout metropolitan areas. Connections to global fiber optic networks were widely scattered throughout urban central business districts, rather than only to a selected handful of buildings.

Winners and Losers in the Spread of New Telecommunications Infrastructure

The patterns of infrastructure development described here indicate that access to advanced telecommunications services decentralized significantly within American cities during the 1990s. While in the decades before only the wealthiest institutions such as investment banks could afford the high-speed telecommunications services delivered from centralized facilities, after the telecom building boom of the 1990s a broad range of firms and individuals had access to advanced digital infrastructure.

The new digital urban infrastructure as also more robust than the previous generation, thanks to the decentralized nature of planning and investment. For example, on September 11, 2001 the local telephone system suffered catastrophic damage when a major central switch was destroyed. In contrast, despite the disconnection of a vital transatlantic information port, digital infrastructures were able to fall-back to alternate routes between continents.

However, while access to world-class telecommunications infrastructure became far more widely available than it was before deregulation in the 1990s, and most metropolitan areas now had a high basic level of connection to global fiber networks, there were wide variations among cities in infrastructure development (as evidenced by the wide variations in network deployment and information warehouses and ports).

Within metropolitan areas, it is clear that little basic infrastructure had been deployed outside central business districts and more affluent residential neighborhoods. Most secondary business districts and residential neighborhoods lacked any fiber optic infrastructure whatsoever, despite the enormous amount of investment in these systems during the 1990s.

In conclusion, it is clear that while the model for digital infrastructure construction and management was a success by technical and regulatory standards – it worked for moving data, was resilient, and encouraged much diffusion – it fell far short of expectations.

Indeed, a place-based "digital divide" had developed, rivaling those based on gender, race, and income. More importantly, this place-based divide was reinforcing existing inequities in opportunity between prosperous and declining cities, and between metropolitan and rural areas. As the next chapter will discuss, the lack of new investment expected in wired digital infrastructure in the first decade of the 21st century meant that this situation was unlikely to change quickly. As a result, the winners and losers in the spread of digital telecommunications infrastructure would have to live with the consequences for many years.

CHAPTER 5

The Fiber Boom and Bust

As seen in Chapter 2, the global spread of the Internet was the culmination of a 30-year scientific and engineering effort to develop packet-switched digital networks. Yet no technology develops in a vacuum, as the literature discussed in Chapter 1 demonstrated. The dynamic cities discussed in Chapter 2 and Chapter 3 were not randomly chosen as the seedbeds of the Internet; their information-based metropolitan economies were the network's raison d'etre. Conversely, by the end of the 1990s, digital networks were having a real impact on the physical fabric of cities, as discussed in Chapters 4.

However, the impact of existing urban patterns on the geographic scope of digital network infrastructure was muted by the hasty, largely unplanned pace of deployment during the telecom boom of the late 1990s. New and old telecom firms alike built speculative high-capacity networks with little foresight in a frantic race to keep pace with the competition. And they built, and built, and built. And the customers never came. And the growth of Internet traffic began to slow. And the fiber glut was born. The carriers were, as *The Economist* put it "drowning in glass."[158]

As the dust settled, it became clear how poorly the telecom carriers had planned the construction of the nation's digital network infrastructure. When laying its national fiber network a carrier might install the same capacity in Chicago as in Cleveland, despite the obvious disparity in economic activity and potential market in those two cities. One carrier executive even admitted his firm's route planning methodology; they built networks near "big shiny buildings".[159] And in the United States the new carriers focused almost exclusively on extensive investment in the top ten or twenty markets, ignoring the 250+ other small and medium-sized metropolitan areas. They drained each other's resources competing over Fortune 500 customers while few areas outside central business districts of large cities saw fiber optic deployment.

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[158] *The Economist.* 2001. "Drowning in glass" March 21.

[159] Personal interview. Bob LeClair. Network engineer. Metromedia Fiber Networks, Inc. July 2000.

In the end, the fiber glut and the resulting financial catastrophe so discredited the telecommunications sector that new investment in telecommunications infrastructure was effectively halted for half a decade. Diffusion of digital networks at all levels came to a screeching halt, locking in place the network structure of the 1990s described in preceding chapters. That structure, the result of all that speculative construction, was a particularly unique pattern of inclusion and exclusion for digital network infrastructure.

This chapter analyzes the telecom bust of 2001-2002 and its implications for the development of digitally networked cities. First it describes how the telecom boom turned to bust at the turn of the century. Then it investigates the underlying causes, beyond the much-publicized accounting scandals, with a particular focus on mistakes and lack of foresight in network design and route planning. Finally, it turns to the consequences of the bust on broadband deployment and the future of wired cities.

The Boom…

By the middle of the 1990s, little new construction of physical network capacity had occurred despite rapid increases in the use of public digital networks like the Internet. While telecom carriers were laying long-haul fiber throughout the early 1990s, these projects were undertaken mainly to improve capacity and quality for voice and fax calls in the increasingly competitive long distance market. At the beginning of the telecom boom, most Internet backbones were overlaid on the existing telephone grid. T1 and T3 lines were really just high-performance leased telephone lines. Little had changed since the early days of NSFNET in terms of how the Internet backbone was provisioned.

While the Internet remained fairly small and applications fairly low in bandwidth utilization (like email and early websites), this arrangement worked well. Consumers and small businesses linked to local network hubs through via dial-up modem connections carried over local telephone grids, while larger institutions relied on high-speed leased lines carved out of pre-existing regional and national telephone networks. As fiber optic trunk lines were introduced in the late 1980s, the Internet's long-haul connections were often carried along these lines. Yet for the most part, traffic on these lines was dominated by voice (and fax) traffic.

As the privatization of the Internet entered full swing in 1995, the number of users and data traffic exploded. The development of the graphics-rich World Wide Web further contributed to the demand for new telecommunications capacity. Even the most conservative estimates of growth, from researchers at AT&T Labs, estimated that the volume of data traffic in the United States doubled annually in the late 1990s, and that data exceeded voice traffic sometime in 2002.[160]

It soon became very clear that the Baby Bells and even AT&T, MCI and other long distance carriers did not have the network capacity or manpower to keep up with the demand for bandwidth and Internet connectivity. Long installation delays and deteriorating quality led to customer revolts, as evidenced by websites like nynexsucks.com that provided a forum for dot-com startup firms to voice their carrier grievances.[161]

Following telecommunications deregulation in 1996 and the rapidly-growing market, dozens of firms sprang up between 1995 and 1998 to build new digital network infrastructure on a massive scale. Level 3, Qwest, and Williams Communications rushed to build new fiber optic grids traversing the continental United States. Others such as Alcatel, 360networks, FLAG, Global Crossing and GlobeNet worked internationally to expand the capacity of the global undersea cable system with new lines across the Pacific and Atlantic Oceans.[162] As seen in Chapter 4, an estimated $90 to 100 billion was spent between 1997 and 2001 on new fiber optic capacity. Another estimate claimed a threefold increase in annual outlays for fiber optic networks from $4.1 billion per year in 1990 to $14.6 billion annually in 2000.[163]

The primary goal of these competitors was to unseat the three companies - AT&T, MCI/Worldcom, and Sprint – who owned most of the domestic fiber in the United States, and the global consortia of national carriers who owned the undersea cables. This represented a fundamental transformation of the international telecommunications

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[160] "The size and growth rate of the Internet", K. G. Coffman and A. M. Odlyzko, *First Monday* 3(10) (October 1998), [http://firstmonday.org/issues/issue3_10/coffman/index.html]

[161] NYNEX was the local incumbent carrier for New York State. It merged with Bell Atlantic in 199X and the combined company was later renamed Verizon.

[162] Telegeography, Inc. *International Bandwidth 2000.* (Washington, DC)

[163] "Multimedia Telecommunications Market Review and Forecast" Telecommunications Industry Association

market, from cautious cooperative ventures among large monopolies, to speculative, publicly financed networks wholly owned by a single firm. (Figure 5.1)

The result of this new entrepreneurial activity was an unprecedented expansion of network capacity. According to one estimate, worldwide capacity on international undersea cables increased some 225 times during the 1990s.[164] Major long distance fiber networks in the United States built by AT&T, MCI-Worldcom, Sprint, Qwest, Williams, and others grew from 2,085,000 fiber strand miles to over 3,500,000 miles between 1990 and 1998.[165,166] As Table 5.1 shows, more than a half-dozen carriers had constructed transcontinental fiber-optic networks by the end of the 1990s.[167]

One of the main uses of this new raw capacity was to deploy IP networks. The expansion of fiber networks permitted a rapid expansion of IP capacity as well (although IP capacity did not grow nearly as fast as raw capacity because it was only deployed when needed).

The surging flow of data across the Internet also generated significant network expansion ventures at the metropolitan and neighborhood level. In fact, regional Bell operating companies and competitive local exchange carriers (CLECs) deployed even more fiber that the long-distance carriers. Between 1985 and 1998, local telephone companies deployed over 15,000,000 miles of fiber strands. More than half of this amount was deployed in just five years between 1993 and 1998, to accommodate explosive growth in demand for additional phone, Internet, and fax lines.[168] Even cable television companies jumped on the bandwagon, laying 2.6 million fiber miles in 1999 to deploy digital cable video and Internet services. Competitive DSL providers such as Covad deployed private DSL networks co-located with the incumbents. Finally, metropolitan area network companies emerged as businesses seeking data transport

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[164] Telegeography, Inc. *International Bandwidth 2000.* (Washington, DC)

[165] A fiber strand-mile indicates a single optical fiber running for one mile. Other commonly used measures of fiber deployment are the sheath mile and route mile, which offer no indication of potential transmission capacity.

[166] *Fiber Deployment Update, End of Year 1998.* Federal Communications Commission, Common Carrier Bureau, Washington DC

[167] Because the FCC does not require carriers to report the activation status of these strands, nor the type of signaling equipment used, there is no data available on the growth of network capacity domestically. However, because of technological advances in transmission technology, it is likely that per strand capacity has increased by several orders or magnitude over the last several years.

[168] *Fiber Deployment Update, End of Year 1998.* Federal Communications Commission, Common Carrier Bureau, Washington DC

among branch offices found Local Area Networks too small and Wide Area Networks too large for "a modest community of users within a 50-kilometer diameter".[169] "For many international carriers, the main justification for building MANs is that they could not get the high capacity they needed any other way. Until 1999, incumbent carreirs did not offer capacity above 2 Mbps in some cities, and some still do not offer capacity above 155 Mbps. When long distance networks are running at 10 Gbps or more, that simply isn't enough."[170] Toward the end of the boom a new group of companies entered the metropolitan fiber optics market, greatly increasing the amount of fiber capacity linking regions into a cohesive unit. Firms such as MetroMedia Fiber Networks (MMFN), deployed so much capacity that they became a supplier of metropolitan data transport for local carriers like Verizon.

...And The Bust

Few fiber companies managed to achieve profitability during the 1990s telecommunications boom. And as the years passed, the situation only continued to worsen. By early 2000, it was increasingly evident to investors and customers alike that long-haul fiber capacity had become a commodity – on any given route there was little in to distinguish one company's product from another. The opening of online exchanges such as Band-X provided a global clearinghouse for buying and selling excess capacity on long haul fiber networks.

Like any product that becomes commoditized, prices for unlit long-haul fiber began to drop sharply. As projects begun in 1997 and 1998 came online in 2000 and 2001, the market collapsed, and wholesale prices for "dark" (unlit or idle) fiber fell from $5,000 a mile in 1997 to just $1,200 a mile in 2000.[171]

Ironically though, while it was over-supply in the long-haul fiber market that was the root cause of the telecommunications bust, it was the last sector to collapse. (Self)-deluded investors continued to place faith in fiber carriers well into 2001, until at last it became impossible to deny the end was near. As late as February 2001, telecom analyst

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[169] Morreale P and G Campbell. 1990. "Metropolitan Area Networks", *IEEE Spectrum*, Vol. 27, No. 5.

[170] "International Bandwidth 2001" *Telegeography* (Washington, DC)

[171] Blumenstein, Ibid.

George Gilder wrote that two telecom firms, Global Crossing and 360networks, would "battle for worldwide supremacy, but in a trillion-dollar market there will be no loser."[172]

Two other sectors of the telecommunications industry, which were somewhat more exposed to investor skepticism failed long before the fiber barons finally succumbed in the spring and summer of 2002. The IP backbone and co-location sectors both succumbed to the boom that would echo even louder in the fiber business.

One of the underlying assumptions of the speculative digital network building boom was an urban myth regarding the growth rate of data traffic across the Internet. Widely cited, this "fact" held that the volume of data traffic on the Internet was doubling roughly every 90 days, driven by a rapidly growing user base and new multimedia network applications. Unfortunately, there was little truth to this claim, which was based upon a very brief period of spectacular growth in 1997. A comprehensive study published in November 2000 found that data traffic was instead only doubling every 12 months during 1999-2000.[173]

This lag in demand for long-haul data transport exacted a high price in the IP backbone sector, whose lashing followed close on the heels of the dot-com bust. Major IP backbone companies were failing at an alarming rate. Intense competition in the IP backbone business resulted in 40-50 percent annual price drops for IP transit.[174,175] One of the biggest failures in the IP backbone sector was that of PSINet, whose roots went all the way back to NSFNET in the 1980s. As some of the largest customers of the long-haul fiber companies, the shakeout in the backbone sector was a disturbing early warning sign.

The next domino to fall was the co-location industry, which built information ports and information warehouses. It collapsed in 3Q2001 after real estate speculators overbuilt in a rapidly contracting market for space after the dot-com bust.

The last of the telecom firms to fail were the big competitive fiber carriers, who relied on larger cash reserves and complex illegal accounting tricks to stay afloat into the spring of 2002. Despite rapidly declining prices for long-haul fiber capacity in preceding years, in 2002 the bottom dropped out of the market. Prices for fiber-optic capacity

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[172] "The great telecoms crash" *The Economist*, July 20, 2002. p9

[173] Koffman and Odlyzko, [http://www.cisp.org/imp/november_2000/odlyzko/11_00odlyzko.htm]

[174] US Internet Geography. 2003 Telegeography Inc.

[175] The higher added value of managed IP backbones softened the crash of prices vis a vis the fiber industry.

dropped another 70 percent in the first half of 2002, and even extremely creative accounting could not postpone the inevitable.[176] Unable to stave off creditors any longer, a succession of long-haul carriers sought bankruptcy protection in the spring and summer of 2002. (Table 5.2)

Although the psychological impact of the dot-com bust grabbed more headlines, it was the telecom bankruptcies of 2002 that shook the global economy to its core. Telecommunications companies accounted for nearly 90 percent of the net loss in stock wealth during the decline of 2000-2002.[177] Global Crossing's bankruptcy, the fourth largest bankruptcy in US corporate history, eliminated some $80 billion in shareholder wealth. All told the new carriers had amassed some $650 billion of debt during their building boom. Chain reactions were felt in many other sectors, most notably the manufacturers of switches for high-speed networks like Nortel, Cisco, and Juniper Networks.

By the time the dust settled, some $2 trillion of stock market wealth had been erased, dwarfing the $150 billion lost in the last major U.S. financial scandal, the savings and loan crisis of the 1980s.[178] Over 500,000 high-paying jobs vanished, affecting dozens of metropolitan areas. As Table 5.3 shows, only one company survived the bust with most of its value intact, the conservative local phone company Verizon.

As 2002 ended the telecom bust was drawing to a close.[179] Analysts began talking about absorption of excess capacity and future prospects for new investment, though that day was far off. Just as speculative building booms and busts characterized the early life of past infrastructure networks like the telegraph, telephone and railroad, contraction and consolidation were seen as signs of a healthy, functioning industry.

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[176] US Internet Geography. 2003 Telegeography Inc.

[177] "Downed lines: Telecom sector's bust reverberates loudly across the economy" *Wall Street Journal,* July 25, 2001.

[178] "How the fiber barons plunged the nation into a telecom glut" *Wall Street Journal,* June 18,2001. Rebecca Blumenstein.

[179] The cellular telephone industry, however, faced an impending wave of consolidation and drastic cost-cutting as mobile telephone revenues began shrinking .

Why the Bubble Burst

The telecom bust at the end of the 1990s was one of the biggest industrial failures in American history. On a macroeconomic scale, the reasons for the bust were clear enough. "Irrational exuberance" on the part of investors large and small had led to overdevelopment of digital network infrastructure. Armed with overly enthusiastic projections of growth in data traffic, entrepreneurs were able to raise capital for nearly twenty times as much network capacity as the market needed. As a result, only about five percent of the nation's long-haul fiber optic capacity was in use at the time of the bust.[180] As late as March of 2001, even with the handwriting on the wall, planned future deployments called for increasing capacity some 70-fold in the United States alone.[181]

Overbuilding, slow demand growth, and intense price competition made it impossible to generate enough revenues to sustain firms and they quickly collapsed. Accounting voodoo allowed some firms to hang on a bit longer, but in the end they all ended up together in Chapter 11 bankruptcy proceedings.

This explanation of the telecom bust is incomplete without addressing the geographic aspects of digital network investment that contributed significantly to the bust. In fact, at least a few long-haul carriers might have survived if their business plans had focused more on developing new markets for digital network infrastructure than merely trying to outflank each other in the prime urban markets. Instead, dozens of carriers built redundant, overlapping networks in selected cities as they competed to capture Fortune 500 clients and what one network executive called "big shiny buildings". Another commonly used deployment technique called for provisioning an equal amount of capacity on all network segments regardless of the market for capacity between those two cities. Since the installation cost was mostly determined by labor and right-of-way, installing a hundred fibers cost little more than installing only the one or two that were actually needed.

During the 1998-2001 period when long-haul fiber networks were being built most rapidly in the United States, there was a tremendous amount of anxiety. Investors

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[180] Telegeography, Inc. 2002. Terrestrial Bandwidth.
[181] *The Economist* "Drowning in Glass" 3/22/2001

and telecom executives believed that whoever built the biggest, fastest, least expensive network first would be rewarded with lucrative contracts to provide door-to-door digital network infrastructure for large corporate clients. This anxiety caused the fiber companies to focus only on the largest and most lucrative markets, namely the central business districts of large metropolitan areas. To a lesser extent, large clusters of office buildings in suburban area – so called "edge cities" – were also targets for network deployment. In many circumstances, carriers behaved like lemmings and rushed heedlessly into markets, deploying capacity based on the real or suspected deployments of a rival. As the Wall Street Journal described the rivalry between Qwest and Level3, "once the big dig was set in motion, it was hard for any one player to scale back."[182]

As a result of this reactionary style of network planning, by the end of 2000 the downtowns of major American cities were serviced by at least 25 competing fiber optic networks. Even central Philadelphia, whose sluggish economy only started to show signs of life towards the end of the 1990s, was found to be well endowed with fiber in a 2000 study. (Figure 5.3) In the Los Angeles area ten new telecom companies were attempting to wrestle business customers away from incumbent SBC Communications.[183] Corporate customers benefited through new services and lower costs, but few carriers made it to profitability in such competitive arenas.

While the carriers chased fool's gold in the big metropolitan markets – cities like Atlanta, Dallas, San Francisco, Chicago, et al – second and third tier regions were ignored. Broadband carriers who did intend to expand into second- and third-tier markets, once they had succeeding in dominating the largest markets, found themselves hamstrung. Slim profits and high expenses in the big metros sapped them of cash needed to finance expansion in non-prime regions, and their ongoing struggles deterred would-be investors from making any additional commitments. Caught in a Catch-22, there was no path to profitability once a carrier had engaged in the battle for America's big business districts. As one analyst noted in late 2000 as the bubble was bursting, "The short-term prospects are not great for underserved urban areas and certainly not for second- and

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[182] Blumenstein, Ibid.

[183] "Glut check: Did corporate America go a little overboard with capital spending?" *Wall Street Journal,* Dec 4, 2000

third-tier markets. Most broadband access companies are in a price war, forcing them to charge low rates while they must spend huge amounts to extend service to new areas."[184]

In retrospect, it is clear that fiber carriers displayed lemming-like behavior. The first few firms to deploy center-city loops and inter-city backbones had favorable indications of demand and even guaranteed customers in a given city. In London, MCI/Worldcom's fiber ring (just 125 km in length) in central London carries some 20 percent of the UK's international telecommunications traffic.[185] Clearly, building networks targeted to large corporate customers made business sense in many markets.

And perhaps there might have been enough business for two, three or even four competitors in a given city. But as successive firms attempted to duplicate the early entrants' success in the same markets, a glut of capacity quickly developed (even while non-prime markets lacked any new fiber). The result, by one estimate, was that nearly $70 billion was wasted on excess capacity in the nation's telecommunications infrastructure.[186,187]

One major reason for the inability of new firms to avoid the overly competitive global city markets and identify and exploit smaller untapped markets was a lack of data on existing and planned fiber deployments. Unlike retailing, real estate development, and numerous other competitive industries where location is important, fiber optic networks were nearly impossible to see after they were installed. Thus it was very difficult to accurately track competitors' investments and market opportunities. On the contrary, if three fast food outlets opened at a given intersection in a single year, a potential investor would be wise to look elsewhere for the future site of his taco stand. It was not until late in the telecom boom that market research firms like Telegeography, Inc. and Geo-Tel, LLC began publishing accurate and comprehensive inventories of deployed fiber optic infrastructure. Even if they had wanted to refine their business plans better, fiber

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[184] Wilde C. 2000. "Broadband Have-nots Face Life Without E-Business" *CMPNet* Dec 27, [http://www.cmpnet.com]

[185] Graham S. 1999. "Global grids of glass: On global cities, telecommunications and planetary urban networks" *Urban Studies*, May, 36 (5-6):929-949

[186] "Fiber optic cost $70b more than necessary" *Boston Globe*, March 11, 2002

[187] The author served as a consultant to several carriers between 1996 and 2000 and was shocked by the lack of in-depth market research used in route planning and network deployment. By contrast, the fast food industry employs highly sophisticated techniques for site selection and market analysis.

companies would have been hard pressed to find the needed background data at any price.

In the end, it is not surprising that the telecom boom of the 1990s ended disastrously for investors and consumers alike, as the business dynamics of the digital network buildout were eerily similar to those of earlier urban network infrastructures. For example, the following 1947 historical analysis of the telegraph boom and bust could – with few changes – have been the *Wall Street Journal's* take on the 2002 collapse.

> "The initial stage in the evolution of [the telegraph industry] may well be termed the 'era of methodless enthusiasm'… private industry came to a somewhat retarded realization of the significance of the Morse invention between 1846 and 1850, and the country was hastily webbed with a crude network of wires. Promoters and stockholders had grandiose dreams of the fortunes which would soon be theirs; but ruthless competition, bad management, and poorly constructed lines took their toll. Enthusiasm gave way to disillusionment as company after company failed to make expenses, let alone pay dividends to their luckless stockholders."[188]

Whether one calls it "methodless enthusiasm" or "irrational exuberance", the end result was the same.

The Built Legacy of the Fiber Barons

As previously described, the behavior of competitive telecom companies in major urban commercial districts led to a dense concentration of digital network infrastructure in those areas. These cities and firms located there thus received most of the benefit of the boom, since they could choose from a wide variety of competing telecom providers. Another way to analyze the built legacy of the telecom boom is to consider which places it did not connect to the global digital network. In fact, there were far more places that were not connected.

Put simply, the fiber optic revolution did not reach many American cities in a significant way. Outside the United States, this pattern was even more pronounced. In

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[188] Thompson R L. 1947. Wiring A Continent (preface)

fact, the built legacy of the telecom boom of the 1990s is limited to a selected group of cities and urban areas. Furthermore, the investment climate at the end of the telecom bust suggested that there would be no new significant investment in long haul, high capacity fiber networks anytime soon. As a result, the footprint of the fiber optic infrastructure at the end of the boom would define the availability of wholesale broadband for years to come.

On a national scale, many small and medium-sized metropolitan areas were bypassed. So-called "NFL cities", those large enough a major league sports team, were usually targeted by competitive carriers, while smaller cities were not. The upstart carriers tended to focus on key markets far more than the incumbent carriers, who were largely upgrading and retrofitting their existing networks to serve a widely dispersed customer base. Consider the differences between AT&T's long-haul network and that of Level 3 (two of the largest networks and direct competitors), shown in Figures 5.2 and 5.3.

