Mapping the Geography of Cyberspace Using Telecommunications Infrastructure Information

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ABSTRACT

Cyberspace refers to the virtual world that is wired by high-speed telecommunications networks connecting people, computers and places. In has been well recognized that cyberspace is quite different from the physical world in the sense that traditional concepts of geography, such as 'nearby', 'distance', and 'connectivity', no longer apply. The relationship between cyberspace and the physical space is an important one and there is a real need to understand, map and deconstruct the complex spatiality of cyberspace. There has been lack of empirical and theoretical work that could derive formal properties of cyberspace. The paper presents a layered framework within which different views of cyberspace are discussed. The framework not only allows opposing views of cyberspace geography to coexist, but also suggest new territories that deserve extensive research. Important spatial properties of each layer are identified, and approaches for deriving those properties are proposed. In particular, the paper suggests spatial models that can be applied to telecommunications infrastructure data in order to understand the geographical distribution of the critical variables such as *network connectivity* and *access bandwidth*. Applications of the model are suggested in defining virtual communities and in evaluating the spatial effectiveness of telecommunications infrastructure.

1. Introduction

Recent advances in high capacity optical fiber, digital transmission and switching, wireless, and satellite technologies are believed to be the major driving forces for the ongoing information revolution (Hudson, 1997). The digitization of human interaction and social mediation through telecommunications have created a virtual space, *cyberspace*, that without doubt will have profound influences culturally, economically, and geographically. This paper takes a geographical perspective to the cyberspatial technology and attempts to map out the spatial structure of cyberspace using geographical information systems (GIS) and associated spatial analysis techniques (Burrough, 1986; Laurini and Thompson, 1992; Worboy, 1995).

When GIS is applied to the analysis and modeling of telecommunications phenomena, it is natural to ask what are the relevant geographical properties of cyberspace that need to be mapped. While cyberspace undoubtedly has geographical implications, some geographers have argued that cyberspace technologies is transforming space-time relations and creating new social spaces that lack the formal qualities of geographic space (Kitchin, 1998; Adams and Warf, 1997).

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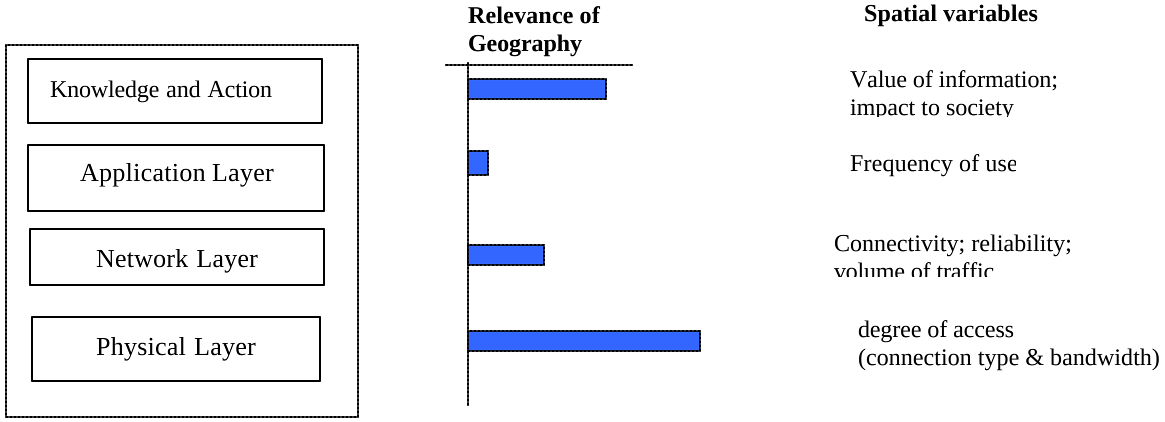
In contesting the nature of cyberspace, there seems to be two opposing positions. The first position argues that the whole notion of geographical space is destroyed and geographic location is not relevant at any scales. For example, Mitchell (1995) made a statement that "cyberspace is profoundly anti-spatial – the Internet is ambient ... nowhere in particular but everywhere at once". The collapse of space-time relationships and the removal of spatial separation have led to radical space-time compression (Harvey, 1989). A person can log on to the Internet from where he or she happens to be and then it becomes timeless and spaceless to reach any sites on the Web. We are turned into nomads who are always in touch (Benedikt, 1991). There is no need to identify geographical locations of participating parties involved in any virtual interaction. The 'spaceless, placesless' social spaces of interaction removes the need for geocoding.