Within metropolitan areas, the contrast between fiber infrastructure in central business districts and less prime secondary business districts was stark. Given that these neighborhoods were intentionally avoided due to a perceived lack of demand, it could be argued that they were subjected to digital "redlining".[189] In New York City, the patterns of fiber optic deployment were stark. As Figure 4.6 shows, of 3,419 fiber-lit buildings in New York City in mid-2002, fully 86 percent (2,945 buildings) were located in Manhattan. The overwhelming majority of these Manhattan fiber-lit buildings were located in the commercial district south of 59th Street. The ability of office buildings to be "lit" largely depending upon the routing of fiber optic networks like Metromedia Fiber Networks' Manhattan backbone (Figure 5.4)

This pattern was certainly not limited to New York City. Published maps of fiber infrastructure other cities, such as Philadelphia (Figure 4.2), San Diego, Jersey City (Figure 4.4) and Atlanta indicated little to no diffusion of fiber infrastructure outside the central business district and inter-city transportation corridors.[190,191,192,193] In the

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[189] Redlining was the practice, common in the 1950s and 1960s, whereby mortgage lenders would refuse to make loans in minority-dominated areas, preventing the residents of those areas from achieving homeownership. The term referred to a red line drawn on a map to indicate the excluded zone.

[190] Center City District, Inc. (Philadelphia, PA)

residential broadband infrastructure market, technological and economic considerations limited broadband deployment to urban and suburban areas.[194]

The implications of the highly limited geographic diffusion of fiber optic infrastructure will have significant negative economic impacts. By far, the largest missed opportunity is the failure of telecommunications competition to deliver the benefits of broadband to small business. As one critic described it in December 2000:

> The increasing number of businesses seeking broadband connections is apparent in the growth numbers predicted for DSL… but choosing where to extend broadband services is a hard call for providers since it often means costly infrastructure upgrades, which include priming copper and installing DSL equipment, or finding space to deploy fiber in overpopulated urban areas and in difficult-terrain rural communities. In many cases, providers simply choose to deploy [digital network] architecture in areas that are easier to access and provide quicker returns… Not surprisingly, incumbents are more interested in snaring multimillion-dollar fish in their home territories… than they are in building a big, expensive network to catch minnows."[195]

Conclusions: The Future of Digital Infrastructure

With 95 percent of the world's long-haul fiber optic capacity lying unused, the senior management of the largest firms under investigation, and persistent problems in building out the last mile infrastructure needed to drive data traffic growth, by the spring of 2003 the future of fiber optic network construction looked bleak.

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[191] "Wired in San Diego: Mapping Bandwidth Bay" *Geospatial Solutions* [http://www.bandwidthbay.org/news/3abouna.pdf]

[192] Hudson County, NJ Cyberdistrict Feasibility Study. Wallace, Roberts & Todd, Inc. (Philadelphia, PA). Scott Page, Walter Siembab.

[193] "Telecommunications Infrastructure" Metro Atlanta Chamber of Commerce, Atlanta, GA. September 2000. [http://www.metroatlantachamber.com/]

[194] Gillett S E and W Lehr. 2000. Availability of Broadband Internet Access: Empirical Evidence , with William Lehr. Presented at 27th Annual Telecommunications Policy Research Conference, Sept. 25-27th, 1999; and presented at Public Utilities Commission Field Hearing, Lowell, MA, May 22nd.

[195] Wilde Candee "Broadband Have-nots Face Life Without E-Business" *CMPNet* Dec 27, 2000 [http://www.cmpnet.com]

Given the haste with which this infrastructure had been built, the huge potential profits, and the highly competitive and secretive business climate, it should come as no surprise that many mistakes were made in the construction of this digital network infrastructure. For better or worse, the poor investment climate suggests that the capacity and geographic extent of this backbone infrastructure will not expand significantly over the next five to ten years.

For urban planners, there are three main findings from a retrospective analysis of the fiber boom and bust that will have a lasting impact on local economic development.

First, large, information-driven metropolitan areas received the bulk of investment in telecommunications infrastructure. As a result they continue to benefit from an advantage through the improved services and reduced prices brought about by competition. Small- and medium-sized metropolitan areas received far less attention from the long-haul fiber carriers and as a result they now possess less capacity and diversity in their connections to other regions.

Second, and perhaps more important, within all sizes of metropolitan areas, only a few districts received of almost all new digital infrastructure deployment. In New York, for example, only 0.5 percent of buildings in the city were linked up to fiber optic networks, and 85 percent of these were located in the Central Business District. (Chapter 4)

Third, the causes of the uneven deployment of fiber optic infrastructure were clear and largely preventable. While there was little planners could do to tame an economic force as large as the telecommunications sector, little was done at the local level to track the deployment of these systems and nudge their growth in more equitable directions.

One of the primary reasons for the irrational buildout of fiber infrastructure was the lack of accurate, comprehensive information about the location of existing capacity. During the boom, researchers trying to uncover geographic trends in the deployment of fiber optic infrastructure were thwarted by the highly secretive practices of the industry. One study in San Francisco in 1996 attempted to map fiber optic networks by analyzing street cut permits. That effort was aborted when a group of telecom companies working in the study area sued for an injunction to prevent public access to the permit information. In 1999, the Center City District in Philadelphia took a more creative approach to mapping that city's telecommunications infrastructure. According to Executive Director Paul Levy, when telecommunications companies refused to share information on routes, he relied on building permits and city council ordinances authorizing related construction and street cuts to reconstruct the routes.[196]

In 2002, the federal government started to map advanced telecommunications infrastructure but not for the purposes of providing information to the public. Rather, these projects were driven by homeland security concerns about the vulnerability of such system to terrorist attack. Much of this work was done by George Mason University's Critical Infrastructure Protection Project.[197] In February 2002, Senator Charles Schumer (D-NY) proposed a cyberterrorism task force be set up within the Department of Homeland Security to:

> "Identify the physical locations of key electronic hardware like undersea wire facilities connecting New York and the entire nation with Europe (all of the fiber optic wires connecting the US to Europe and the Middle East – known as Submarine Fiber Optic Communications Systems – funnel into just two locations in lower Manhattan) and telecom hotels that store thousands of servers that comprise the electronic backbone of the local economy (roughly 80% of Internet traffic routes through fewer than a dozen facilities across the country).[198]

Clearly, awareness of the importance of long haul and metropolitan fiber optic infrastructure – and the enormous gap in knowledge about the location and capacity of these system - had penetrated the highest levels of government. The need for a national telecommunications infrastructure-mapping project was clear.

In conclusion, it is clear that the current state of digital infrastructure as embodied by fiber optic networks cannot be considered a success. These advanced networks do not serve most parts of the nation and even in the places that are served access is highly segregated between commercial and residential districts, between central and secondary business districts, and between rich and poor. Instead of a single Digital Divide between rich and poor, or white and black, the geographic Digital Divide cuts many ways.

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[196] Telephone interview, August 2000.

[197] [http://techcenter.gmu.edu/programs/cipp.html]

[198] [http://www.senate.gov/~schumer/SchumerWebsite/pressroom/press_releases/PR00844.html]

But, conversely, should the rapid buildout of wired digital network infrastructure be considered a failure? The answer is no for two reasons.

First, the fiber optic backbone is not the first network infrastructure to develop from a rapid boom-and-bust speculative frenzy. The telegraph, telephone, railroad, and even electric power infrastructure all developed along a similar path. It was only well after the initial buildout, collapse, and consolidation that these systems were rationalized as regulated monopolies. The railroad bust of 1873 and the telecom bust of 2002 played out almost identically, with similar sets of dishonest hucksters and duped investors. There is good reason to suspect that just as the excess railroad capacity built during the 1860s was eventually absorbed, so too will the 95 percent of the fiber infrastructure that currently sits idle.

The second main reason why the fiber boom can be considered as success is that it provides a platform for the next great evolution of telecommunications infrastructure – broadband wireless networks. As discussed earlier, during the fiber boom there was considerable awareness of the slow pace of development of last-mile infrastructure that would distribute broadband services to offices and homes. The fiber bust occurred before significant progress was made in this area, and the resulting "information superhighway" had great capacity on inter-city routes but few on-ramps.

However, the appearance of many exciting technologies for wireless voice and data communications coincided with the fiber bust. Based on the success of the wireless mobile phone and data networking technologies like Wi-Fi, it is increasingly clear that wireless technologies are superior for last-mile infrastructure. Wireless offers more flexibility, less cost, and seamless integration with human social and physical needs for mobility. But without a robust fiber-optic backbone, the wireless last mile cannot function properly.

Thus, the future of digital network infrastructure is moving towards a hybrid of wired and wireless media, each employed at the functions in which it excels. Wired fiber optic infrastructure provides cheap, secure long-haul transmission and inter-connection of networks. Wireless provides mobility and less cost over the last mile. The final chapter of this dissertation describes the evolution of wireless technology and its integration with wired digital networks into this new, hybrid communications infrastructure.

CHAPTER 6

The Untethered City

With the collapse of the telecommunications industry at the turn of the 21st century, it was clear that the wired e-topia of the future would be longer in coming than was anticipated. The poor management and planning of new telecommunications companies had led to investment decisions that concentrated digital infrastructure in a small number of urban zones. The lack of public knowledge or oversight of this infrastructure-building process meant that little was done to avert an inequitable diffusion of network capacity. By the end of the telecom collapse, most places still lacked affordable access to broadband digital networks.

Yet even before the telecom industry unraveled during 2000-2002, a new model for building digital network infrastructure was emerging. During the boom, most of the interest in telecommunications among investors and urban planners alike had focused on the enormous potential of fiber optic technology. However, during that same period enormous technological improvements were made in mobile wireless communications, spawning a global consumer phenomenon even larger than the Internet. In fact, cellular subscribers had always outnumbered Internet users. (Table 6.1)

This new digital network infrastructure model was deployed in both voice networks like the cellular telephone system and data networks like the Internet. Employing a hybrid topology of long-haul wired infrastructure and short-haul wireless infrastructure, this model took advantage of the strengths of each technology. Wired technologies were superior for secure, high capacity backhaul transmission, while wireless excelled at providing a flexible, mobile last-mile link for the end user.

The implications of the new infrastructure model were only just beginning to be understood as the first decade of the 21st century unfolded. Instead of being isolated within offices and homes, connectivity was spreading to streets, parks, coffee shops, and other newly digitally mediated urban public spaces. Instead of bringing the user to the network, for the first time the network was being brought to the user. Suddenly, digital networks could be integrated with the best urban spaces to reinforce their value as venues for face-to-face interaction. Far from bringing about the death of cities, as the urban dissolutionists had envisioned, digital infrastructure actually was enhancing the advantages of dense urban spaces for human interaction.

This chapter concludes the analysis begun in Chapter 1, whose purpose has been to understand the evolving geography of digital network infrastructure within the complex social, political, and economic creations that are cities. This chapter introduces the concept of the "untethered city" to describe a new form of urbanization. Untethered cities are characterized by high degrees of personal mobility and telecommunications, which permit more flexibility in the structuring of personal social and economic networks. Yet at the same time, this increased mobility and ability to communicate reinforces these networks and the urban space in which they inhabit.

The four sections of this chapter describe the emergence of the untethered city. The first section describes the evolution of wireless technologies and the important role cities have played in shaping their development. The second section describes the wired-wireless hybrid network that has emerged in the early years of the 21st century as the dominant organizing logic of digital infrastructure. The next section present conceptual tools for understand the fundamental changes to urban dynamics made possible by this new network. Finally, this chapter concludes with an investigation of the author's experience developing digitally mediated urban spaces in the parks of New York, where free local wireless networks represent the next wave of untethered infrastructure.

The Emergence of the Untethered City

About the same time that the promise of fiber optic technology began to rapidly wane, mobile wireless technology came of age in the marketplace. By 1999 there were nearly 500 million mobile telephones in use throughout the world, accounting for over one-third of the world's entire installed base of telephones. Leading nations for mobile telephone adoption were mainly concentrated in Europe and Asia. (Table 6.2) There would be no turning back. Cities throughout the world had gone wireless.

As was seen in previous chapters, digital networks are highly complex technologies that evolved over many decades. Mobile wireless technologies were no different, with the earliest wireless technologies dating back to the late 19th century.

Ironically, however, while mobile communications technologies were designed to free us from the constraints of wired infrastructure, they have been deeply shaped by the spatial structure of our cities. While existing patterns of settlement exerted influence over the development of wired networks, they have even more forcefully shaped the evolution of wireless technologies.

Cellular telephony illustrates the symbiosis between wireless technology and urban form particularly well. Vehicle-based mobile telephones had been in use, mainly by law enforcement, in the United States since 1946 when AT&T deployed systems in 25 cities.[199] This system was very limited in capacity because it relied upon a single transceiver to service all subscribers in an entire metropolitan area. From the 1940s until the early 1980s, this radiotelephone system could only support a few thousand subscribers in each city.

The solution lay in a Bell Labs patent that had moldered on the shelves of Murray Hill since the late 1940s.[200] This patent called for increasing wireless network capacity by splitting cities up into grids of cells. Instead of sharing a given set of radio channels throughout the entire city, the whole set of frequencies could be reused many times in different parts of the city. (Figure 6.1) Using less power at both the transmission tower and the mobile phone meant that the signals would not bleed over into adjacent cells. To err on the safe side, channels would be alternated between cells to reduce the possibility of interference. Capabilities were added so that as a caller moved from one cell to another, the call could automatically be switched to the next tower. As one government report put it, "cellular [was] not so much a new technology as a new idea for organizing existing technology on a larger scale."[201]

This first-generation wireless network was typically referred to as "analog" cellular. The analog cellular network improved capacity by an order of magnitude over the earlier radiotelephone system. (Table 6.3) However, falling prices and a dramatic increase in business travel during the 1980s soon exhausted the capacity of the analog cellular service in major business centers as subscriber demand for mobile telephones

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[199] SRI. 1997. "The Role of NSF's Support of Engineering in Enabling Technological Innovation"
[200] SRI, Ibid.
[201] National Academy of Sciences. 1997. *The Evolution of Untethered Communications* (Washington, DC) [http://stills.nap.edu/html/evolution/]

grew rapidly. In particular, the financial sector in New York, government in Washington, and the entertainment industry in Los Angeles were three large clusters subscribers who pushed the capacity of urban analog cellular networks to their limits.

With the city already divided into cells, the next technological breakthrough to increase capacity in cellular networks by dividing up radio channels more efficiently. Digital cellular technologies were launched in the early 1990s in Scandinavia and spread throughout the world's major cities by 1996. Digital technologies utilized scarce radio spectrum 6 to 10 times more efficiently than analog systems by sharing channels using a variety of modulation techniques, rather than dedicating an entire channel to a caller for the duration of the call. When a subscriber was not talking, that channel could be used to transmit another subscriber's call.[202]

Consumer demand for mobile telephones seemed limitless, and by the early 2000's even the highly sophisticated digital cellular network was stretched to capacity in large metropolitan areas. A third generation of cellular technology used an even more refined combination of techniques to increase capacity for voice calls and add new broadband data services. First, urban cells were subdivided into even smaller "microcells" and "picocells" so that the same spectrum could be reused many more times over throughout the city. Second, even more advanced digital encoding techniques were employed to fully maximize use of that spectrum. Third, new portions of spectrum were licensed by national governments to create new channels.

Thus several times throughout its history, because of its popularity in dense urban areas, the mobile telephone had become a victim of its own success. But that success also fueled expectations of future growth, and research and development led to technological advances to accommodate the communications needs of city dwellers by expanding capacity several orders of magnitude over a quarter century. Table 6.3 summarizes these developments.

The other major contributor to the untethering of cities was wireless local area network (WLAN) technology. WLAN technology actually predates wired LANs by

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[202] SRI, Ibid.

several years, and the core technologies that underlie it also date back to World War II.[203] First demonstrated in 1971 in the University of Hawaii's ALOHANET project, WLANs operated on unlicensed bands of the radio spectrum reserved for experimental use. Two bands were typically used for WLANs, 2.4 Ghz and 5Ghz.

WLAN technology was used throughout the 1980s and 1990s in industrial settings such as warehouses, distribution centers, factory floors, and construction sites to link workers with databases and equipment. Several competing standards were in use, and there was minimal deployment in corporate office settings and a very small residential market.

In early 1999, however, a long-anticipated standard for WLANs was released by the IEEE, the electrical engineering professions equivalent of the ICMA.[204] Dubbed 802.11b and later "Wi-Fi", this new standard sparked a frenzy of deployment by corporations, consumers, and educational institutions. With just a few years nearly every major corporation in the United States had meeting and conference rooms lit up with Wi-Fi, and most large universities were building extensive Wi-Fi networks in classrooms, lounges, and libraries. Millions of homes were unwired as consumers installed inexpensive wireless routers to extend the functionality of residential broadband Internet connections throughout their abode. As Figure 6.2 shows, sales of Wi-Fi quickly grew both at work and home. Finally, tens of thousands of public wireless networks (both free and pay) were deployed in public and semi-public spaces like parks, hotels, and airport lounges where people might want to check email or surf the web.

Mobile Communications and Urban Dynamics[205]

As the preceding section has shown, the demands of urban lifestyles and urban spaces have been a major force shaping the development of wireless technologies. Conversely, this section seeks to address changes in urban dynamics that are

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[203] The fundamental technologies of frequency hopping radios, which forms the basis of wireless technologies such as Wi-Fi and ultrawideband, were first patented by the actress/inventor Hedy Lamarr in 1940.

[204] International City and County Management Association

[205] This section is a highly condensed version of Townsend A M. 2001. "Mobile Communciations in the 21st Centruy City" in The Wireless World, Barry Brown, ed. (?????)

accompanying the rise of mass mobile communications.

In the late 1990s, observers noted changes in the mobility patterns of teens in countries around the world that exhibited high levels of mobile phone ownership. Rather than meeting at landmarks in public locations like plazas or street corners, youths tended to loosely coordinate movements and meetings through constant communications via mobile phone.[206] Repeatedly and independently in various cities this pattern of coordinated mobility was referred to as "flocking".[207]

The flock-like behavior of teens using mobile phones was neither unique nor representative of a limited phenomenon. This behavior merely was the most visible manifestation of a widespread new type of emergent behavior in the untethered city, the micro-coordination of daily activities.[208] Put simply, the mobile phone permitted a much freer flow of information through social and professional networks about the status of those networks and their members. Operating at a highly decentralized level, these untethered networks carried the viral-like flow of information first observed in email usage on the Internet into streets, cafes, offices, and homes. In these intimate, everyday locales, untethered digital networks became far more essential and intricately interwoven into human society than any wired network ever was.

As a result of this widespread change in the minute-to-minute flows of information people, by the first decade of the 21st century mobile communications technology had led to the creation of a massively hyper-coordinated urban civilization. These flows had remarkably destabilizing impacts on existing social and economic structures. Employed by "smart mobs" these new patterns of communication massive ad-hoc anti-establishment political demonstrations and actions from Manila to Manhattan.[209]

While changes in the social networks of the untethered city were increasingly well documented, there was little research to help urban planners begin understanding the complex impacts of these changes on the physical forms of the city. Clearly, untethered

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[206] Kopomaa T. 2000. The City in Your Pocket. (Gaudemas, Helsinki)

[207] Howard Rheingold, address at "Wireless Communications and the Future of Cities" Workshop, April 2, 2003, Taub Urban Research Center, New York Univeristy. Streaming video clip at http://www.urban.nyu.edu/events/wireless

[208] Yttri B and R Ling. 2002. "Hyper-coordination via Mobile Phones in Norway" in Perpetual Contact: Mobile Communication, Private Talk, Public Performance" James E. Katz, Mark Aakhus eds. (Cambridge University Press, Cambridge, UK)

[209] Rheingold H. 2002. Smart Mobs: The Next Social Revolution. (Perseus, New York)

communications provided more flexibility in travel and supported higher levels of mobility. The ability to stay connected everywhere helped increase the pace of all types of transactions, from making a date to making a business deal. With the ability to rapidly get information to and from the people who mattered most to any decision, the efficiency and flexibility of organizations to deal with changing conditions was greatly enhanced.

In cities, it was also clear that the urban environment generated an enormous amount of information that needed to be anticipated, reacted to, and incorporated into everyday decision-making. Information about constantly changing traffic, weather, and economic conditions could be better transmitted through mobile phones and other wireless digital media. Traditionally, cities had functioned on a daily cycle of information flow with mass media like newspapers, third spaces like bars and cafes, and family conversations at the dinner table as the primary means of information exchange. With ubiquitous untethered communications, however, this old cycle was dramatically speeded up. As the information cycle sped up, there was a corresponding increase in the rate of urban metabolism – the pace at which urban economic and social life consumed information and materiel. In effect, instead of the synchronous daily rhythm of the industrial city coordinated by standardized time, untethered communications were leading to a city coordinated on the fly in real-time.

Untethered Infrastructure

The real-time pace of the untethered city was a significant departure from previous urban models, and it could only exist because of the appearance of a new communications infrastructure to support it. Without the mobility permitted by the wireless capability of these technologies, the messages missed when an individual stepped away from his terminal would continue to waste resources and drag down the rate of urban metabolism.

As a result, a new "untethered infrastructure" has emerged to provide the flexibility, capacity, ubiquity and reliability needed to support real-time functioning of urban social systems by combining the strengths of both wired and wireless communications technology in a hybrid network. Instead of providing end-to-end connectivity as they previously were designed to do, in the untethered infrastucture model wired networks are relegated to cheap, highly secure, long-haul transport of data, or backhaul. Digital wireless networks are employed at what they do best, providing reasonably secure reliable communications to mobile users in a variety of built environments. This hybrid infrastructure operated on a number of scales depending upon the capabilities of the wireless segment. For cellular networks, the wired backhaul is typically aggregated at the neighborhood level. For WLANs, the wired backhaul may extend to an area as small as a single room. (Figure 6.3)

The untethered infrastructure model solved two major problems that had arisen during the development of "wired" cities in the 1990s. First, the last-mile was just going to be too expensive to build – the best estimates put the figure in the hundreds of billions of dollars. After the wreckage of the 1990s telecom spending spree it was even less likely that private investors would provide financial resources for such a project.

Secondly, people didn't want to be tethered by wires anymore. Instead of going to the terminal to connect to the network, telecommunications users wanted the network to follow them around as they conducted their daily activities of work and leisure. Real-life users had a demand for telecommunications service that geographically was far more mobile than the available wired infrastructure.

By the turn of the 20th century, this new infrastructure model was well established in cities throughout the world. The transition to this model was most clear during the late 1990s as, in nation after nation, the number of mobile phone lines surpassed the number of fixed lines. By 2000, 725 million of the world's 1.7 billion telephones were mobile.[210] Not surprisingly, in developing countries where there had never been a significant investment in last mile infrastructure, the untethered model was utilized from the start. In these places mobile lines surpassed fixed line very early in the 1990s. However, even in highly developed nations such as Finland and Taiwan, by the end of the 1990s the untethered infrastructure model was firmly in place.

The establishment of the untethered model provided an unprecedented opportunity for transforming the urban experience. With that system in place, it became

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[210] International Data Corporation (IDC). 2000. "Wireless Access to the Internet, 1999: Everybody's Doin' It"; International Telecommunications Union. 2000. ITU Telecommunications Indicators Update. Oct/Nov/Dec. p.1.

possible to deliver or receive information from any inhabitant of an urban area. Combined with automatic positioning technologies like the Global Positioning System, it became possible to attach digital information to places in a searchable and retrieval form.[211] The untethered infrastructure provided a medium to link physical and virtual landscapes and create digitally mediated spaces.

Unwiring Bryant Park

This thesis has presented a large amount of information on the structure, evolution, capabilities, and limitations of digital network infrastructure. Throughout, it has relied upon the assumption that digital network infrastructure is a fundamentally benevolent technology, and the communications capability and connectivity it provides are fundamentally good. However, it has repeatedly presented evidence that the benefits of digital networks have been extremely limited geographically in scope. Most urban spaces lack digital network connectivity, particularly the public spaces most highly valued by urban designers as key components of healthy, open, democratic communities.

The untethered infrastructure model offers the potential to dramatically transform the delivery of digital connectivity in public spaces. In so doing it transforms the nature of those public spaces as well. The cellular telephone was designed to provide network connectivity in the public spaces of highways and sidewalks, and has transformed them into workplaces. Yet at the same time it has also permitted social interactions into the workplace. Local wireless network technology was intended to connect workers in shared office and warehouse environments to their corporate data networks, and has reshaped those sites into smarter workplaces. However, like the cellular phone, Wi-Fi is injecting outside social networks into wirelessly enabled workplaces such as university lecture halls.[212]

However, the economics of this new infrastructure model and the sober financial realities of the post-boom telecommunications industry dictate that difficult decisions

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[211] Townsend A. 2001. “The Science of Location: Why the Wireless Development Community Needs Geography, Urban Planning, and Architecture”. Position paper presented at CHI 2001, Seattle, Washington, March 31-April 5.

[212] Guernsey L. 2003. “In the Lecture Hall, A Geek Chorus”. *New York Times*. July 24. Sec G, Pg 1, Col 2.

must be made regarding which spaces to digitally mediate through network extension. Some of these decisions will be made by telecommunications engineers based on technical capability and cost, but not as many as in the past because of the new ability of wireless technology to reach into a wider variety of spaces. Instead much of the design decisions about where to provide network access will be made by urban designers, architects, and real estate developers. These professional had already begun thinking about the potential and challenges of integrating digital network connectivity into new and existing urban spaces.

The case of New York City's Bryant Park offers one of the few large-scale production-grade experiments in creating a digitally mediated space. In June 2002, the author along with several volunteers from the grassroots wireless user group NYCwireless launched a wireless local area network in Bryant Park. This network provided free access to the Internet using Wi-Fi technology.[213] The service was available 24 hours a day throughout the entire year.

The network was the result of a partnership between NYCwireless and the Bryant Park Restoration Corporation (BPRC), a non-profit organization that is contracted by the city to manage Bryant Park. BPRC is a business improvement district (BID), a special type of corporation funded by local property owners and responsible for providing additional safety and sanitation services in the park. Dozens of similar organizations operate throughout New York City, and the idea has been widely copied in other American cities.

Aside from sanitation and security which are all BIDs primary mission, many also participate in promoting economic development and providing or arranging for additional local amenities in the space they manage. After being approached by NYCwireless, Bryant Park immediately saw the enormous added value in providing wireless Internet access to park patrons. Since the spread of mobile phones in the early 1990s, the park management had noticed that during good weather many workers from nearby office buildings would remain in the park and do paperwork or hold small meetings with colleagues. Being available by mobile phone offered them the flexibility to remain in the

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[213] Begay J. 2002. "Escaping to Bryant Park, But Staying Connected to the Web" *New York Times*. July 3.

park for an extended time.[214] Since the Internet had become nearly as vital a business communications tool by 2002, it seemed only natural that this service should be available in the park. However, wireless carriers had failed to bring broadband mobile data products to market in New York. Providing Wi-Fi emerged as a superior alternative to the only remaining option of providing wired Ethernet data ports on park benches.[215]

Both NYCwireless and BPRC, however, were interested in more than just providing a raw connection to the Internet. One of the most important goals of the project was to design the network and integrate it into the park's existing physical and mental images in a seamless fashion. This goal led to two important design elements.

First, to preserve the visual appearance of the park as a managed natural setting, antenna installations were designed to be as small as possible. Additional paint camouflage was used to hide the antenna structures. Figure 6.3 shows how three antenna locations were used to provide seamless coverage throughout the park.

Secondly, a portal server was used to channel users of the wireless network through a splash page. The portal server runs the freely available Debian distribution of the Linux operating system, an Apache webserver, and the *NoCatAuth* open source gateway server. Developed by community wireless activists in Sonoma, California, *NoCatAuth* is designed to restrict access from the local wireless network to the Internet based on conditions set by the network administrator. In the case of Bryant Park, *NoCatAuth* was configured to require users to view a splash page containing information about Bryant Park and an acceptable use policy for accessing the Internet through the wireless network. (Figure 6.4) Unless the user agrees to the Acceptable Use Policy by clicking on the "I accept" button, she cannot access the Internet through the Bryant Park wireless network.

An additional benefit of the portal server is that it serves as a research tool, allowing the network managers to collect statistics on usage patterns. The Bryant Park wireless network's popularity exceeded even its creators' expectations. In the three months following the service's launch (July, August, September 2002) some 2,936 logins were recorded, an average of 32 users per day. As shown in Table 6.4, Mondays were

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[214] Personal interview with Jerome Barth, manager of Bryant Park, October 2002.

[215] Remarkably, this foolish idea was actually implemented by Microsoft in a park in England in 2001. [http://www.informationweek.com/story/IWK20010717S0005]

peak activity periods due to the HBO Monday Night Movies in Bryant Park event, which draws thousands of young singles from around the city each week. Fully 12 percent of all logins during these three months were between 4pm (when people typically start arriving to stake out lawn space) and 11pm (when the movie ends) on Monday nights. As shown in Table 6.5 the hours just before sunset on Monday evening (and the subsequent start of the movie), and lunchtime were the busiest hours for the wireless network. However, in the top 10 busiest hours were two mid-afternoon hours on Tuesday and Thursday, suggesting that the park's stated goal of attracting wireless users during off-peak hours was successful.

The wireless network served both tourists and visitors as well as people who regularly visited the park. According to analysis of log files, about 45 percent of users tried the network once and never returned. About 20 percent used the network twice during the summer, and another 20 percent used it 3 to 5 times during the summer. Little more than five percent of users (a core group of about 75 individuals) used the network once per week or more.

The most surprising finding of this analysis was that people used the network for exceptionally long periods of time. Throughout the three-month study period, the average session length was around one hour, with very little variation by day of week or time of day. However, there was a core group of users who regularly maintained sessions of up to three hours in length. Presumably these users exhausted their laptop power supplies in the process, since no sessions over three hours were recorded.

The Bryant Park wireless network experiment offers many basic but valuable lessons for the design of mediated public spaces. There are summarized below.

Most importantly, anecdotal evidence suggests that the wireless service is leading to a substantial blurring of boundaries between the park and neighboring office buildings. Numerous individuals and groups were observed working and conducting meetings that utilized the wireless Internet service. This blurring has helped reinforce the mixed-use character of the neighborhood, provide and alternative working environment, and render the Midtown's starkly barren office buildings more transparent by drawing workers (and their work) out to the park. The long session times recorded were further evidence that people were setting up shop in the park with wireless-enabled laptops and accomplishing real work.

The usage statistics presented here clearly indicate a strong linkage between activity in cyberspace and its physical space. When there was physical activity and visitors in the park, the wireless network was busy. However, beyond just a correlation between the number of occupants and the volume of data traffic, usage was higher before and during special events. Just as mobile phones are widely used to coordinate meetings and events, it appears that wireless Internet usage was driven by the need to organize groups of people for special events.

Just as Bryant Park's high quality, flexible public environment engendered a sense of communal ownership amongst park visitors, so did the high-quality wireless service. So few of the park's famous movable folding chairs were stolen each year that inventory was no longer taken at the end of the season, and people routinely pick up litter in the park – there was no where else in New York City where this type of behavior could be observed. Similarly, despite intense usage and vigorous monitoring, there were no detected instances of misuse or hacking on the park's wireless network.

Finally, providing this service was an affordable proposition, and achievable using off-the-shelf technology. The monthly costs for T1 Internet backbone service were about $1200 per month, and NYCwireless donated all installation and management services. Including equipment ($2,500 amortized over three years), it cost Bryant Park about $1.34 to service each user session over the three months of July, August, and September 2000. This figure would continue to drop as usage figures increased a projected 150 percent during 2003 and a final agreement was reached to replace the costly T1 with donated gigabit Ethernet from the adjacent New York Public Library.

While it was widely hailed as a successful, innovative project, several promising opportunities for more effectively linking virtual spaces and physical space through public WLANs remained unexplored at Bryant Park, mainly due to a lack of resources. However, other wireless projects the author is engaged in are pursuing these possibilities.

The potential for storing digital media content in a local archive is intriguing and could easily be accomplished with a standard webserver. This could take either of two forms.

As is the case with the South Street Seaport Wireless Network, the splash page provides links to archival information about the local area provided by the local business improvement district. This information is a duplicate of material used elsewhere on the organization's website and printed promotional materials. (Figure 6.5) The Brooklyn Museum of Art intends to use its wireless network splash page to provide virtual access to its entire collection, only a fraction of which can be on display in its physical galleries at one time. (Figure 6.6)

Another possibility would be to provide anyone with the ability to publish digital media content to a particular location's wireless network. This archive could develop much in the way that local social capital develops, accumulating and disintegrating with the passage of time. Of course, along with this capability comes the potential for misuse and abuse (digital graffiti!). This model seems to be the natural evolution of the home page and weblog phenomena that were driving factors in the popularity of the World Wide Web from its earliest days.

Perhaps the most interesting unexplored possibility lies in developing applications for the local wireless network that are local in nature – that is, they do not require access to the Internet. The Bryant Park experience has shown that providing wireless Internet access in public spaces has significant consequences for those spaces and how they are used. However, from a technology perspective there is little different between a website when it is viewed in the park on a laptop or in an office on a desktop computer. Email is the same wherever and whatever the access medium, although wireless email is obviously a greater convenience.

The potential exists to create server applications that run locally over the wireless network to enhance the park's ability to relax, fascinate, and connect people to each other. Among the possibilities explored have been scavenger hunt games, local chat rooms only accessible to users in the park, and digital graffiti boards (perhaps even being projected back into physical space). However, while intriguing, these applications have been slow to emerge in these earliest stages of experimentation. It is expected that as the number of Wi-Fi users grows, application frameworks are standardized, and greater experimentation results we will see the emergence of new applications that take advantage of the unique setting of untethered users in public spaces.

Bryant Park in particular, highlights the possibility of using untethered applications to enhance the function of the physical space. During special events like movie night, it would be possible to gather a large number of users for projects of collaborative expression on the big screen, or to provide tools for people trying to locate each other. One signature element of movie night is the colored balloons groups use to signal their position on the enormous lawn. Could untethered users develop their own improved version of this system?

Finally, the Bryant Park experience shows that supporting untethered individuals will require certain physical modifications to existing public spaces. Current interfaces devices (laptops) do not carry long-life power supplies, nor are their displays visible in direct sunlight. In the future, park designers will need to consider the special needs of untethered individuals just as they would any other type of user group.

CHAPTER 7

Policy, Planning, and Design for the Digitally Networked City

Despite the waning public enthusiasm for technology following the telecom bust of 2000-2002, digital network infrastructure had matured to the point where it as a common facet of most people's daily lives in cities of the developed world.[216] This thesis has chronicled the evolution of that infrastructure within cities from the earliest experiments with distributed networks such as ARPANET to the spread of free wireless networks in New York City's public spaces. It has demonstrated how social, economic, and geographic forces have reshaped digital networks from a military means of decentralizing vulnerability in the Cold War to an untethered urban nervous system for postmodern "smart mobs".

This chapter reviews the key findings of this research. However, because it is now more widely recognized as a crucial component of urban infrastructure, digital networks are increasingly an object of attention from urban policymakers, planners, and designers. Therefore, what lessons can be drawn from this research to inform these efforts? What does this research mean for city building and management? The following sections address these questions for each of the three areas of urban planning, urban policy, and urban design. Finally, it concludes with a discussion of future directions for urban research in this area.

Summary of Key Findings

This dissertation has sought to answer several questions about the geographical diffusion of digital network infrastructure during the late 20th and early 21st century. To do this, it has used a combination of qualitative and quantitative techniques to analyze events and data that can be used to understand this poorly documented process.

Chapter 1 explained the recent history of research and thought on the role of communications and digital networks in urban space. While traditionally communications

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[216] Mitchell W J. 1999. E-topia. (MIT Press, Cambridge)

geography has been an obscure field of scholarly inquiry, its theories and lessons are now of broader interest as people interact more frequently and intensely with digital networks.

Chapter 2 described the global structure of the Internet that has emerged after a decade of exponential growth, which is highly unequal and the product of historical social, economic and political disparities between nations and regions.

Chapter 3 extended this analysis to the urban scale, confirming the dominance of a handful of "global cities" in the geography of digital network infrastructure. However, contrary to recent urban research, it also found that a small group of "network cities" actually led the development of new communications grids like the Internet, and maintain surprisingly important hub roles. Instead of producing technology, global cities now are largely importers of new technologies created elsewhere.

Turning from the Internet's backbone topology to the actually underlying physical components, Chapter 4 described how new facilities for production, transmission, switching and storage of digital data have been interwoven into existing urban fabric. Akin to their industrial city counterparts used for goods handling, these facilities enable information cities to process their most valuable product – information. Remarkably, though, despite public belief that digital networks are universally deployed, they in fact remain the most concentrated and inequitable distributed of major urban infrastructure networks (which include road, rail, power, water, gas, and communications).

Poor planning in the face of hyper-competitive, privatized, and deregulated telecommunications infrastructure markets are largely to blame for the incomplete deployment of digital networks in cities during the 1990s. Chapter 5 investigated the telecom boom and bust cycle that occurred at the end of the 20th century and argued that while the largest metropolitan areas received enormous investments in telecommunications infrastructure during the 1990s, little was spent elsewhere. As a result many parts of developed countries lack broadband digital network services. Largely, the beneficiaries of this investment were Fortune 1000 corporations whose facilities were already located alongside the new information highways. Small businesses and residents have yet to see broadband infrastructure extended to them on a widespread basis. With the bust of 2000-2002, it seemed that the process of diffusion would slow even further.

While wired technologies such as fiber optics received the bulk of public attention and speculation during the 1990s, wireless communications networks grew even more rapidly. In fact, there have always been more mobile telephone users than Internet users. As Chapter 6 explained, a new model for digital network infrastructure has emerged, combining the best features of the largely unfinished wired grid with the flexibility of wireless networks in the last mile to the user. This untethered infrastructure has emerged as a response to social needs for mobile computing and communications, reflecting a social reshaping of technology that was once expected to reshape societies.

Fundamental Characteristics of Digital Networks

Through the course of these six chapters, three main points of interest have repeatedly emerged; regardless of the scale of investigation, the technology or the time frame at hand. These points address the main implications of this research in the areas of urban planning, urban policy, and urban design.

First, digital network infrastructure is not the city-shattering technology it was hoped, feared, or objectively considered to be by many observers in the late 20th century. In fact, as this dissertation as shown, digital networks have evolved within existing urban geographies without significantly altering them. On the contrary, again and again digital network technologies have been re-engineered to deal with the problem of distributing access and transmission capacity to connect clusters of users in urban areas. Wired digital networks have evolved into a hierarchical hub and spoke system so similar to the air transport network that its routers are often named after airports. Wireless networks like the cellular telephone system and wireless LANs have repeatedly been re-engineered to cope with the density, built environment, and socioeconomic metabolism of our cities. Put simply, digital networks themselves were far more flexible than the urban fabric into which they were inserted.

Second, national telecommunications policies became de facto urban policy during the 1990s for the first time in history. For although digital network infrastructure did not lead to the dispersion of economic activity out of cities, it was a key aspect of competitiveness between urban regions. The regulatory model that governed the deployment of digital network infrastructure in the 1990s, pursued most relentlessly by the United States government, was one of laissez-faire capitalism. This included scant oversight, few interventions, and a lack of leadership or policy of geographical diffusion. Combined with hyper-competitive bubble markets, extremely poor information on existing and planned infrastructure deployments led to a duplication of network infrastructure 10, 20, or even 30 times within and between in the central business districts of major metropolitan areas. Yet, at the same time most other urban, suburban, and rural areas were lucky to see the expansion of services on existing communications networks, and few saw the development of truly competitive broadband networks.

Third, urban space is now the unique stage for experimentation with new lifestyles based on digital network connectivity. Because cities have remained vital despite the rise of digital networks, and because these networks have generally not been deployed outside major urban areas, there is a great opportunity for urban design to leverage this new infrastructure to create more unique, livable urban spaces. New York's public wireless networks described in Chapter 6 are but the first crude example of this opportunity.

These three conclusions challenge the way that the professions of urban planning, urban policy, and urban design must respond to this new urban infrastructure. The follow three sections offer the author's recommendations in each area based on this research. This is a modest attempt to begin refocusing the discussion around urban digital networks from theoretical speculation (where it often leads to) to practical problem solving. The final section of this chapter offers some observations on where future urban research should proceed in this area.

Planning: Putting Telecommunications on the Map

For urban planning, the diffusion of digital network infrastructure raises many practical challenges. Techniques for addressing these challenges have emerged in communities around the world. This section provides an initial set of recommendations that can be employed in three general areas of planning: economic development, land use and transportation planning, and community development.

Local economic development agencies have traditionally ignored telecommunications infrastructure because it was seen as a private sector activity, outside the purview of local government. However, in recent years economic development agencies have began assessing local telecommunications infrastructure for marketing purposes as well as for planning strategic infrastructure investments. (See examples in Chapter 4) Because there is so little information or certainty regarding the availability of digital network infrastructure, these kinds of studies can be highly effective tools for new or relocating firms. However, planners need to clearly understand that most telecommunications-driven redevelopment strategies failed even in the go-go 1990s. For instance, the DigitalNYC program in New York City sought to lure Internet firms to pre-wired loft buildings in post-industrial districts in Brooklyn, Queens, and the Bronx. But without convenient access to customers, a qualified labor force, and transportation the project sites failed to attract tenants. High-quality telecommunications infrastructure was simply not enough. Rather, planners must understand digital network infrastructure as a pre-requisite for competing for economic growth.

The planning research literature on telecommunications infrastructure has long been focused on the land use impacts of these technologies. Yet the overall consensus is muddled, with little concrete quantitative evidence to support the claim that telecommunications technologies are responsible for either centralization or decentralization of economic activity on a widespread basis. Yet these debates are largely uninformative for practicing planners, since they focus macroeconomic outcomes that are quite remote from the planner's everyday task. As Moss noted during the defense of this dissertation, in metropolitan areas in the United States, firms and households are employing digital network technologies for "selective, planned dispersion".[217] Land use and transportation planners are better advised to focus attention on how telecommunications is being used within local communities to complement or substitute settlement and travel decisions.

Finally, planners focused on encouraging community development, particularly in inner-city neighborhoods, need to recognize the disadvantages that result from a lack of

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[217] Moss M L. Dissertation defense of Anthony M. Townsend, May XXX, 2003. Massachuestts Insitute of Technology.

digital network access. While the "Digital Divide" appears to be closing when one looks at national statistics, these averages obscure concentrated pockets of poor, minority residents that cannot gain access to these tools for self-development. Programs like E-rate and HOPE VII have sought to bring network access to inner-city schools and public housing projects, but these programs are often infrastructure-focused and do not provide the training necessary to use these networks effectively. Better examples such as Boston's Computer Clubhouse and the Camfield Estates Wireless Network show how digital networks can be more seamlessly integrated into community networks.[218]

Policy: Infrastructure, Connectivity, & Competitiveness

The nature of urban policy changed significantly in the 1960s as scholars, government planners, and activists alike realized the degree to which housing policy, monetary policy, and immigration policy had enormous impacts on urban areas. It has become widely recognized that these policy areas serve as de facto urban policy, most notably in the United States, which lacks comprehensive urban policy at the federal level.

This dissertation recommends that telecommunications policy be treated as another important de facto urban policy, because of the large and increasing importance of tele-connectivity to the economic and social health of cities. Just as seaports and airports have connected local economies to the global economy in the past, information ports connect them together today. For post-industrial cities, this infrastructure is vital to being able to import raw materials (information) and export finished products (knowledge).

Recognizing the powerful role of telecommunications policy in urban economic development, through the control of digital network infrastructure deployment, means considering changes in those policies as well. Yet, despite dramatically different conditions among cities, nearly all telecommunications regulation is conducted at the national and state/provincial level. Furthermore, most federal telecommunications policy

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[218] See Richard O'Bryant's doctoral dissertation at the Department of urban Studies and Planning, Massachusetts Institute of Technology. 2003.

is inherently anti-urban and designed to cross subsidize the far more costly deployment of services in suburban and rural areas.

This dissertation recommends devolving some of the authority to regulate telecommunications infrastructure to the local level. Telecommunications is unique among urban infrastructure networks to enjoy such freedom from regulation. In the United States, local governments actively participate in the market for all sorts of urban infrastructure – power, water, and other utilities. Yet there are tightly restricted from participating in telecommunications franchises, and pre-empted by federal law from regulating the actions of telecommunications carriers to achieve public objectives. Only in a single area, the siting and design of cellular antenna structures, have local governments exerted any control over the deployment of telecommunications infrastructure. Yet despite widely varying norms among communities, the cellular industry has been able to cost-effectively deploy this infrastructure in a timely manner. Thus, one of the main arguments against the imposition of local authority over telecommunications infrastructure – that it would drive up the costs of extending networks – appears largely unfounded.

Design: Mediated Urban Space

Of all the professions concerned with the quality of urban life, digital network infrastructure poses the greatest challenge to urban design. The profusion of mobile, wireless communications and computing devices is certain to raise the frequency and duration of human interaction with digital network infrastructure. The increasing scope of this infrastructure will draw these users into a greater number and variety of urban environments. To date, these activities had been confined to home, office, or classroom settings for the vast majority of users of digital networks like the Internet.

As the example of Bryant Park shows, urban places will need to adapt to the changing needs of digitally networked inhabitants.

Beyond just reacting, however, there are tremendous opportunities to leverage new digital infrastructure to improve the function of urban spaces. In the first decade of the 21st century untethered networks, navigational technologies like the Global

Positioning System, and geographic databases will be increasingly integrated into portable devices such as pocket computers and mobile phones. As geographer Ronald Abler has noted, this system will make it possible to easily retrieve everything that is "known" about a place from that place.[219] Thus, a powerful set of computational tools will insert a layer of mediation between the user and his environment, shaping experiences and understanding of the built environment. Whether this obscures the reality and disconnects the user from the reality of the city, or helps her in engaging it even more fully will largely be a factor of how these systems are designed and how the information they provide is organized and presented. Both the opportunity and the threat are almost beyond understanding.

Unfortunately, there is to date very little indication that urban designers are being engaged in discussions about the future of untethered network infrastructure and its applications for mobile, wireless users. No mention of such topics can be found in recent design and architectural journals.[220] However, as outlined in Chapter 1, computer scientists seeking to liberate networks and software from the desktop are actively investigating these issues. As a result, much of this research is making its way into products and services shaped by information scientists and technologists, without any sort of nuanced approach to urban and architectural space.

One notable exception to this rather dismal track record is the collaboration between the Seoul Metropolitan Government, Seoul Development Institute, and MIT's City Design and Development Program on the Digital Media Street (DMS) project. This project has involved planners, designers, and information technologists to rethink the nature of the street in the digitally networked city of Seoul. The team has envisioned simple, elegant ways in which to integrate new digital technology in rather traditional ways that enhance the ability of the built environment to function.

The work of the DMS team highlights an important danger. Just as urban planners of the mid 20th-century were over-enthusiastic about the benefits of the automobile, they must avoid the temptation of technological utopianism regarding digital networks. Digital

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[219] Abler R. 2000. Address to International Geographic Union annual meeting, South Korea.
[220] *Journal of Urban Design, Journal of Architectural and Planning Research.*

technologies should not be seen as a panacea for urban problems, but as a new tool for increasing the quality and flexibility of urban space.

In conclusion, while the arrival of untethered infrastructure poses many challenges for urban design, these changes are likely to be slow and incremental rather than rapid and all-transforming. As the case of Bryant Park illustrates, custodians of public space are proceeding carefully with the construction of digitally mediated space, so as not to undermine the delicately crafted urban experiences they have worked so hard to create.

Future Directions for Urban Research

As evidenced by the theme of the 2003 ACSP-AESOP Joint Congress, "The Network Society: The New Context for Planning", the urban research community has fully engaged the importance of networks in city building. This recognition has been in large part due to the widespread awareness of how digital networks are changing individual lifestyles and urban activity patterns around he world. Debates begun by influential thinkers like Mitchell and Castells nearly a decade ago have helped refocus research around the implications of digitally network cities.[221]

This research has sought to expand on the published research on urban telecommunications infrastructure since the mid 1990s by looking at these systems in a comprehensive way by investigating its present structure, its historical origins, and its future evolution. In so doing, it has raised many questions for further research. In conclusion, there are three main questions that the author would invite his colleagues to focus their efforts on going forward. These questions all derive from the rise of mass mobile communications in urban areas described in Chapter 6. These technologies, so seamlessly interwoven into our daily lives, and with such enormous power to let us reshape our use of urban space, will surely define the trajectory of urban development for the next 100 years.