(a) (b) (c)

Figure 1. A framework for understanding cyberspace geography

In contrast to the radical position which consider cyberspace to be 'placeless' or 'anti-spatial', others suggest that space and locations continue to play important roles in understanding cyberspace phenomena. Kitchin (1998) presented three major reasons in support of this position.

1. The degree of access to telecommunications services is unequally distributed in the geographical space. The degree of access is measured in terms of connections and bandwidth (how fast a communication connection is).
2. The usefulness of the communicated information differs from locale and depends on who and where the information is received.
3. The operation of cyberspace depends on real-world spatial fixity such as access points and physical wires that are embedded in the geographical space. Even wireless systems are dependent on the spatial distribution of receivers and transmitters.

Among all the components of information technology, telecommunications infrastructure exhibits the strongest ties to geography. The infrastructure elements are carefully located to reach geographically distributed customers as much as possible. They tend to persist in their location for long period of time, and all the service provision and consumption activities are organized around these infrastructure.

This paper takes the position that cyberspace has a multi-layered organization, with each layer showing different type of spatiality (See Figure 1). Four layers can be identified that have distinct geographical properties: physical layer, network layer, application layer, and knowledge and action layer. In understanding the relative importance of geography in the study of each layer, the bar graph on Figure 1b is helpful. In such a framework, the above arguments are no longer contradictory since they deal with the spatial properties of cyberspace in different layers.

At the physical layer, the distribution of telecommunications infrastructure and the concentration of service providers are highly biased in geography. This results in spatial variations in the types of available services and access bandwidth. At the network layer, a set of locations can be minimally connected or maximally connected, depending on the reliability requirements and traffic characteristics. Application layer is the least sensitive to geographical locations, since it doesn't matter where one logs in to run a network application. This is where the 'spaceless' position holds most of its truth. The 'knowledge and action' layer refers to the fact that information exchanged in the virtual space needs to be integrated into the user's knowledge or to induce some real-world actions which generate different local effects.

Most of the existing studies about the geography of cyberspace have been focused on the top layer. For example, the geography of information economy is concerned with the restructuring of the economic landscape in response to development of telecommunications technologies (Warf, 1995; Castells, 1996; Kitchin, 1997). Social geographies of cyberspace have asked many geographical questions relating to community, democracy, privacy, access and exclusion (Jones, 1995; Schuler, 1995). On the other hand, there has been lack of empirical and theoretical work that could derive formal properties of cyberspace in the physical and network layers.

This paper will present some formal GIS approaches to the study of cyberspace geography at physical and network. In the physical layer, the bandwidth of access is mapped as a surface from telecommunications infrastructure information using a spatial model that combines '*proximity*' and '*distance decay*' transformations. In modeling customer's proximity to the nearest infrastructure elements, Voronoi diagram algorithms is used to define the ultimate region of influence of each infrastructure element. The distance decay effects of metallic pair access technologies is modeled by the buffering transformation that is a commonly available GIS tool. The result can be directly applied to practical problems such as discovering gaps of infrastructure in a region (also called 'gap analysis') and detecting significant bias in the distribution of infrastructure elements. In the network layer level, we suggest using a family of planner graph models (nearest neighbor graph, minimum spanning tree, relative neighbor graph, Gabriel graph, and Delaunay triangulation) for the study of fiber connectivity pattern among a set of locations (section 4). Finally, an agenda for future research is outlined.

2. Preliminary Discussion

2.1 Telecommunications Infrastructure

Telecommunications networks, which provides access, transport, switching, and signaling functions for the process of information exchange, is the core component of modern technology infrastructure. We make distinctions between infrastructure facilities and non-infrastructure facilities in telecommunications networks. The term "*telecommunications infrastructure*", or "TI" for brevity, is used here to refer to those elements of telecommunications systems that are *highly shared*, *carrying high volume telecommunications traffic, and, in most cases, spanning large geographical distance*. Examples of telephone company's infrastructure include LEC's inter-office networks, IXC's backbone networks, and their switching equipment. In contrast, non-infrastructural network elements refer to facilities that are not shared and that are usually local extensions or value-added customizations of the infrastructure elements. According to this definition, all the local loop circuits, whether they are plain telephone lines, advanced DSL lines, or even fiber loops, are all non-infrastructure elements because they are not publicly shared.

Because of their shared nature, telecommunications infrastructure components can achieve enough economy-of-scale so that they are always equipped with the most advanced technology, and have almost unlimited capacity. Technology innovations, such as scalable design and Wavelength Division Multiplexing (WDM), have made it easy for a digital, fiber based infrastructure to meet the growing demand for high capacity without significant expansion or reconfiguration. For example, many circuits can be multiplexed onto the same fiber depending on the terminals and repeater technologies used. Therefore, by changing the terminal and repeater technology, a carrier can significantly increase its capacity without installing new fiber due to increased optical channels at different wavelengths. In some cases, carriers have deployed newer fiber called "dispersion shift fiber" to support multiple wave length technologies.

As telecommunications networks become totally digital, it is now possible that a *single digital telecommunications infrastructure* can serve many diverse sets of information services that were traditionally served by separate data, voice, and video networks. Modern telecommunications network shows a clear trend towards an all-fiber, all-digital infrastructure. In the meantime, networks of different types and owners are increasingly interconnected and integrated to expand their geographic reach. Based on such observations, these have been visions of information infrastructure in global, national, local and enterprise levels (Targowski, 1997). Unlike traditional infrastructures which are public utility offering a limited and monopolistic service and operating in a stable market structure, the new telecommunications industry is able to provide a host of different services and products, and operate in a highly competitive market system (Vogelsang and Mitchell, 1997).

We will limit our discussion to two types of infrastructure elements, wire centers and fiber routes, although there are many other types of infrastructure related to microwave, wireless, and satellite communications technology. Wire centers are places where digital switches are hosted, and they are major access points for subscriber loops and interconnection points among facilities of different companies. Optical fiber has penetrated both in the backbone, access and local area network where it replaces classical coaxial cable or twisted pair networks. Due to its unlimited bandwidth, its immunity against electromagnetic interference, its very low losses (below 0.5 dB/km) it became the preferred transmission medium for long distance or high bit-rate connections.

2.2. Twisted Pair Based Loop Technologies

It is becoming increasingly clear that telephone companies are going to utilize existing twisted-pair loops in their next generation broadband access networks (http://www.adsl.com/adsl_tutorial.html). This is largely due to the technology advance in high bandwidth modem systems which are able to convert twisted pair telephone lines into access paths for multimedia and high-speed data communications. Horak (1997) provided a discussion of a group of advanced twisted pair local loop technologies in terms of bandwidth and distance limitations. Among these access technologies, *Asymmetric Digital Subscriber Line* (ADSL) and its variants, Very high rate Digital Subscriber Line (VDSL), are believed to be the most viable broadband solution to most customers. An ADSL circuit connects an ADSL modem on each end of a twisted-pair cable, creating three information channels: a high- speed downstream channel, a medium speed duplex channel, and a voice channel. It depends upon advanced digital signal processing and creative algorithms to squeeze as much information as possible through twisted pair wires. It is a repeaterless technology, which means that no significant reengineering work is needed to install ADSL service on an existing twisted pair loop. VDSL employs essentially the same set of techniques as ADSL, but is designed to deliver much higher bandwidth over shorter distance. The variations of ADSL/VDSL can be considered as a continuum, a set of transmission tools that delivers about as much data as theoretically possible over varying distance of twisted-pair telephone wires. Table 1 provides a summary of various data rates available on a 24 gauge twisted pair wire. The relationship between access bandwidth and distance to the serving wire center is shown in Figure 2.