First, what exactly is happening to the metabolism of cities as they become untethered? As the author has argued in Chapter 6 and elsewhere, wireless mobile

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[221] Mitchell W J. 1995. City of Bits (MIT Press, Cambridge)

communications and computing technologies can dramatically short—circuit information feedback systems in cities.[222] While the Internet raised our awareness of how messages about markets, political and social events, and fashion trends could spread globally in a matter of hours, urban researchers have not yet investigated these trends at urban scales. Put simply, how does information flow through the wireless networks of the untethered city? What impacts does it have on how people live and move about in the city? While largely an empirical question, the results of this work will raise fundamental theoretical issues on the changing nature of urban dynamics.

Second, how is the relationship between public and private space being reshaped in the untethered city? Most elements of urban space are designed to either restrict or encourage access to other locations. As Mitchell has noted, the logic of public and private were rapidly implemented in cyberspace during the early days of the Internet.[223] Untethered technologies like mobile phones ringing at the move theatre, daily bring private cyberspace into conflict with public urban space. At the same, they give individuals the ability to reach into other public realms such as the Internet or Global Positioning System to retrieve information about their surroundings. Does the information about a place belong to that place? How do public wireless networks blur boundaries between private office space and urban parks?

Third, how should cities and networks be reshaped to fit together better? How, can and should we design digitally mediated spaces? What do people want from them? This is the most important question in the end because answering it properly will determine the quality of life in urban areas for a century or more to come. However, only a handful of urban researchers are considering these questions. Sophisticated inquiry on topics such as ways of digitally encoding human concepts of place is being carried out in industry and computer science, not urban design.[224] What types of information do people need in public spaces? How should interfaces be designed to enhance understanding of the built and social environment? What psychological thresholds about the amount of

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[222] Townsend A M. 2001. "Mobile Communications in the Twenty-first Century City" in B Brown The Wireless World. (Springer-Verlagm Berlin)

[223] Mitchell, City of Bits, Ch 5.

[224] The field of computer-supported collaborative work (CSCW) is a particularly rich area of investigation that is still largely oblivious to urban researchers. For example, Quentin Jones' work at NJIT on digitally encoding human perceptions of place is of particular interest.

information present in an urban space need to be addressed?

It is clear that we are on the threshold of a new era of urban transformation. By reaching out to other disciplines, we can better understand the way in which new objects are being put to use to change our cities. From this understanding, it is hoped that we can redesign our cities as better venues for prosperous lives.

Table 0.1
Cost of Selected Urban Network Infrastructure Systems

Project	*Construction Period*	*Cost (2003 $ billion)*
Apollo Space Program	1967-1972	125
US Interstate Highway System	1957-1995	350
Erie Canal	1817-1825	0.125
Three Gorges Dam (China)	1994-2011	25
US long-haul fiber optic grid	1997-2001	100+

Sources: Apollo Space Program, Erie Canal: Economic History Services Fileserver. [http://www.eh.net/hmit/compare/]; Interstate Highway System: US Federal Highway Administration; US Long-haul fiber grid: Wall Street Journal; Three Gorges: "Some Facts about the Three Gorges Project" (Nov 1, 1997) [http://www.prchina.net/Cgi-Bin/Press.pl?gorges04].1967

Table 0.2
Per Kilometer Costs, Selected Urban Network Infrastructure Systems

Type of Network	*Per Kilometer Cost*
Road	$550,000
Water	$195,000
Electricity	$145,000
Gas	$85,000
Fiber optic	$22,000-35,000
Coaxial cable	$12,000-20,000
Copper twisted pair	$7,000-15,000
Wireless	$3,500-15,000

Source: Canadian Broadband Task Force Report, 2001.

Table 2.1
The Seven Layer Open System Interconnection (OSI) Model

Layer	*Name*	*Purpose*	*Examples / Uses*
7	Application	File transfer, screen formatting	telnet, ftp, SMTP/POP
6	Presentation	Encryption, compression	
5	Session	Session Management	E-commerce baskets
4	Transport	Send and receive packets	TCP, NetBios
3	Network	Establish and maintain networks	IP, IPX
2	Data Link	Error checking	Ethernet, Wi-Fi, PPP
1	Physical	Physical transmission of bits	ISDN

Table 2.2
Interconnection Points on the Early Internet, 1995

Name	*Metro Area*	*Municipality*	*Operator*
PacBell NAP	San Francisco	Walnut Creek, CA	Pacific Bell
MAE-East	Washington	Vienna, VA	MFS
Ameritech NAP	Chicago	Chicago, IL	Ameritech
Sprint NY NAP	New York	Pennsauken, NJ	Sprint

Table 2.3
Internet Hosts per Capita, October 2000

Country	*Internet Hosts per 1000 Inhabitants*
United States	234
Finland	159
Iceland	131
Canada	127
Norway	116
Sweden	106
New Zealand	93
Netherlands	82
Australia	75
Denmark	72
Switzerland	63
Austria	58
United Kingdom	53
Belgium	40
Italy	33
Japan	32
Germany	32
Ireland	31
Luxembourg	31
France	19
Spain	16
Hungary	15
Portugal	13
Greece	13
Czech Republic	13
Korea	11
Poland	8
Mexico	4
Turkey	3
World	16

Source: OECD, Communications Outlook 2001, from Netsizer (www.netsizer.com), April 2001

Table 2.4
Intercontinental Internet Bandwidth, 1999

Route	*Deployed IP Backbone Capacity (Megabits per second)*
US - Europe	13,258
US – Asia/Australia	5,916
US – Latin America	949
US – Africa	170
Europe – Asia/Australia	152
Europe – Africa	69
Europe – Latin America	63
Asia/Australia – Africa	3

Source: Telegeogprahy, Inc. 2000. International Bandwidth 2000.(Washington, DC)

Table 2.5
Audience Reach for Top Web Content Producers

Site	*% Audience Reach*
AOL Websites	59.08
Yahoo!	56.44
MSN	42.08
Lycos Network	25.62
Microsoft	24.53
Excite@Home	24.3
Walt Disney Internet Group	20.68
Time Warner	17.48
About The Human Internet	16.23
Amazon	15.27

Source: Nielsen/NetRatings

Table 2.6
Waning U.S. Dominance of Internet Population
1996-2002 (millions)

Region	*1996*	*1998*	*2000*	*2002*
US & Canada	40 (72.7%)	79.3 (53.9%)	148 (39.3%)	182.67 (30.2%)
Europe				190.91
Asia / Pacific				187.24
Other				44.78
World Total	55	147	377	605.60

Source: NUA Internet surveys. "How Many Online?" http://www.nua.ie

Table 3.1
Overseas Telephone Traffic from U.S. Cities, 1982

Area Code	*City*	*Overseas Message Units (Excluding Canada and Mexico)*	*Percent*
212	New York City	22,718,027	19.8 %
213	Los Angeles	9,310,028	8.1
415	San Francisco	4,535,474	3.9
213	Chicago	4,028,709	3.5
All	USA	115,001,763	100.0

Source: AT&T Communications, cited in Moss M L. 1987. "Telecommunications and the future of cities" Land Development Studies. 3:33-44

Table 3.2
IP Backbone Capacity Growth in Regional Internet Hubs, 1997-1999

Metropolitan Area	*1997 (Mbps)*	*1999 (Mbps)*	*Growth Index (Fraction of US Growth)*
Washington	7,826	28,370	0.70
Dallas	5,646	25,353	0.86
San Francisco	7,506	25,297	0.65
Atlanta	5,196	23,861	0.88
Chicago	7,663	23,340	0.59
New York	6,766	22,232	0.63
Los Angeles	5,056	14,868	0.57
US Total	75,606	393,574	1.00

Source: Author's analysis originally published in A M Townsend. 2001.

Table 3.3
Domain Name Density, U.S. Metropolitan Areas, January 1999

Metropolitan Area	*Population (millions)*	*Registered Domain Names Per 1,000 Persons*
San Francisco Bay Area	6.6	15.9
Austin	1.0	14.9
Provo, UT	0.3	12.6
Seattle	3.4	12.4
San Diego	2.7	12.1
Miami	3.5	11.9
Denver	2.3	11.5
Las Vegas	1.1	11.1
Phoenix	2.5	11.1
Minneapolis	2.8	11.0
Gainesville, FL	0.2	11.0
Boston	5.8	10.9
West Palm Beach, FL	1.0	10.8
Washington, DC	7.2	10.7
Portland, OR	2.0	10.7
Orlando	1.4	10.1
Los Angeles	15.7	9.8
Dallas – Fort Worth	4.5	9.7
Atlanta	3.5	9.7
Houston	4.2	9.0

Source: Domains on Disc (www.domainsondisc.com).
Author's analysis originally published in A M Townsend. 2001.

Table 3.4
ARPANET and NSFNET Points of Presence in Major U.S. Metropolitan Areas, 1980-1992

Metropolitan Area	*1990 Population (millions)*	*ARPANET 1980*	*ARPANET 1971*	*NSFNet T1 Backbone 1989*	*NSFNet T3 Backbone 1992*
New York	17.8	-	X	-	-
Los Angeles	14.5	X	X	-	-
Chicago	8.2	-	-	-	X
San Francisco	*6.2*	*X*	*X*	*X*	*X*
Philadelphia	5.9	-	-	-	-
Boston	*5.7*	*X*	*X*	*X*	*X*
Washington	*5.4*	-	*X*	*X*	*X*
Detroit	5.2	-	-	-	-
Dallas	4.0	-	-	-	-
Houston	3.7	-	-	X	X
Atlanta	n/a	-	-	X	X
Seattle	n/a	-	-	X	X

Source: Compiled by author from published maps.

Table 3.5
IP Backbone Capacity in U.S. Hubs, 1997-2000

Metropolitan Area	*1997*	*1998*	*1999*	*2000*	*Annual Growth Rate 1997-2000*
New York	6,766	9,543	22,232	234,258	226%
Chicago	7,663	14,809	23,340	221,738	207%
Washington	7,826	14,174	28,370	208,159	199%
San Francisco	7,506	14,924	25,297	201,772	200%
Dallas	5,646	10,985	25,343	183,571	219%
Atlanta	5,196	5,426	23,861	149,200	206%
Los Angeles	5,056	9,397	14,868	140,649	203%
Seattle	1,972	5,409	7,288	109,510	282%
Denver	2,901	5,942	8,674	97,545	223%
Kansas City	1,080	2,715	13,525	89,292	336%

Sources: Author and Malecki, E. 2002. The Economic Geography of the Internet's Infrastructure," Economic Geography, vol. 78, no. 4, October 2002

Table 3.6
International Backbone Hubs, 2000

City	*International Backbone Capacity (Mbps)*
North America	
New York	13,205
Washington, DC	3,998
San Francisco	3,950
Chicago	2,666
Seattle	2,607
Los Angeles	740
Europe	
London	17,969
Amsterdam	10,874
Frankfurt	10,516
Paris	9,687
Brussels	6,213
Geneva	5,947
Asia	
Tokyo	2,393
Seoul	1,106
Hong Kong	541
Singapore	497
Taipei	324
Kuala Lumpur	188

Source: Telegeography, Inc.

Table 4.1
Per Unit Price for Internet Bandwidth from New York
Summer 2000

Destination	*Capacity*	*Per Unit Price ($ / Mbps / year)*
Washington	2.5 Gbps	148
Washington	622 Mbps	401
Washington	155 Mbps	564
London	2.5 Gbps	1,162
London	155 Mbps	2,323 – 2,510
Dublin	2.5 Gbps	5,250
Dublin	155 Mbps	5,758
Paris	155 Mbps	10,510
Frankfurt	155 Mbps	10,510
Milan	45 Mbps	12,222
Vienna	45 Mbps	16,222
Prague	45 Mbps	16,222
Tokyo	45 Mbps	40,644
Hong Kong	2 Mbps	144,640

Source: Compiled by author from listings on Band-X Bandwidth Exchange

Table 4.2
Broadband Subscribers by Region, 2000-2004

(in millions)	*2000*	*2001*	*2002**	*2003**	*2004**
North America	7.6	13.5	20.4	28.6	38.0
Europe	1.5	6.0	11.3	18.7	26.8
Asia / Pacific	5.8	12.6	20.1	31.0	50.0
Total**	14.9	32.0	51.9	78.2	114.4

Source: Emarketer.com, June 2002.

**Projected*
***Totals may not agree due to rounding*

Table 4.3
Broadband Subscribers by Country, 2001

Country	*Broadband Households (millions)*	*Penetration*
United States	11.2	10.4%
South Korea	7.5	51.7
Japan	2.6	5.8
Canada	2.3	19.7
Germany	2.1	5.4
Taiwan	1.1	18.2
France	0.6	2.5
Netherlands	0.6	8.1
Hong Kong	0.6	26.0
Sweden	0.5	13.4

Source: Emarketer.com, June 2002.

Table 4.4
Broadband Subscribers by Metropolitan Market, 2001-2002

(thousands)	*2001*	*2002*	*Growth Rate*
New York	1,630	2,780	70.5%
Los Angeles	940	1,766	87.9%
Boston	755	1,120	48.4%
San Francisco	917	1,110	21.0%
Philadelphia	462	785	69.9%
Seattle	565	691	22.3%
Dallas	552	623	12.8%
Chicago	487	555	13.9%
Washington	210	532	153.2%
Atlanta	275	517	87.7%
San Diego	432	497	15.0%
Sacramento	191	416	117.8%
Detroit	381	411	8.0%
Orlando	142	401	183.0%
Minneapolis	189	368	94.3%
Tampa	254	368	45.0%

Source: Nielsen/NetRatings netReporter. "Biggest Broadband Cities Get Bigger"

Table 4.5
Information Warehouses by Metropolitan Area, 2000

Metropolitan Area	*Information Warehouses / Data Centers*
San Francisco Bay Area	42
London	35
Washington, DC	28
New York	26
Los Angeles	22
Tokyo	18
Amsterdam	17
Boston	15
Hong Kong	14
Stockholm	12
Chicago	11
Dallas	11
Atlanta	10
Seattle	9
Denver	7
San Diego	6
Phoenix	5
Columbus	3
Houston	3
Miami	3

Source: Stratsoft, LLC (Concord, MA)

Table 4.6
Information Port Space Inventory, Major Global Cities, 2001

City	*Total Information Port Space Built (million ft^2)*	*Average Facility Size (ft^2)*
Frankfurt	1.20	85,469
Paris	1.16	88,881
London	1.09	64,123
Amsterdam	0.95	94,673
Miami	1.50	107,332
New York	0.85	31,653
San Francisco	0.85	44,661
Los Angeles	0.80	41,646

Source: Telegeography. Accessed Oct 14 2002.
[http://www.telegeography.com/resources/statistics/bandwidth/co02_colo_space.html]

Table 5.1
Selected Major US Fiber Networks

Carrier	*Route miles deployed (1Q2000)*
MCI	77,000
AT&T	53,000
Sprint	30,000
Williams	25,770
Qwest	24,500
Global Crossing	19,500
Teleglobe	14,000
Level 3	9,334

Source: "Unmasking the fiber barons", America's Network, March 1, 2000

Table 5.2.
Bankruptcies in the Digital Infrastructure Sector, 2001-2002

Company	*Date of Bankruptcy*
Information Ports	
Colo.com	May 2001
Exodus	September 2001
Long-haul fiber	
360networks	June 2001
Global Crossing	January 2002
Williams	April 2002
FLAG Telecom	April 2002
Metromedia fiber Networks	May 2002
Teleglobe	May 2002
KPN Qwest	June 2002
XO	June 2002
Northeast Optical Network	July 2002
Worldcom	July 2002
Local/metro networks	
Northpoint	January 2001
Rhythms	August 2001
Covad	August 2001
Adelphia	April 2002

Source: Public sources

Table 5.3
Market Capitalization of Telecommunications Firms, 2000-2002

Company	*Market Value ($ billion)*	
	March 2000	*September 2002*
Baby Bells	**362.1**	**201.6**
Verizon	94.5	80.1
SBC	143.3	76.8
Bellsouth	88.1	40.7
US West/Qwest	36.2	4.0
Carriers	**383**	**63.303**
Qwest	36.9	1.5
AT&T Business	61.9	23.3
Sprint Fon	49.8	20.1
Level 3	38.6	2.0
Worldcom	129.7	0.0
Cable and Wireless	32.5	8.2
Global Crossing	32.0	8.2
Genuity	1.6	0.003
Cable Companies	**130.6**	**53.59**
AT&T Broadband	26.1	8.6
Comcast	37.4	17.9
Time Warner Cable	20.4	10.8
Cox	29.1	13.8
Cablevision	8.9	2.4
Adelphia	5.5	0.0
Charter	3.2	0.09
DSL	**10.8**	**0.2**
Rhythms Netconnections	0.5	0.0
Covad	7.3	0.2
Northpoint	3.0	0.0

Source: Wired "The Bit Business, Before and After" November 2002, p. 197

Table 6.1
Cellular vs. Internet Users (millions)

Year	Mobile Cellular Subscribers	Internet Users
1991	16	4.4
1992	23	7
1993	34	10
1994	56	21
1995	91	40
1996	145	74
1997	215	117
1998	318	183
1999	490	277
2000	740	399
2001	955	502
2002	1,155	580
2003	1,329	665

Source: International Telecommunications Union.

Table 6.2
Leading Nations in Mobile Telephone Adoption, 2002

Nation	Mobile Phones per 100 Inhabitants
Taiwan	106.5
Luxembourg	101.3
Israel	95.5
Hong Kong	93.0
Italy	92.7
Iceland	90.3
Sweden	88.5
Czech Rep	84.9
Finland	84.5
UK	84.5
Norway	84.3
Greece	83.9
Slovenia	83.5
Denmark	83.3
Austria	82.9
Spain	82.3
Portugal	81.9
Singapore	79.1
Martinique	79.0
Switzerland	78.8

Source: OECD Communications Outlook 2003.

Table 6.3
Evolving Capacity of Cellular Networks

Network	*0G*	**1G**	**2G**	**3G**
Technology	Radiotelephone	Analog cellular	Digital cellular	Enhanced digital cellular
Deployment	1946-1983	1983-1992	1990-2002	2002-
Cells per city	1	30	100	1,000+
Subscribers per city	500	64,000	500,000	5,000,000

Source: Sean Gorman, George Mason University

Table 6.4
Bryant Park Wireless Network, Session by Day of Week, Summer 2002

Day	*Sessions*	*Percent*
Sunday	255	6.5%
Monday	802	20.5%
Tuesday	666	17.0%
Wednesday	651	16.6%
Thursday	611	15.6%
Friday	614	15.7%
Saturday	314	8.0%

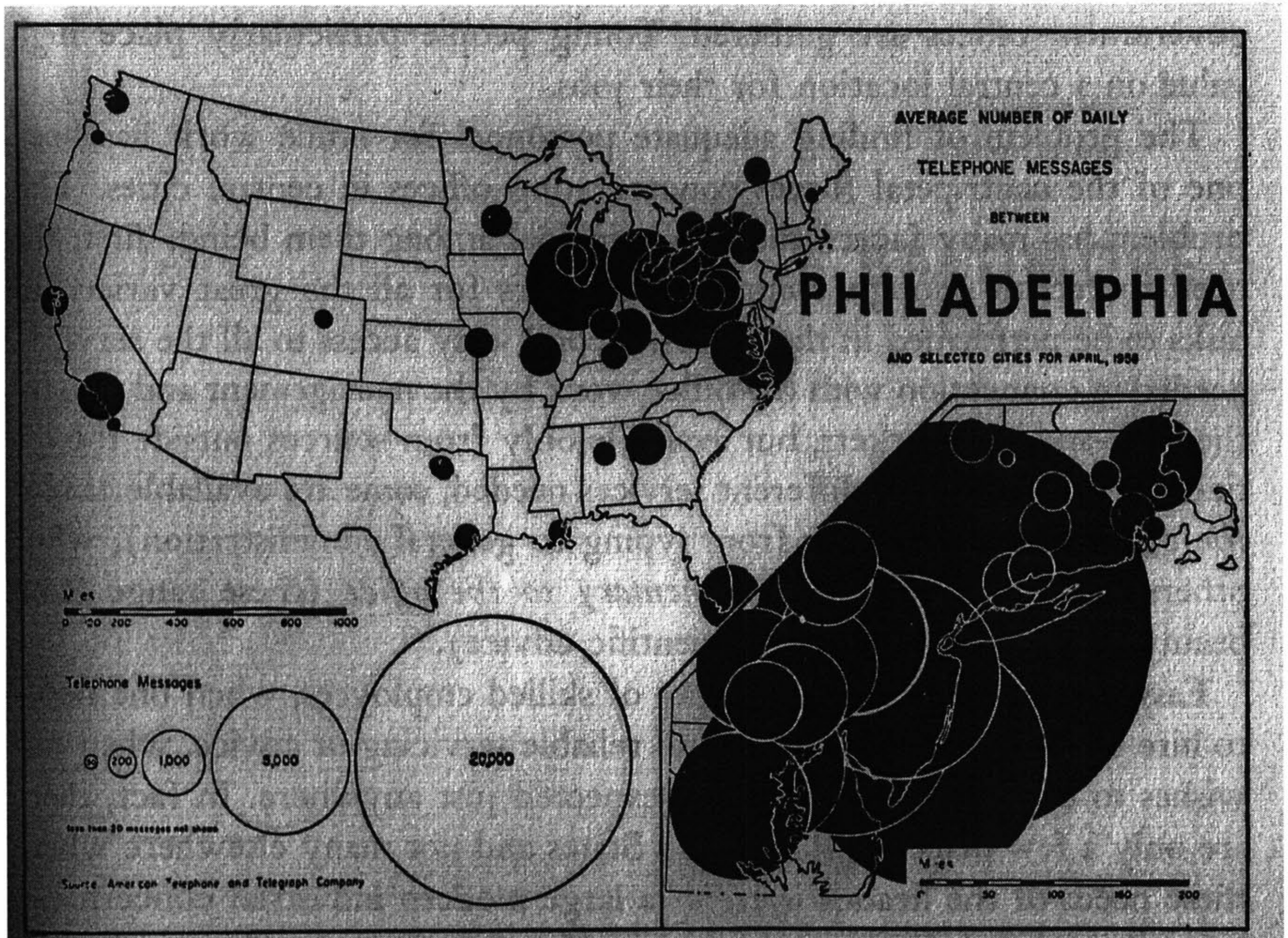
Source: Author's analysis of log data.

Table 6.5
Bryant Park Wireless Network, Busiest Hours, Summer 2002

Day	*Hour*	*Sessions*	*Percent*
Mondays	7-8 pm	114	2.9%
Mondays	6-7 pm	102	2.6%
Fridays	12-1 pm	84	2.1%
Wednesdays	1-2 pm	81	2.1%
Tuesdays	3-4 pm	80	2.0%
Mondays	5-6 pm	79	2.0%
Mondays	8-9 pm	70	1.8%
Thursdays	2-3 pm	69	1.8%
Tuesdays	1-2 pm	68	1.7%
Fridays	1-2 pm	66	1.7%

Source: Author's analysis of log data.

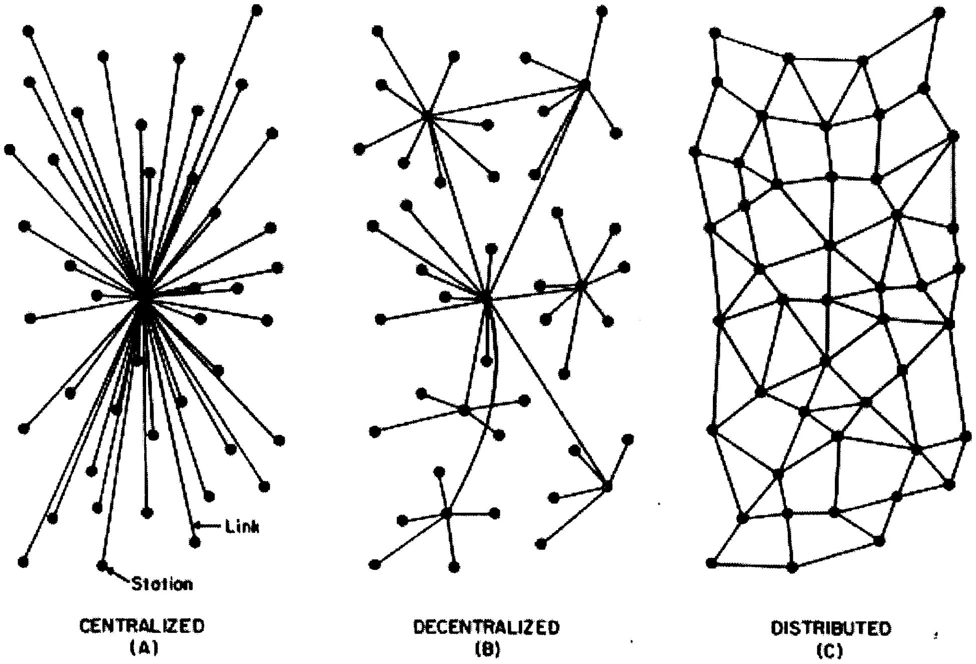
Figure 1.1
Telephone Traffic in Megalopolis, 1960



Source American Telephone and Telegraph Company

FIG. 179. *Courtesy of Neil C. Gustafson*

Figure 2.1
Network Topologies



CENTRALIZED
(A)

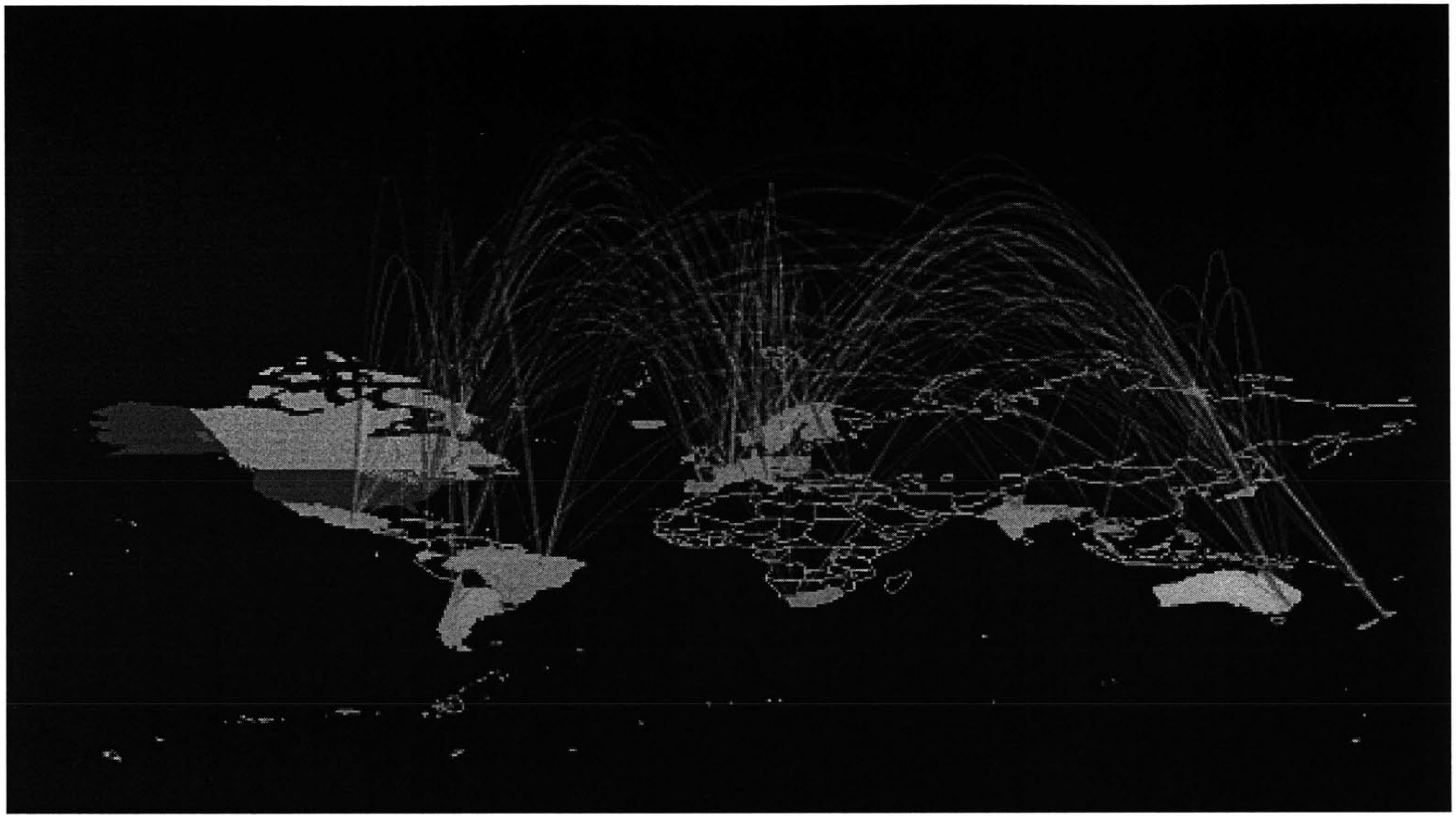
DECENTRALIZED
(B)

DISTRIBUTED
(C)

FIG. I — Centralized, Decentralized and Distributed Networks

Source: Baran, P. 1964. "On Distributed Communications: I. Introduction to Distributed Communications Network". Memorandum RM-3420-PR. (RAND Corporation, Santa Monica, California)

Figure 2.2
Visualization of International Internet Traffic, 1993



Source: Cox K C, Eick S, and He T. 1996. "3D Geographic Network Displays". Sigmod Record, 24:4:(Association for Computing Machinery)

Figure 2.3
Global Internet Infrastructure, 2000

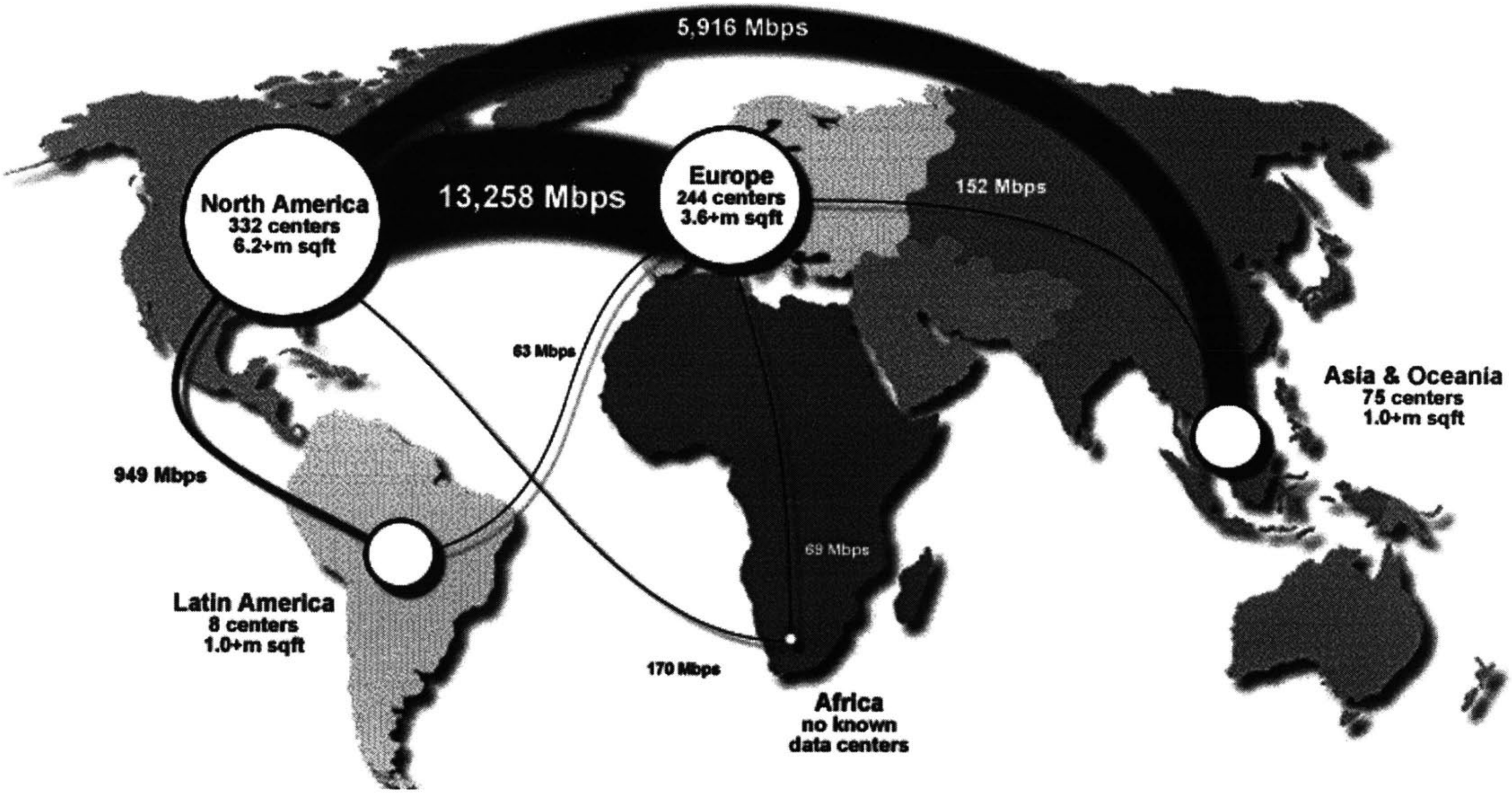
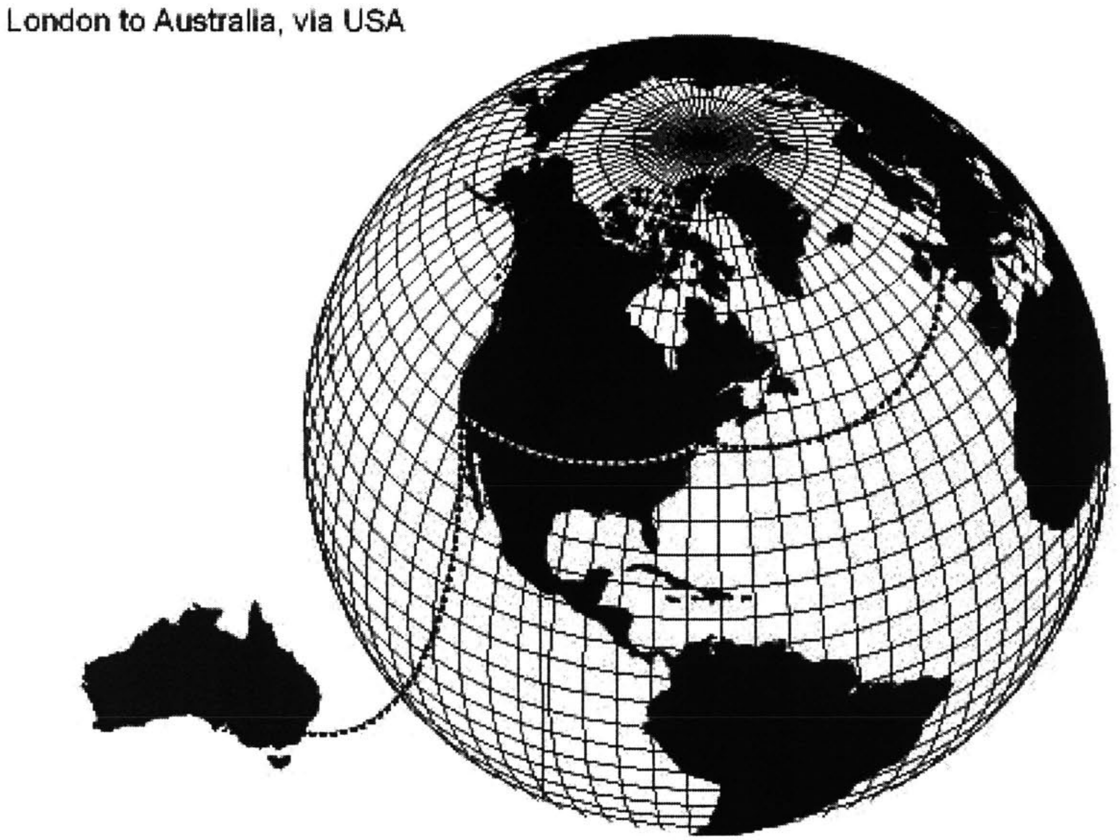
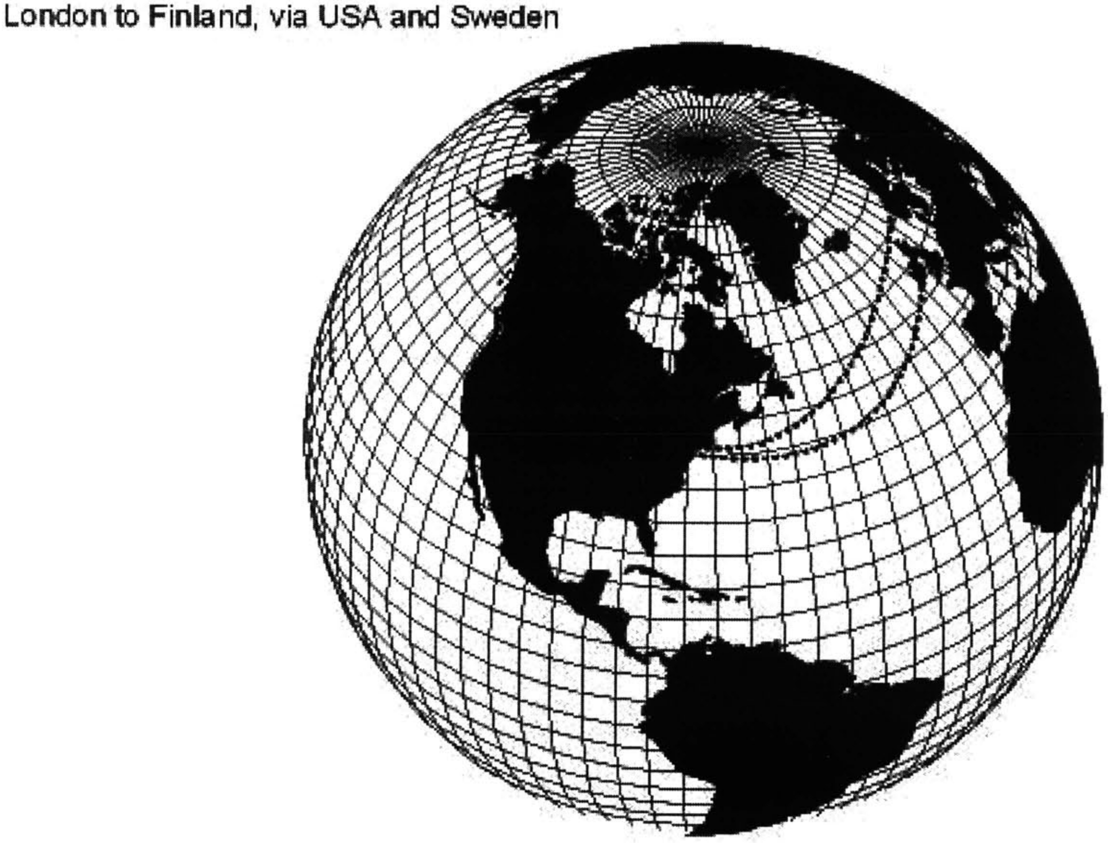


Figure 2.4
Traceroute between London and Australia



Source: Townsend A M. 2001. "Network Cities and the Global Structure of the Internet" American Behavioral Scientist.

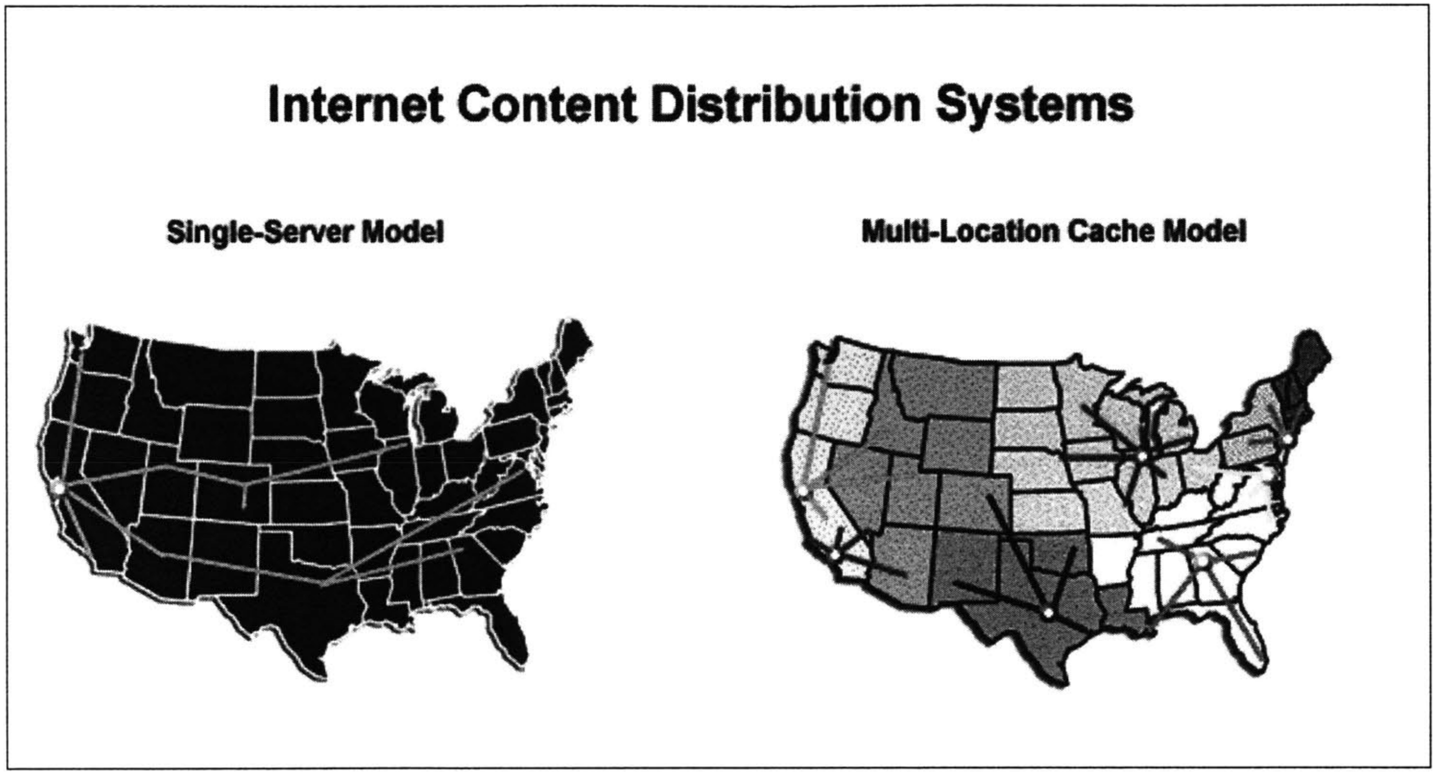
Figure 2.5
Traceroute between London and Helsinki



London to Finland, via USA and Sweden

Source: Townsend A M. 2001. "Network Cities and the Global Structure of the Internet" American Behavioral Scientist.

Figure 2.6
Content Distribution Network Topologies



Source: Anthony M. Townsend, Doctoral General Exam Response, December 2000.

Figure 3.1
General Motors' Futurama Exhibit at the 1939 World's Fair

Source: The History Project. University of California, Davis. [http://historyproject.ucdavis.edu/index.php]