Signal Level	**Data Rate**	**Serving distance**
DS1 (T1)	1.544 Mbps	5.5 km (18000 feet)
E1	2.048 Mbps	4.9 km (16000 feet)
DS2	6.312 Mbps	3.6 km (12000 feet)
E2	8.448 Mbps	2.7 km (9000 feet)
¼ STS-1	12.96 Mbps	1.4 km (4500 feet)
½ STS-1	25.92 Mbps	0.9 km (3000 feet)
STS-1	51.840 Mbps	0.3 km (1000 feet)

Table 1. Practical limits on data rate in relation to cable length (assuming 24 gauge twisted pair wire)

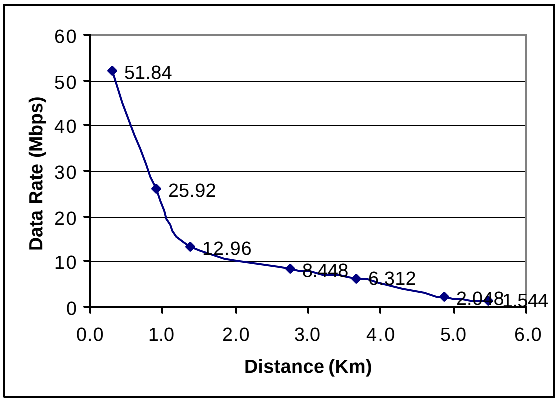


Figure 2. Access bandwidth as a function of cable length (Assuming 24 gauge twisted pair wire)

3. Mapping the Geography of Access

The inequality of access to advanced telecommunications services is well recognized in the literature (Thomas, 1995). Such inequality can be attributed to the geographically biased distribution of telecommunications infrastructure and the biased distribution of service providers. But, future telecommunications market will be based on facility-based competition model, hence the factor of service providers will fade out. For such reasons, telecommunications infrastructure will be the primary determinant of the geography of access. In the same time, the capability of the infrastructure in a region will be better understood if it is translated into the magnitude of communication bandwidth that the infrastructure could provide to each location in the region.

3.1. Assumptions

In order to establish a quantitative relationship between the distribution of telecommunications infrastructure and the geographical variation of access, we make the following assumptions:

(1). *Facility-based market competition*.

Market competition among different service providers will be totally based on the quality and spatial reach of their facility. Recent regulatory changes, as indicated by the Telecommunications Act of 1996 (TA96, 1996) have moved telecommunications market towards true competition, and the service barriers like price distortion, lack of profit, and service boundaries are likely to be removed totally.

(2). *The capacity of infrastructure elements can be considered as no-limit.*

With the scalable design and multiplexing technologies, the capacity of the existing digital switches and fiber circuits can be increased to meet the growing demands without significant reconfiguration.

(3). *Majority of the access circuits will remain to be twisted pair metallic cables within the near future*.

These assumptions allow us to model the geography of access based solely on spatial information about wire centers and fiber optic cables in a region. The assumption (1) means that the access bandwidth of a location is dependent only on its distance to the nearest infrastructure elements. The assumption (2) makes the case that we do not need to know the capacity of individual infrastructure elements as long as we know that they are digital switches and fiber cables. The assumption (3) implies that the access bandwidth of a location is constrained by the electrical characteristics of twisted pair metallic wires. In general, longer wires will induce more signal impairment, and hence less effective bandwidth available in the communication channels.

3.2. The Model of Access

Based on the assumptions we have made, we propose a model that will derive the access bandwidth of every location in a region that is served by a set of wire centers and a set of fiber optic cables. The model is based on nearest neighbor and distance decay principles and is fully implementable in GIS systems. In order to given a formal description of the model, the following notations is defined

R: a region representing the study area.

WC: a set of points within R, representing the location of wire centers serving that region.

FO: a set of line segments within R, representing the location of optical fiber cables.

C: a set of points within R, representing a group of customers (for example, schools, libraries, and hospitals)

$Wc(r)$: the wire center nearest to $r \in R$

$Fo(r)$: the fiber cable nearest to $r \in R$

$NND(r, WC)$: the distance from $r \in R$ to $Wc(r)$, the nearest wire center.

$NND(r, FO)$: the distance from a point $r \in R$ to $Fo(r)$, the nearest fiber cable..

$B_{wc}(d)$: the characteristic function of copper wires that represents the deliverable bandwidth as distance decay function of the distance to nearest wire center.

$B_{FO}(d)$: the characteristic function of copper wires that represents the deliverable bandwidth as distance decay function of the distance to the nearest fiber optic cable.

Then, the access bandwidth, A(r), of any point r in the region R can be represented by

$$A(r) = \text{Maximum} \{ B_{wc}(NND(r, WC)), B_{FO}(NND(r, FO)) \} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

In order to calculate $A(r)$ for a point r in a GIS, these are the steps:

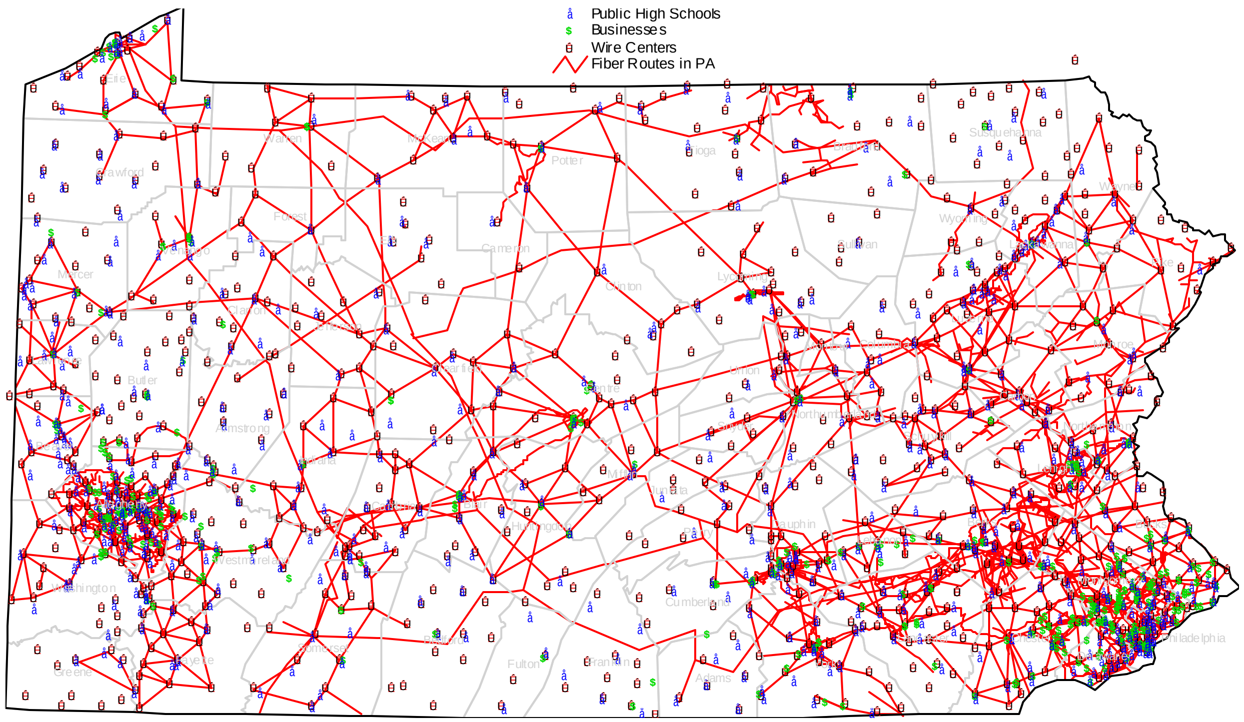


Figure 3. Distribution of businesses and schools in relation to wire centers and fiber optic cable routes.

(1). Calculate the Voronoi diagram for all the wire centers and for all the fiber routes. This can be done using the point and line Voronoi diagram algorithms described in (Okabe et al, 1992; Aurenhammer, 1991; Preparata and Shamos, 1985). Clipping the Voronoi diagrams with the boundary of region R;

(2). Derive $Wc(r)$ and $Fo(r)$ by a 'point-in-polygon' test. A wire center Wc is the nearest to the location r only if r is within the Voronoi region of Wc. Same way to find the nearest fiber cable;

(3). Calculating the nearest neighbor distances $NND(r, WC)$ and $NND(r, FO)$;

(4). Calculate $A(r)$ using formula (1).

Since a value of $A(r)$ can be calculated for every location in the region R, the model will result in a three dimensional surface which predict the access bandwidth of any location from the spatial distributions of wire centers and fiber cables.

3.3. Applications of the Model

The model we suggested can be used for two kinds of studies.

- Redefining the spatial relations of the virtual community in cyberspace; and
- Understanding the strength and weaknesses of any existing (or proposed) infrastructure.