Figure 3.2
U.S. Internet Backbone, 1997

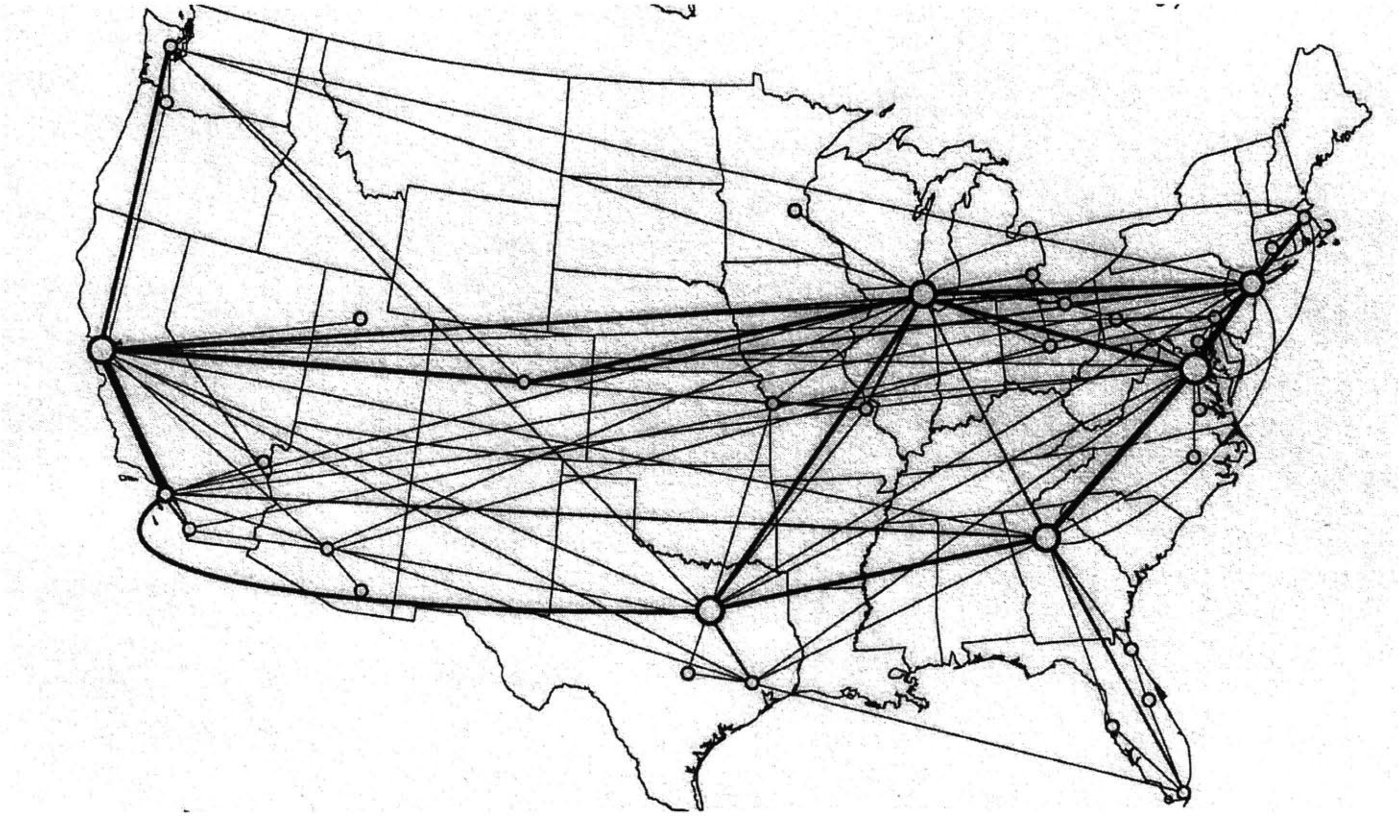


Figure 3.3
Internet Backbone, 1999

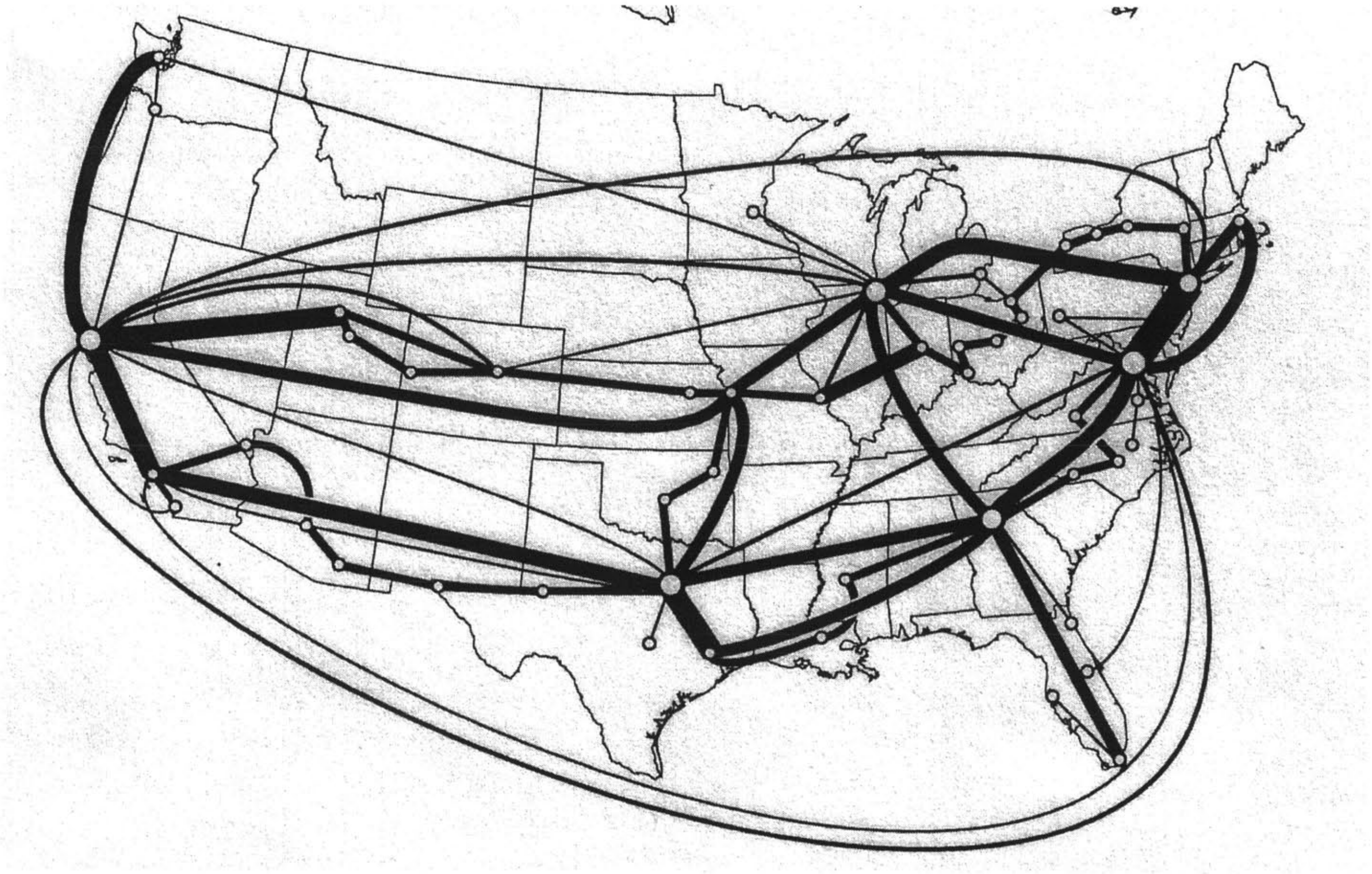


Figure 3.4
Rank-Size Distribution of Backbone Links

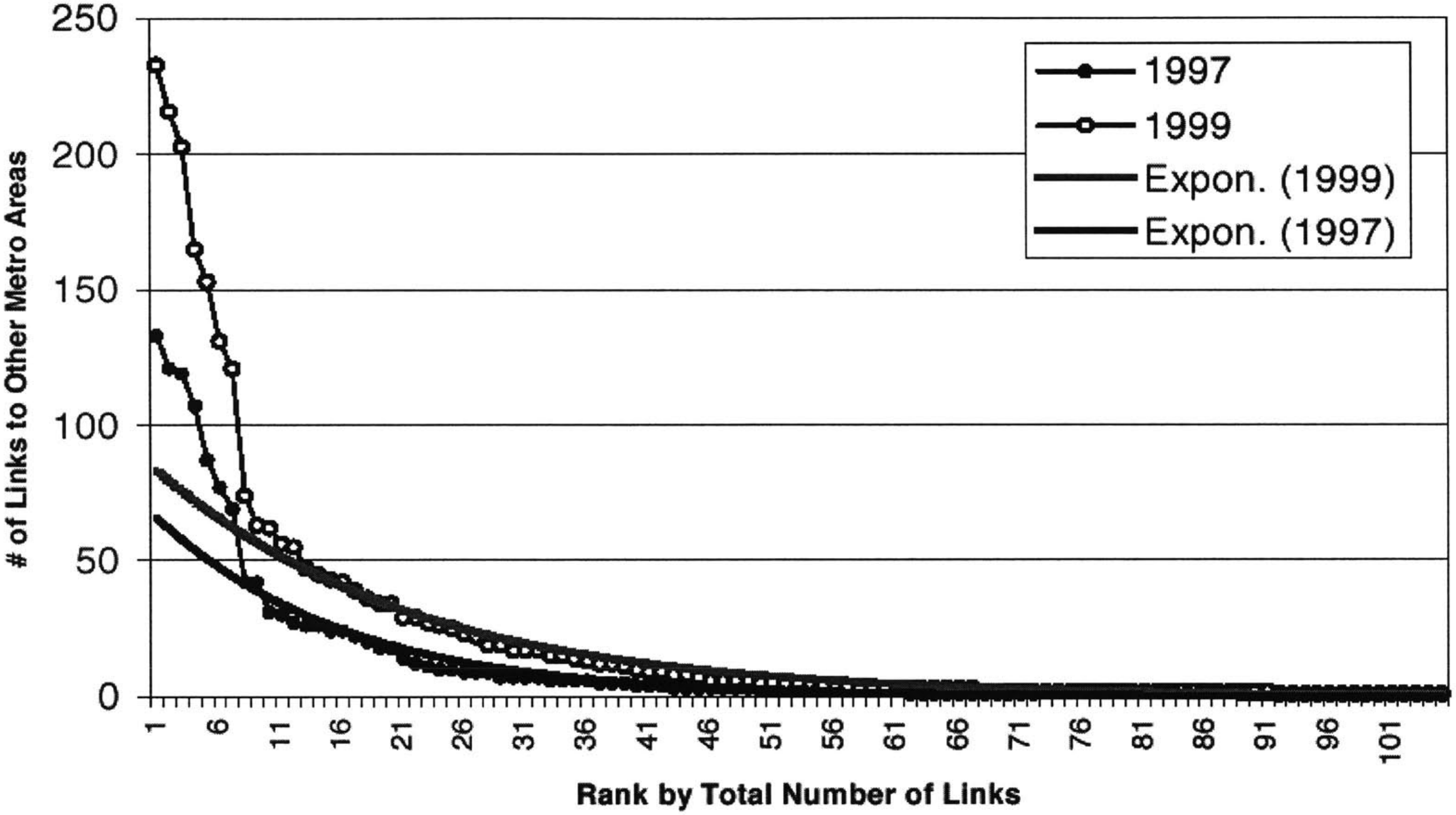
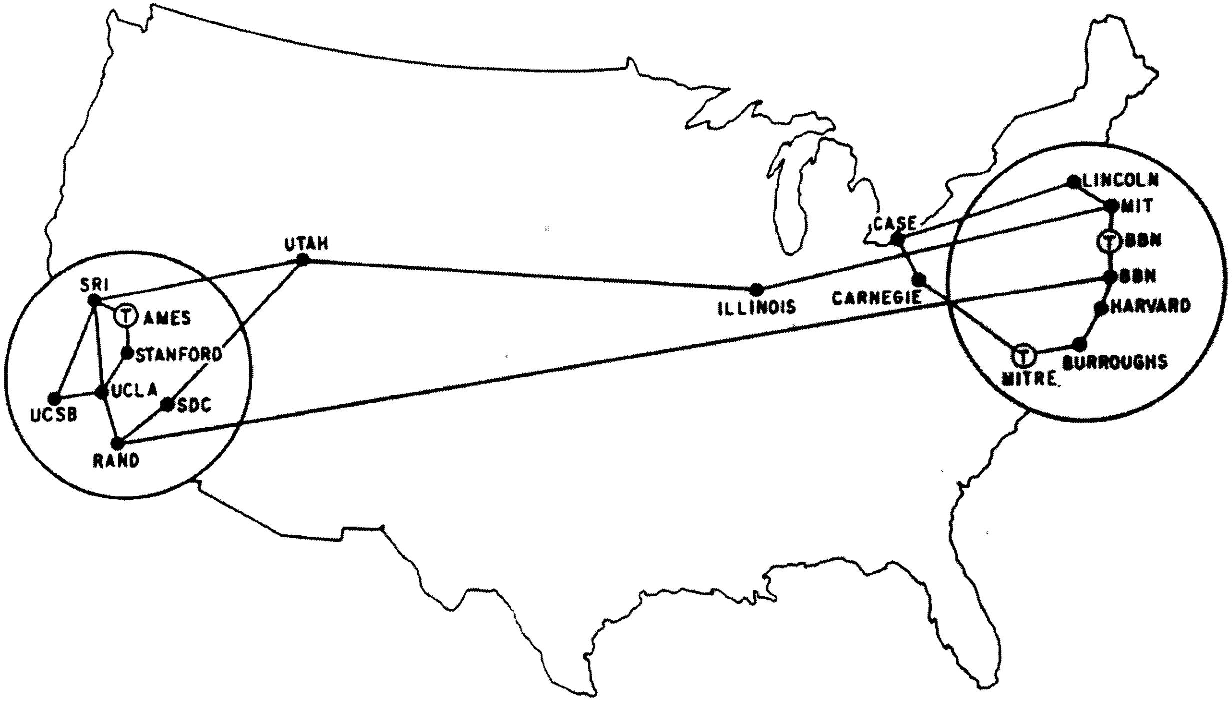


Figure 3.5
ARPANET, 1971

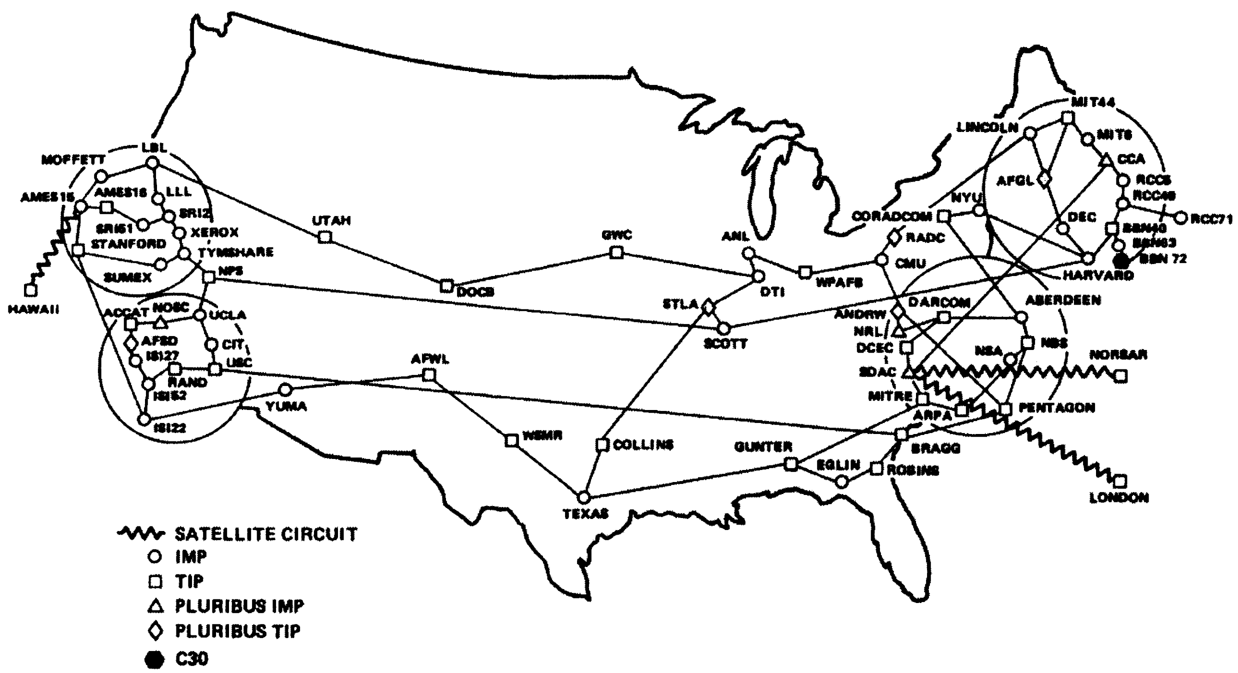


MAP 4 September 1971

Source: Peter Salus, "Casting the 'Net"

Figure 3.6
ARPANET, 1980

ARPANET GEOGRAPHIC MAP, OCTOBER 1980



(NOTE: THIS MAP DOES NOT SHOW ARPA'S EXPERIMENTAL SATELLITE CONNECTIONS)
NAMES SHOWN ARE IMP NAMES, NOT (NECESSARILY) HOST NAMES

Source: Peter Salus, "Casting the 'Net"

Figure 3.7
NSFNET T1 Backbone, 1989

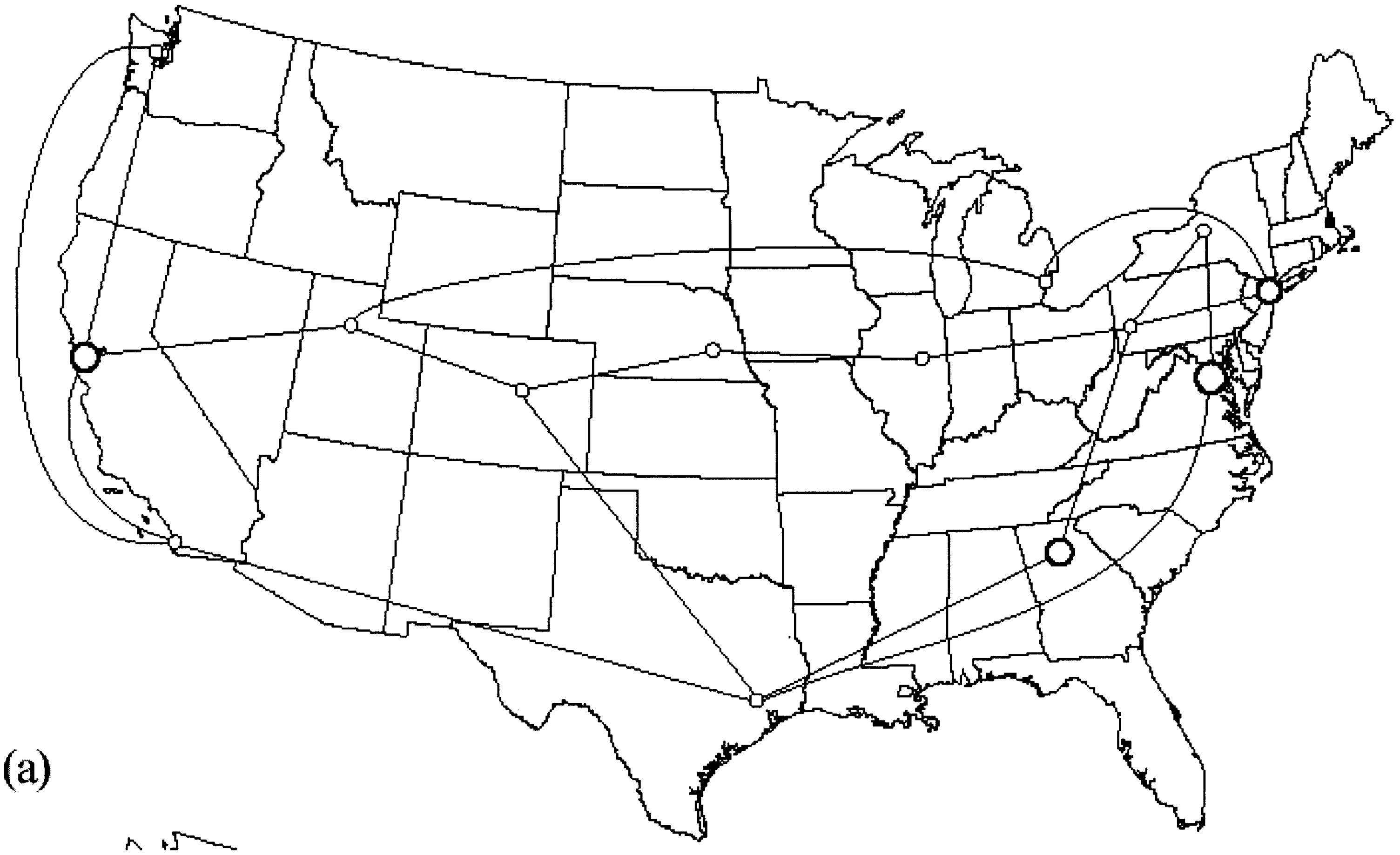
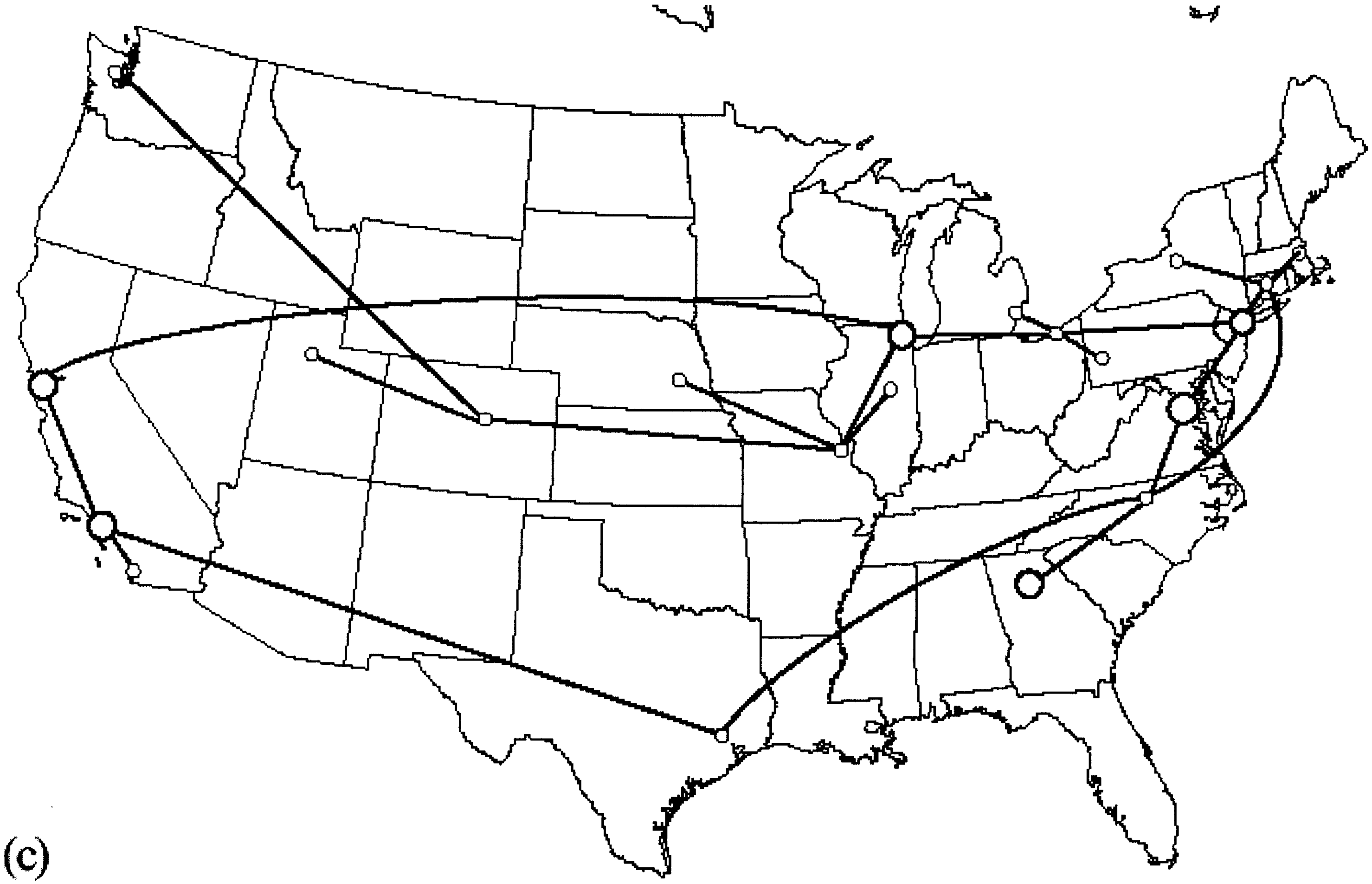
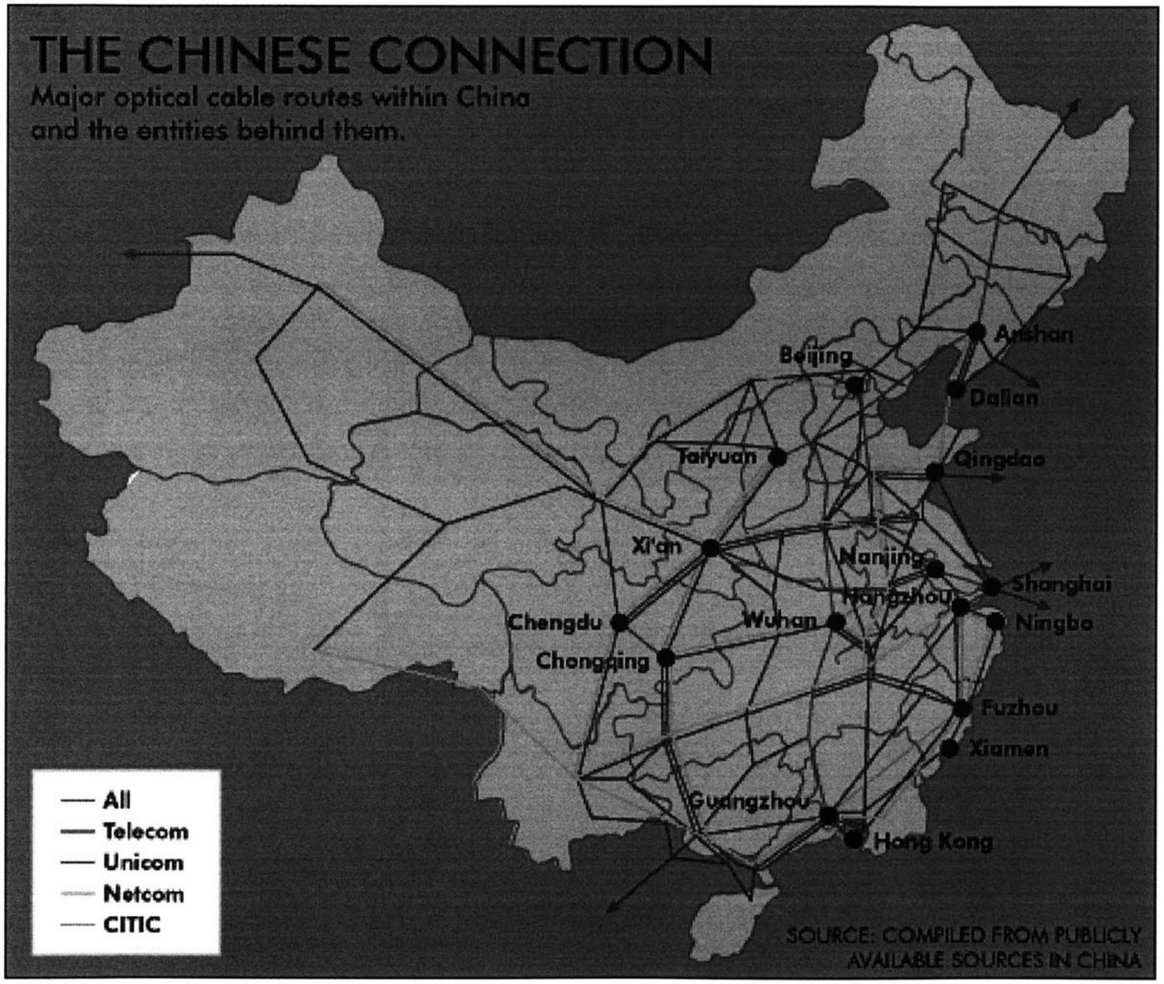


Figure 3.8
NSFNET T1 Backbone, 1991



(c)

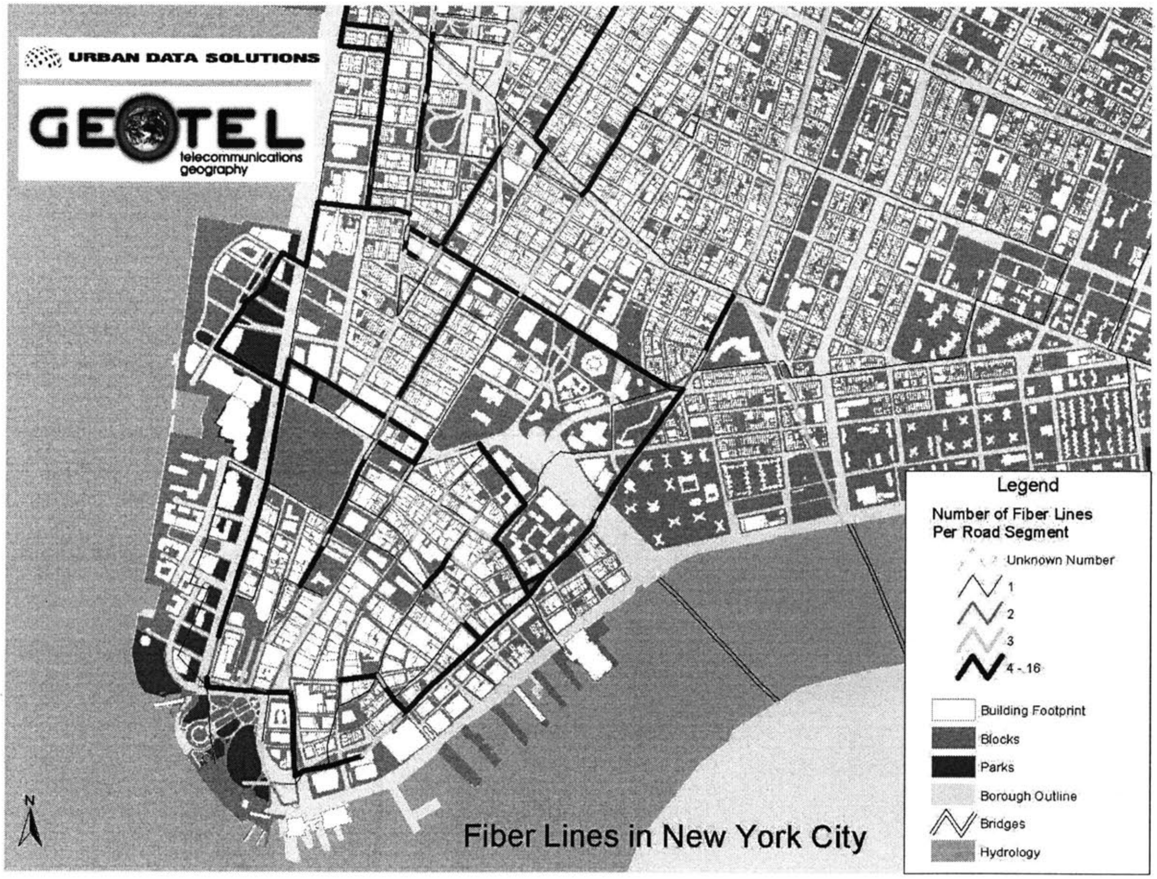
Figure 4.1
Long-Haul Fiber Optic Infrastructure in China



Source: Asiaweek

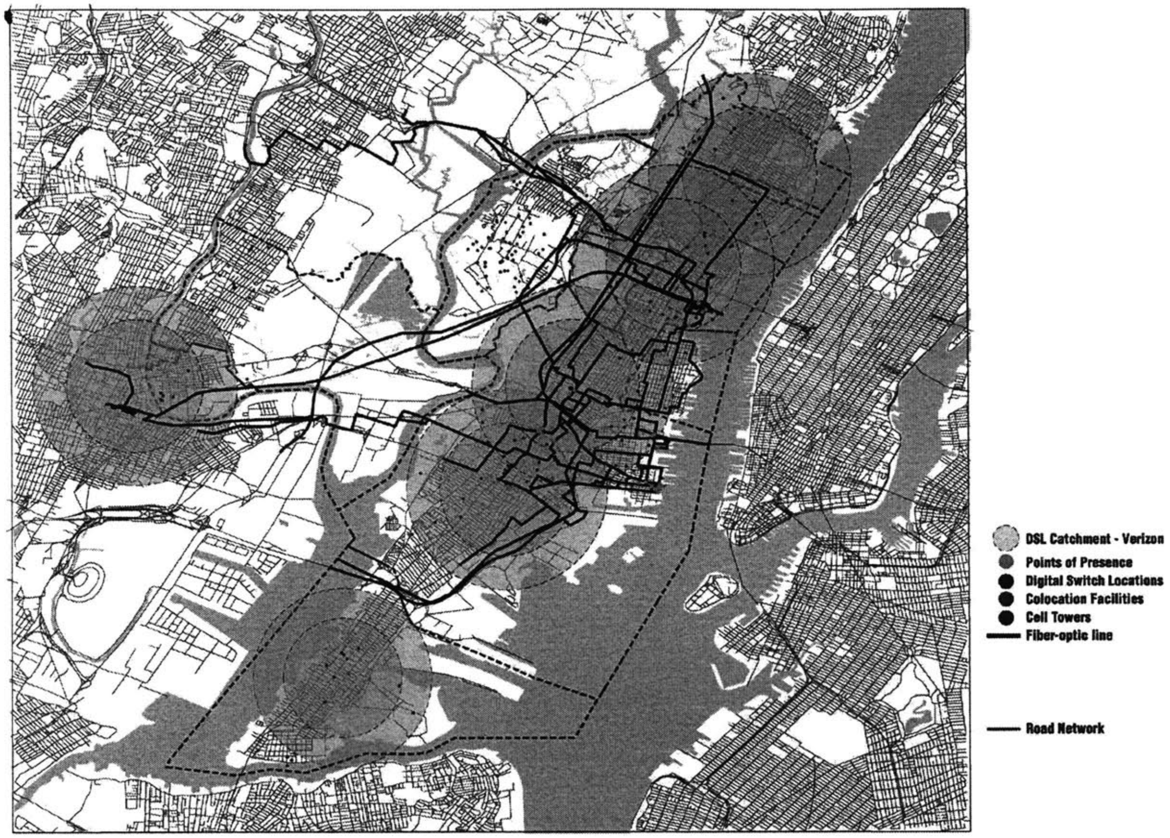
Figure 4.2
Fiber Optic Networks in Central Philadelphia

Figure 4.3
Fiber Optic Networks in Lower Manhattan



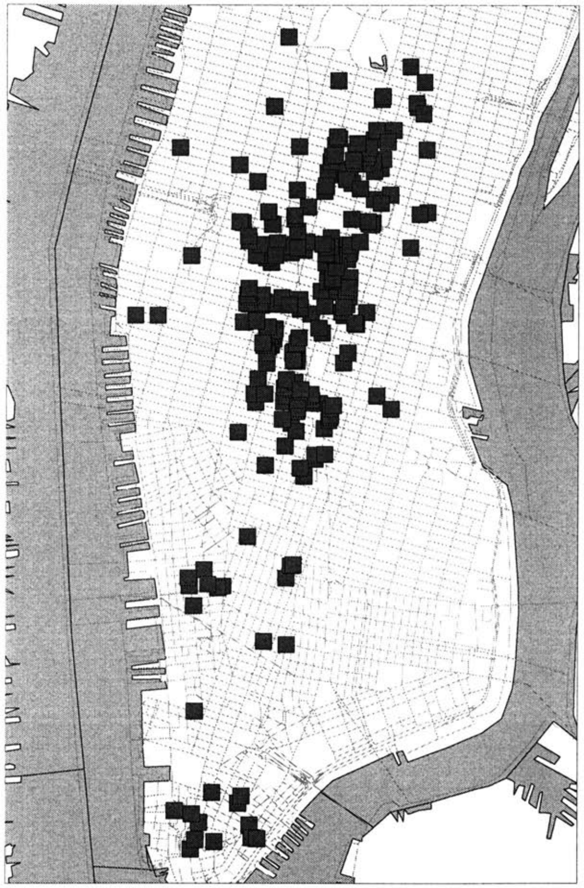
Source: GeoTel Communications, LLC

Figure 4.4
Fiber Optic Infrastructure in Hudson County, New Jersey



Source: Wallace, Roberts & Todd, Inc. Based on data provided by Geo-Tel Communications, LLC.

Figure 4.5
Office Buildings in Manhattan Wired by Intellispace

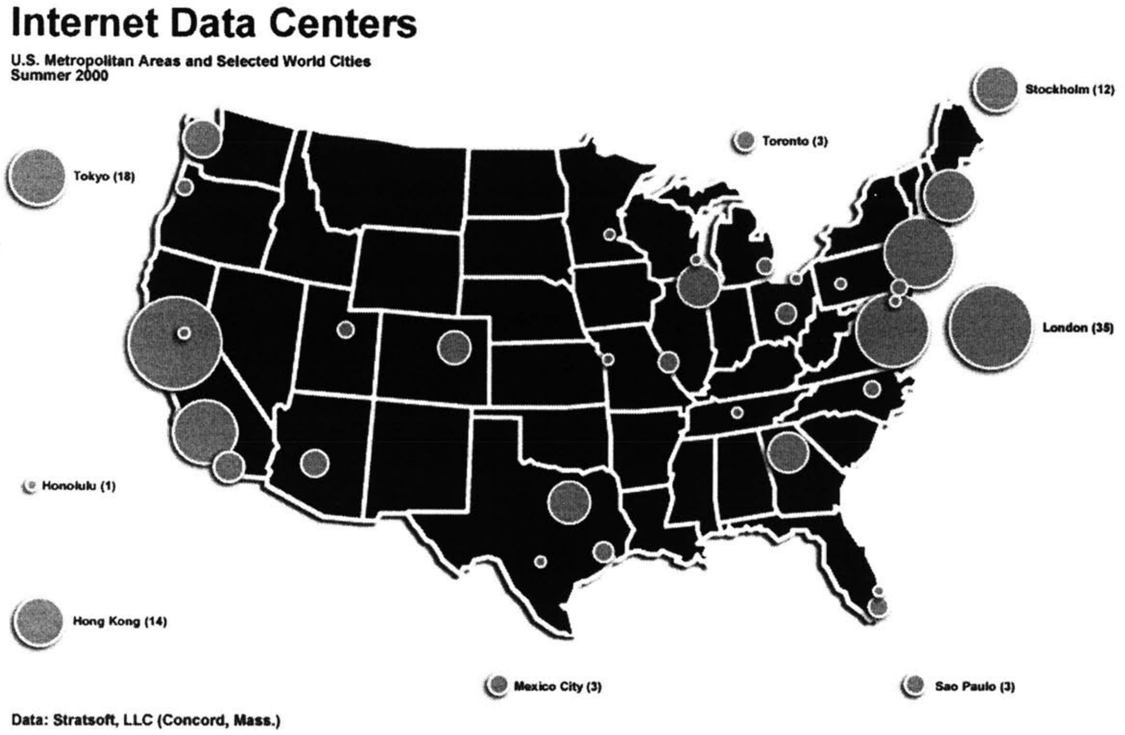


Source: Author's analysis of data provided by Intellispace.

Figure 4.6
Fiber Lit Buildings in New York City, by ZIP Code

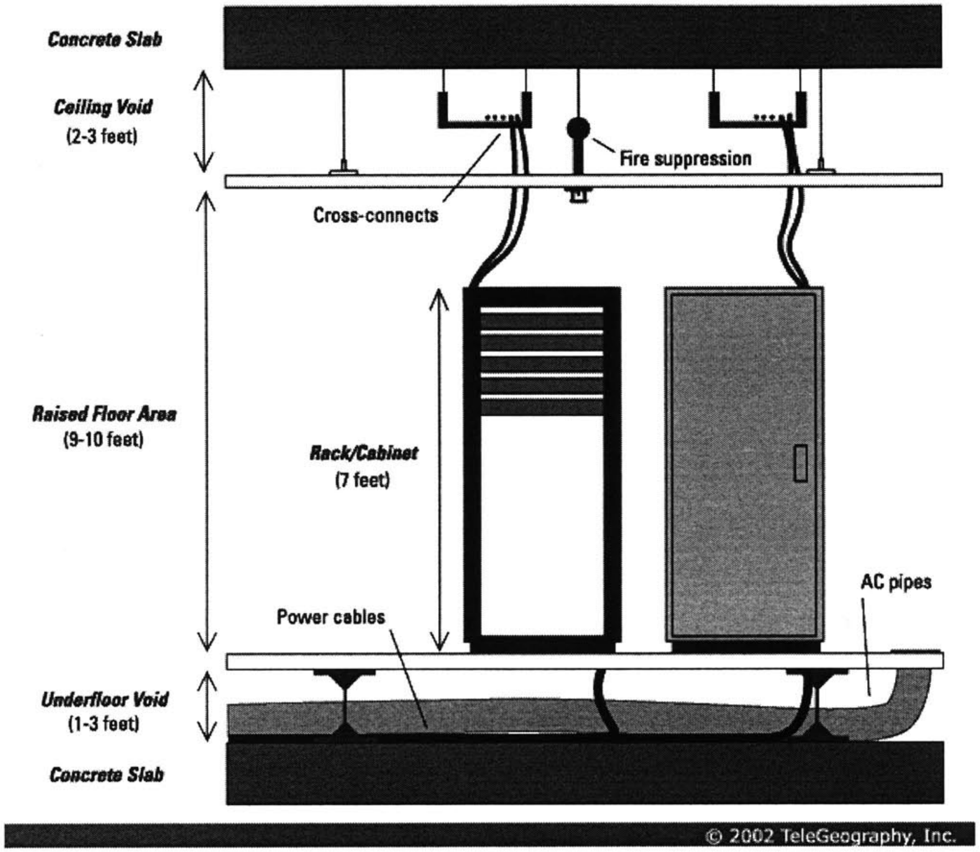
Source: Author's analysis of data provided by GeoTel Communications, LLC.

Figure 4.7
Information Warehouses by Metropolitan Area, 2000



Source: Author's analysis of data provided by Stratsoft, LCC

Figure 4.8
Cross-section of an Information Warehouse



Source: Telegeography, Inc. website [http://www.telegeography.com/resources/maps_and_schematics/bandwidth/co02_cross_section_colo.html]

Figure 4.9

The New Metropolitan Infrastructure

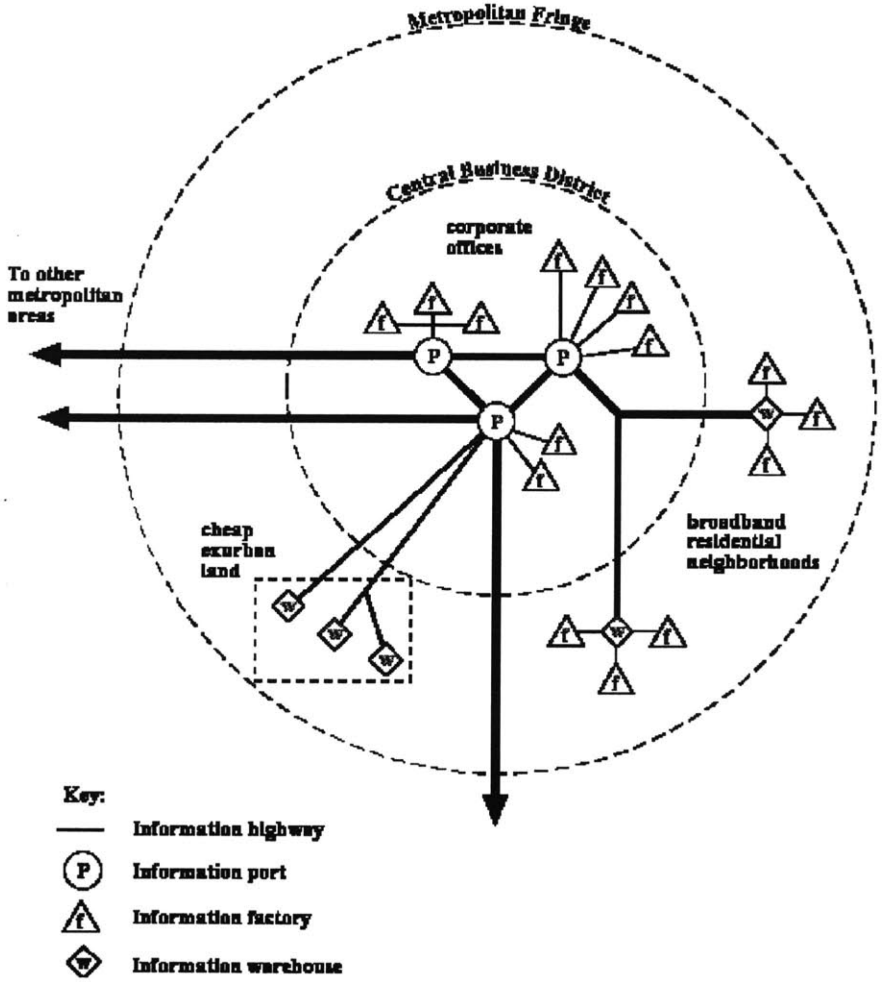
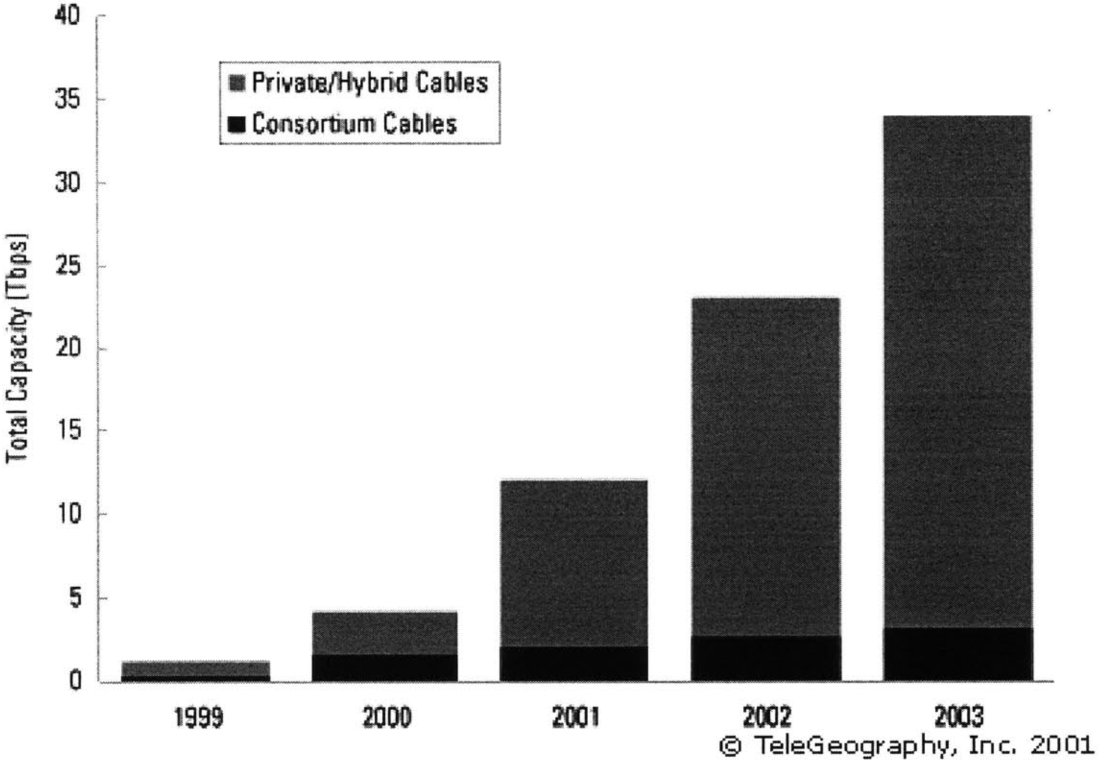
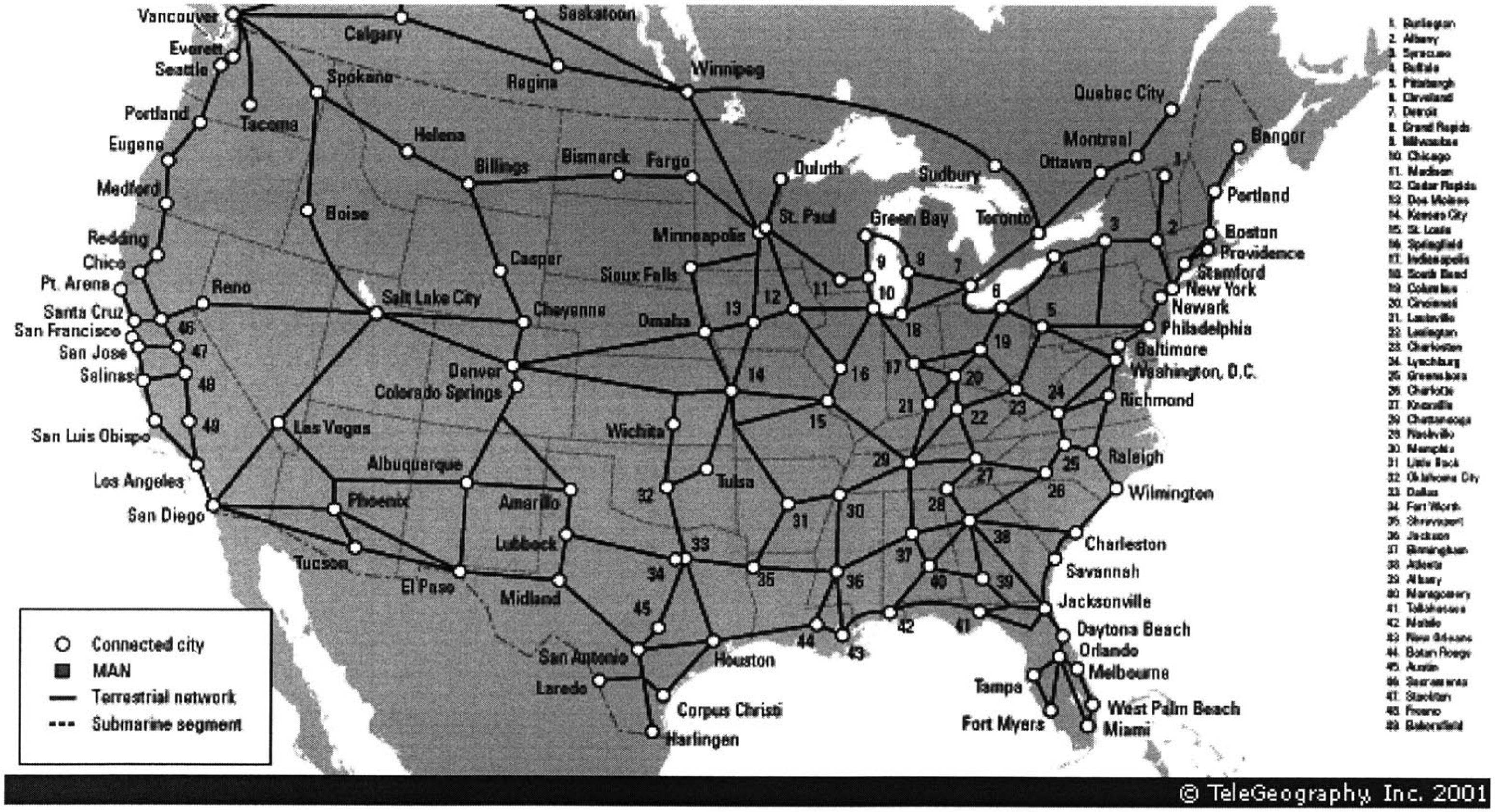


Figure 5.1
Ownership Structure of International Telecommunications Capacity, 1999-2003



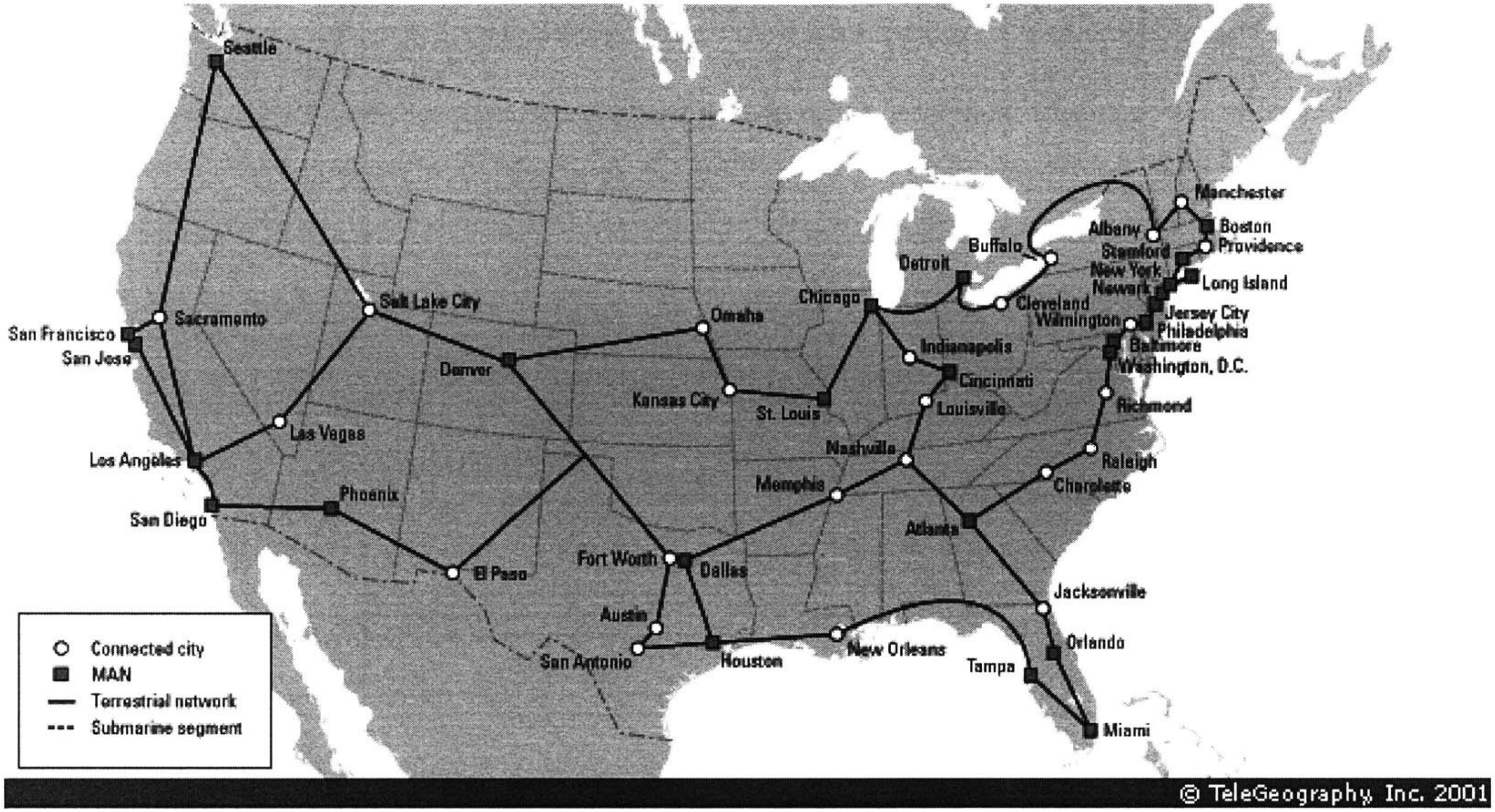
Source: Telegeography, International Bandwidth 2000.