Throughout the discussion of applications, we will use the data set shown on Figure 3 for illustrative purpose. The data set is the partial result of a large-scale survey conducted by the State of Pennsylvania (Technology Atlas, 1998; Williams and Sochats, 1998). It shows the locations for two types of infrastructure (the wire centers and fiber optic cables) and two types of customers (major businesses, and public high schools) within the State. Figure 4 shows the result of applying the model of access to (only) the wire centers[1]. The green, white, and orange colors represent areas that have broadband, wideband, and narrowband access, respectively.

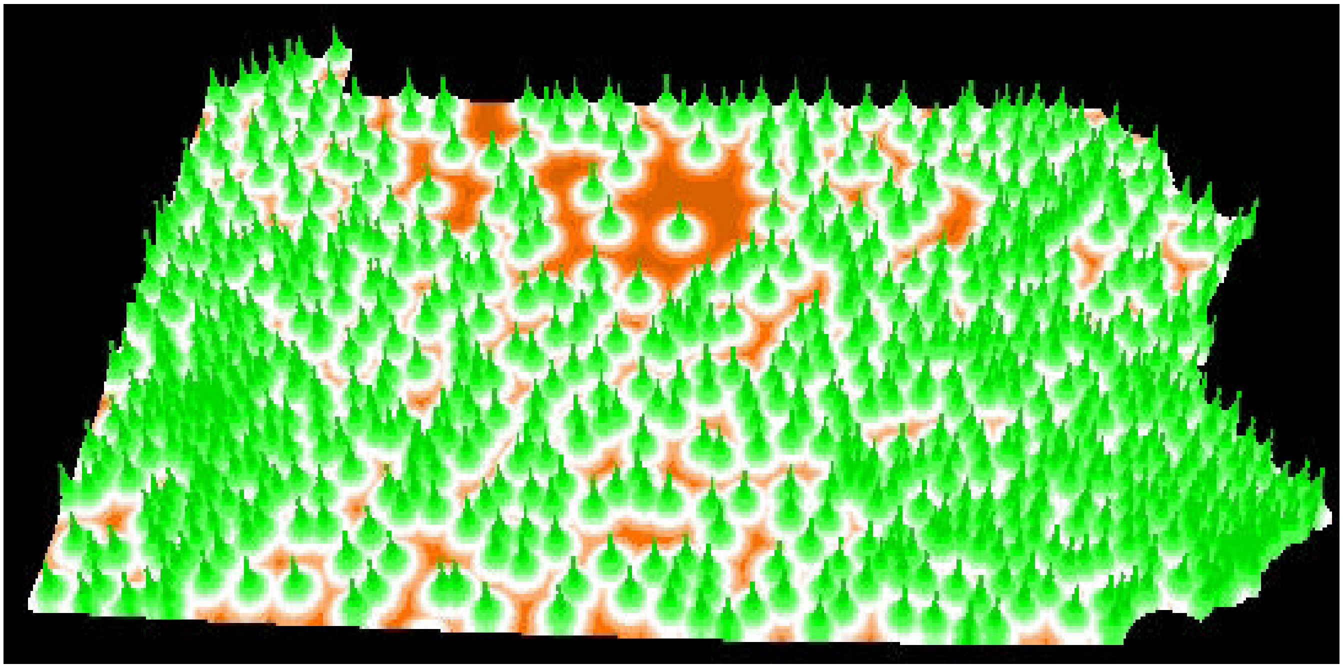


Figure 4. Surface Model of Access Bandwidth deliverable from Wire Centers

3.3.1. Redefining Spatial Relations

Spatial relations of virtual communities in cyberspace do not correspond to the geographical relations in a simple way. For example, you no longer ‘go to’ a ‘community’, but you ‘log in’ onto the net. So the traditional concepts of ‘distance’ and ‘nearby’ no longer apply. But we could argue that the variations in the access bandwidth may generate feeling of ‘distance’, because the higher the bandwidth, the shorter the time to wait in large transactions. In this sense, the concept of ‘near’ between two entities can be redefined according to the maximum capacity of the communication channel they can set up for exchanging information. For the example in figure 4, the *virtual distance* between location *a* and *b* can be expressed as: (assuming that all the wire centers are connected by optical fiber networks)

$$VD(a, b) = \text{minimum}\ (\ A(a), A(b)\ )$$

This provides the possibility to quantitatively define and map those virtual communities, such as ‘virtual city’, or ‘virtual school’.

3.3.2. Gap analysis.

Telecommunications consumption activities may be associated with spatial point objects in the geographical space, such as households, schools, libraries, supermarkets, and office buildings. When the existing infrastructure can not support the desired services from the consumer points, we say that the infrastructure has ‘gaps’, or ‘holes’, with it. But the discovering of these gaps can not be simply done by counting the number of facilities (e.g. number of wire centers or length of fibers) in a particular area. The model proposed above could provide a formal approach to this task.

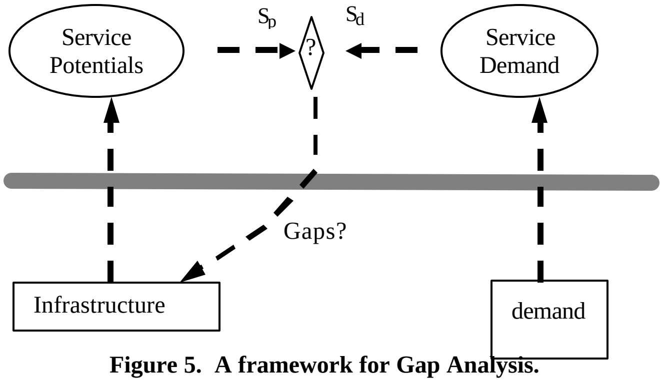


Figure 5. A framework for Gap Analysis.

For convenience, these points will be referred to as *consumption points*, or *C-points*. We may characterize each C-point by three measures: *Existing service* (S_e) refers to the current usage of any telecommunications services; *Service potential* (S_p) refers to the maximum possible telecommunications capacity that current infrastructure is capable of delivering to the C-point; *service demand* (S_d) is the total need of telecommunications capacity. All

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[1] The decision to consider only wire centers for this example is for simplifying discussions, and should not affect generality of the model.

three variables are dynamically changing and interacting with each other over time. Whenever (and wherever) S_p is lagging behind S_d, it is an indication of less than adequate infrastructure. Figure 5 shows the relationships of these variables.

As an example, suppose that all the public high schools in the State of Pennsylvania are expected to be exchanging courses through high quality distance learning networks, which requires at least T1 (1.544Mbps) connection. By spatially sampling the value of surface in Figure 3 with the location of those schools, the gaps of infrastructure can be identified by comparing the required bandwidth with the bandwidth predicted by the model.

3.3.3. Detection of Bias .

The existence of telecommunications infrastructure tends to be geographically biased towards major metropolitan areas and business centers, comparing to the relative sparse facilities in rural and less developed areas where the demand is marginal. Such biased pattern occurs because that the acquisition of these facilities requires huge capital investment, that it is only economically feasible in areas of high existing (and/or projected) demand. Castells (1996) suggested that telecommunications technologies are actually reinforcing urban hierarchies through the processes of restructuring. In the process of spatial reorganization, corporations actively locate and relocate their control centers in areas with suitable infrastructure in order to take advantage of the global reach of telecommunications technologies. The telecommunication industries, in turn, are attracted by major business centers where they can reach large number of customers within a small geographical area.

Telecommunications infrastructure is not only biased by geography, but is also biased towards serving certain categories of consumers. For example, Figure 3 shows a pattern that the existing infrastructure in the state of Pennsylvania is strongly biased towards businesses comparing to schools. There are many reasons for such a pattern to occur. First, businesses have been historically the earliest and strongest demands for telecommunications services, and the telecommunication industries have been attracted to businesses as a source of customers. In contrast, other customers, such as schools, libraries, churches, area located to serve residential areas, and may historically have relatively small influence on the location of infrastructure elements. This means that an existing infrastructure that supports the networking of businesses may be found inadequate to support an educational network which connects all schools, libraries, and homes. If such bias is found to be significant in a region, then public policies and government investment must be designed to correct such infrastructure bias

As an example, both types of bias are clearly shown in the map of Figure 3. This has significant implications in the geography of access to telecommunications services. It is in this sense that the *spatial distribution of telecommunications infrastructure determines the landscape of access.* Biased existence of telecommunications infrastructure contributes to the geographic unevenness in terms of access to advanced telecommunications services. While the biased pattern does exist, the degree of such bias varies from region to region, and we need a method to test the hypothesis for a given area.