Figure 5.2
AT&T National Fiber Grid



Source: International Bandwidth 2001, Telegeography (Washington, DC)

Figure 5.3
Level 3 National Fiber Grid



Source: International Bandwidth 2001, Telegeography (Washington, DC)

Figure 5.4
Metromedia Fiber Networks Manhattan Backbone

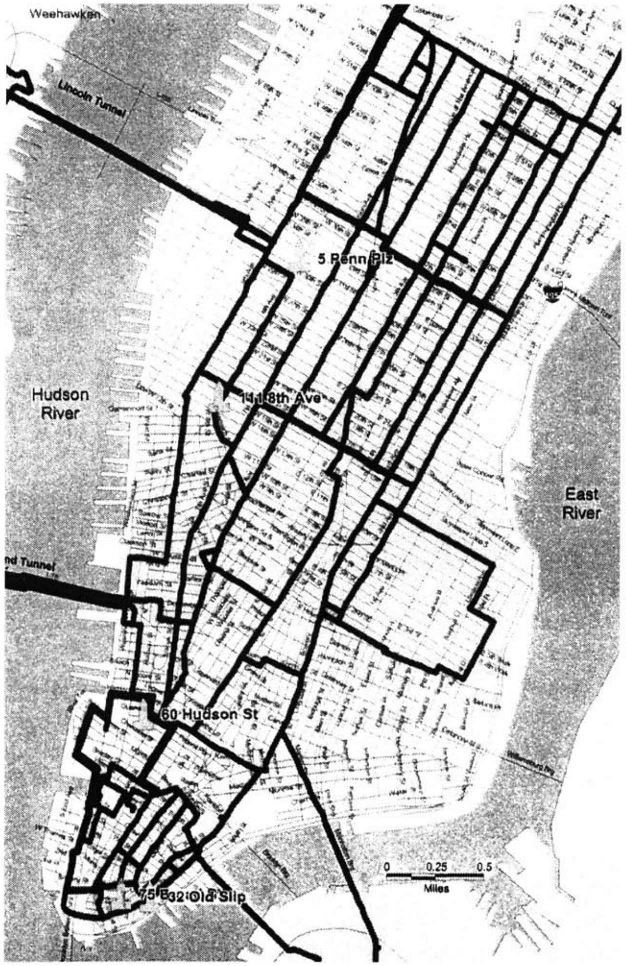


Figure 6.1
Cellular Grids

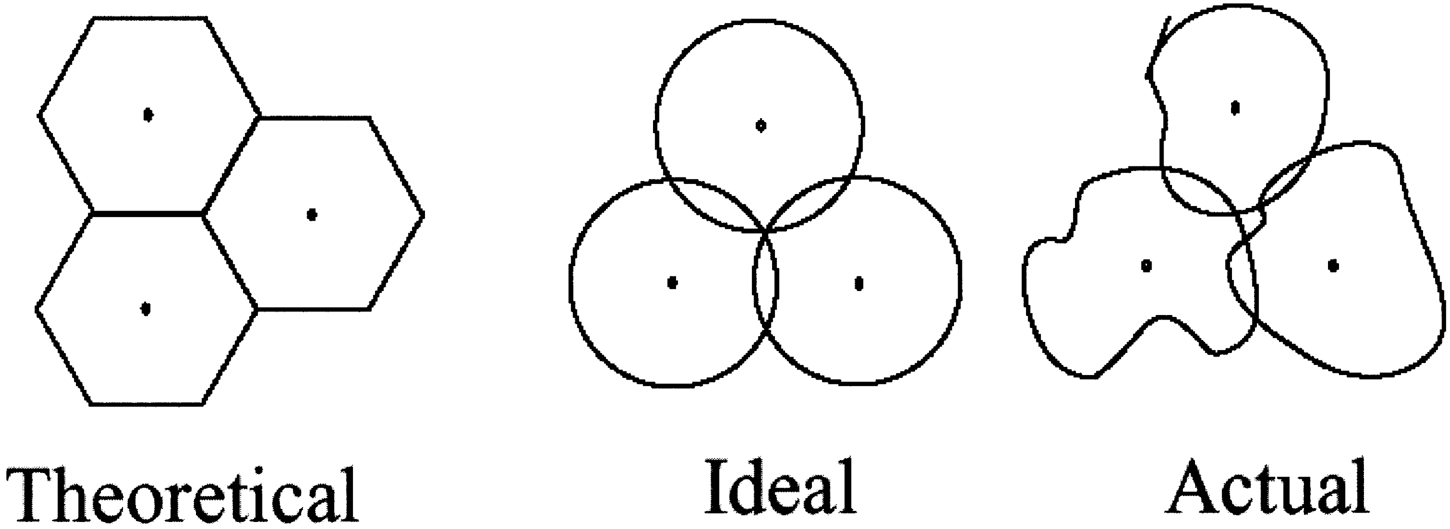


Figure 6.2 Growth of Wi-Fi Equipment Sales, 2000

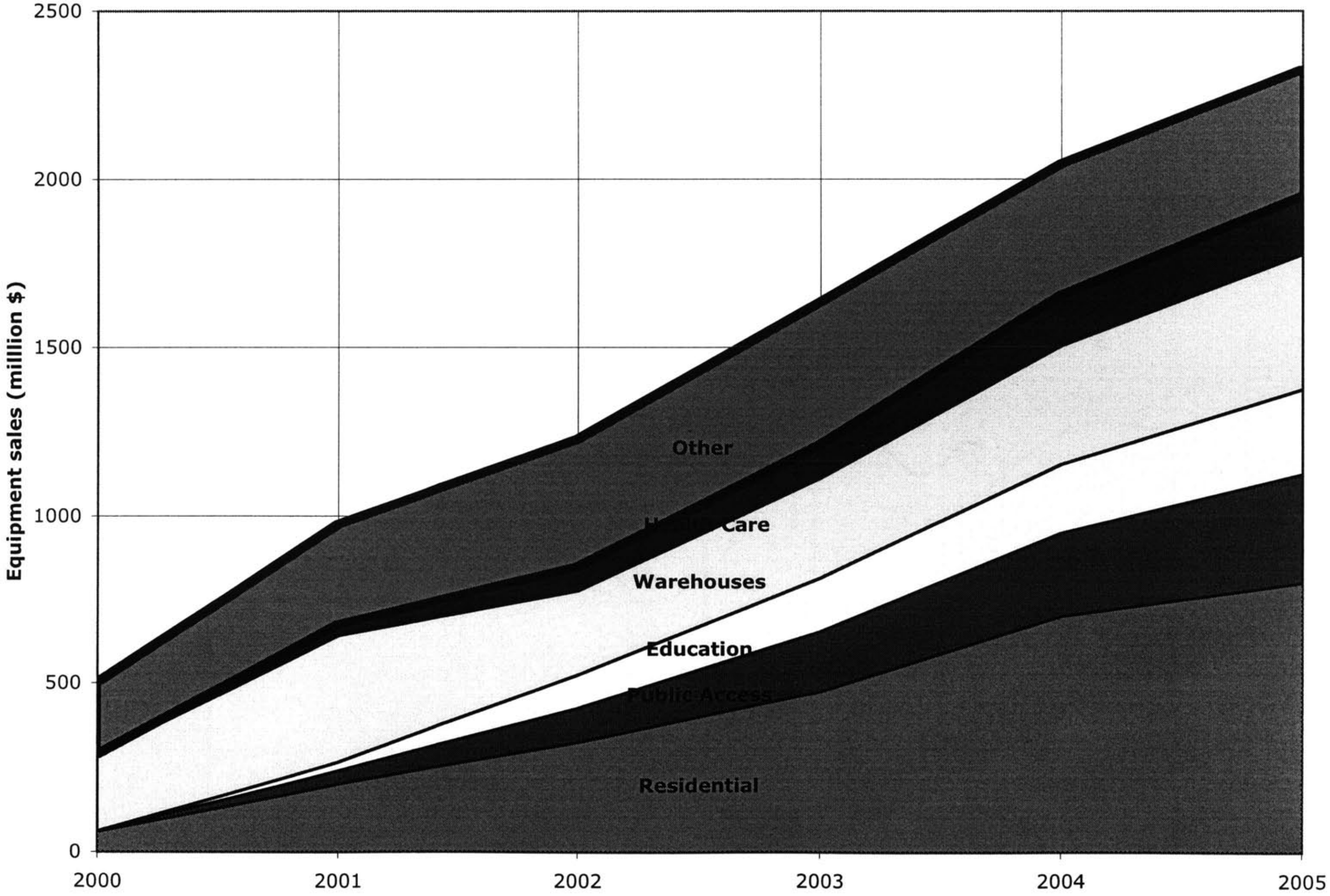
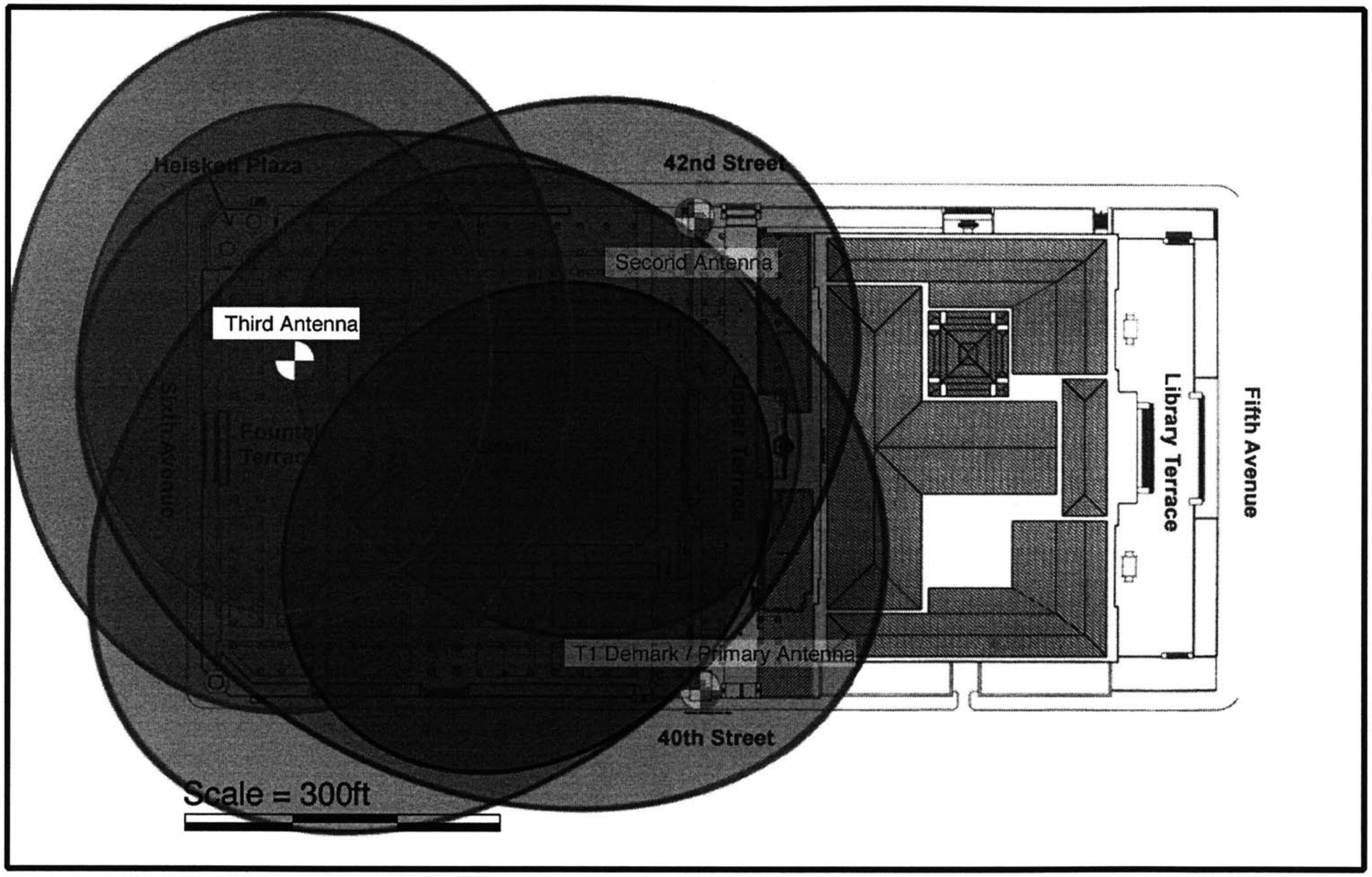
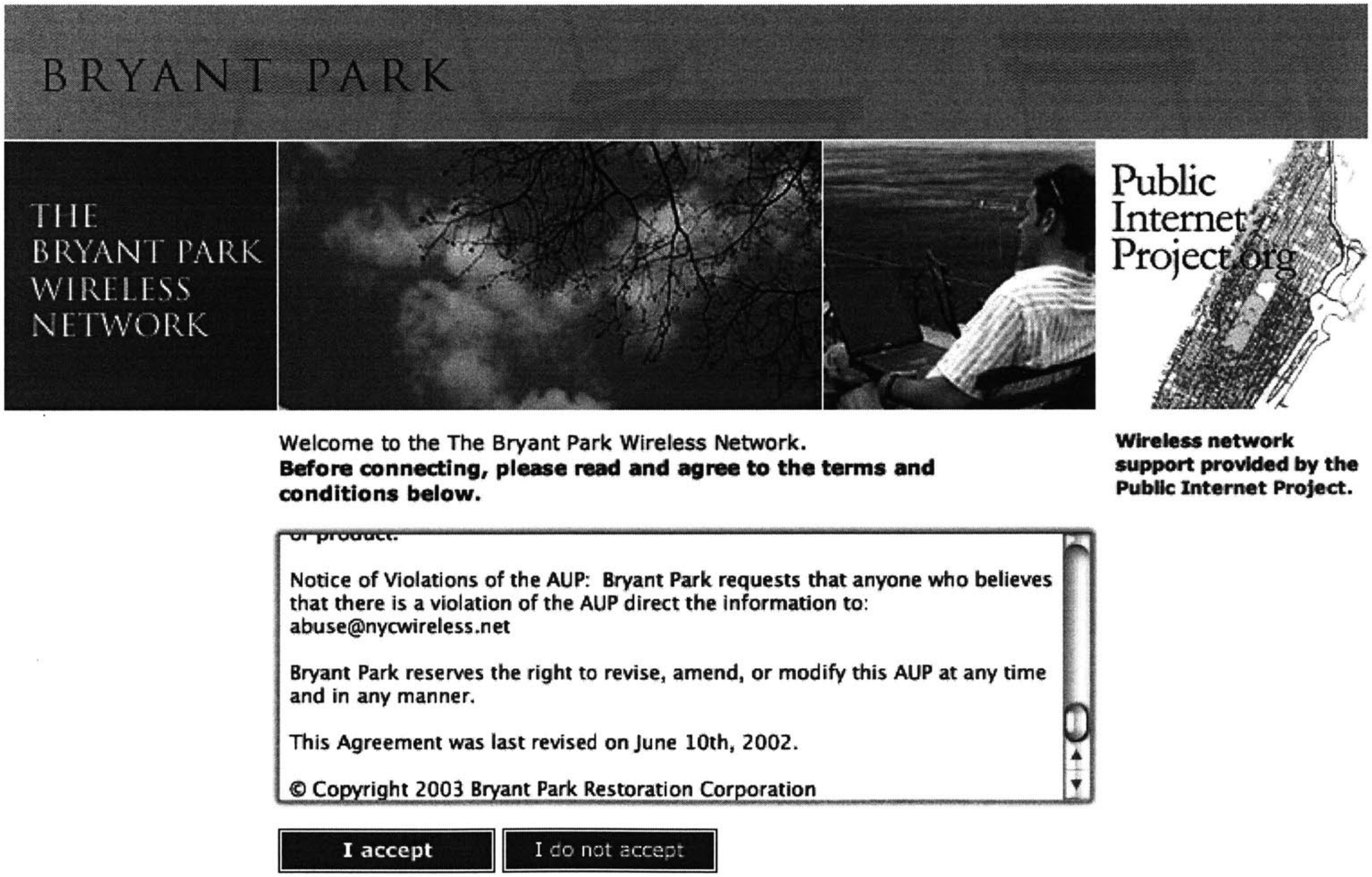


Figure 6.3
Bryant Park Wireless Network



Source: NYCwireless, Inc. Design by Marcos Lara

Figure 6.4
Bryant Park Splash Page



Welcome to the The Bryant Park Wireless Network.
Before connecting, please read and agree to the terms and conditions below.

Wireless network support provided by the Public Internet Project.

or product.

Notice of Violations of the AUP: Bryant Park requests that anyone who believes that there is a violation of the AUP direct the information to: abuse@nycwireless.net

Bryant Park reserves the right to revise, amend, or modify this AUP at any time and in any manner.

This Agreement was last revised on June 10th, 2002.

© Copyright 2003 Bryant Park Restoration Corporation

Source: NYCwireless, Inc.

Figure 6.5
Splash Page for South Street Seaport Wireless Network, Summer 2003

welcome to the Lower Manhattan Wireless Network

step out. log on.

Welcome to South Street Seaport and Lower Manhattan, the home of the world's first wireless business district!

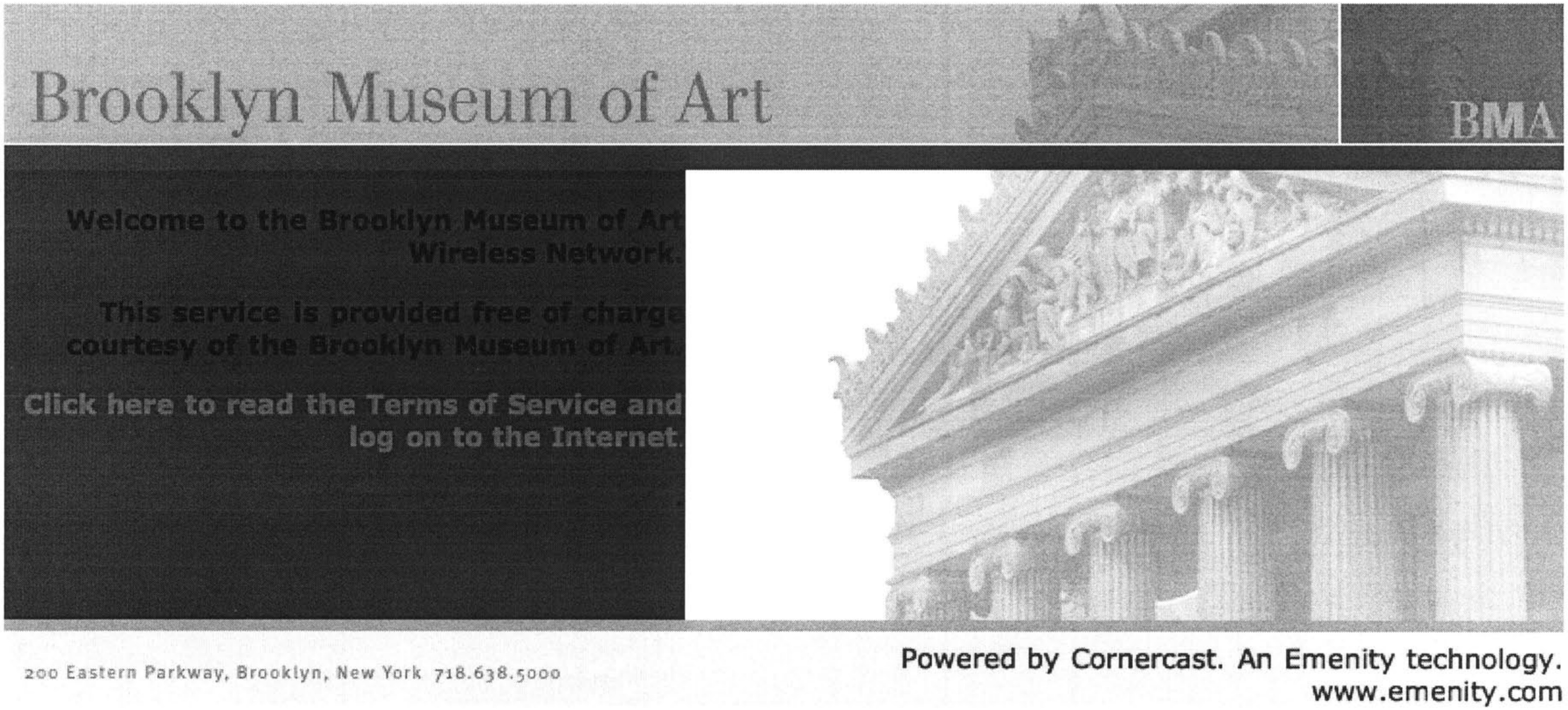
This wireless service is sponsored by the Allliance for Downtown New York, Inc. From here, you can access local content about Lower Manhattan or surf the Internet at broadband speeds.

Click here for important security information

© 2003, Emenity, Inc.

Source: Emenity

Figure 6.6
Brooklyn Museum of Art Wireless Network Splash Page, Summer 2003



Brooklyn Museum of Art

BMA

Welcome to the Brooklyn Museum of Art Wireless Network.

This service is provided free of charge courtesy of the Brooklyn Museum of Art.

Click here to read the Terms of Service and log on to the Internet.

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