Since the degree of such bias may vary from region to region, and from one type of consumers to another, there is a real need for a method to statistically test the significance of such bias.

Here we suggest a method to test the significance of bias based on the surface model of access. The method is explained by an example study about Pennsylvania's business and public high schools. Figure 6 shows the result of sampling the access surface in Figure 4 by two separate point sets: public high schools and businesses. Let $f(u)$ and $g(u)$ represent the probability density function of businesses and schools, respectively. We can detect significant bias by testing the Null hypothesis that the net effect function:

$$\mathbf{e}(u) = f(u) - g(u) = 0$$

The result of χ^2 test on the data in Figure 6 shows significant bias of wire centers towards serving businesses.

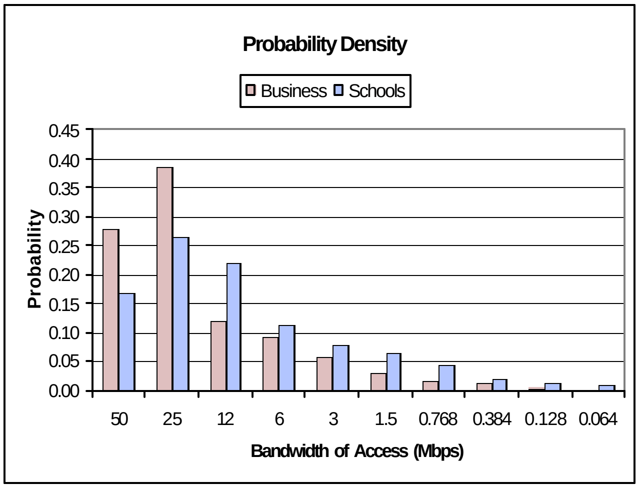
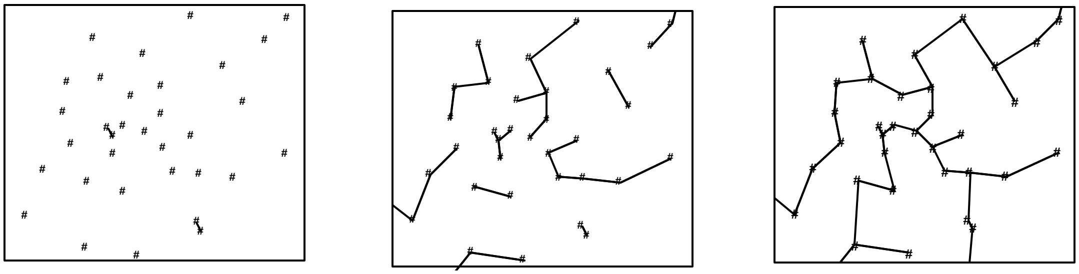


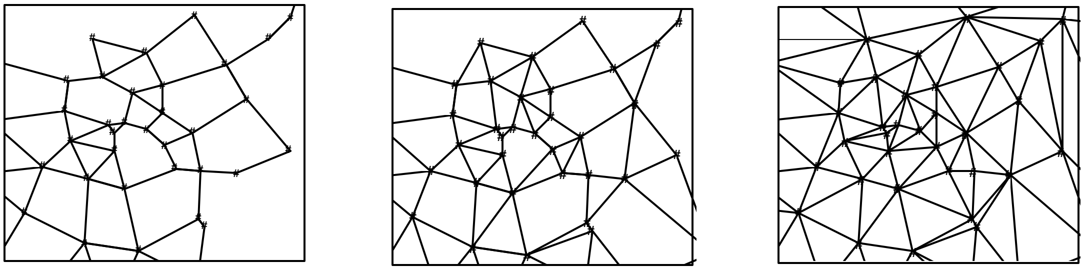
Figure 6. Probability distributions In relation to access bandwidth

4. Mapping the Geographical Variations at the Network Level

Telecommunications networks can be modeled as planner graphs in order to study their connectivity patterns. To measure the network connectivity of the telecommunications infrastructure, one can take two approaches. First, one could measure various properties of the underlying network graph, such as the number intersections per unit area, number of circuits formed by edges in the graph, or frequency distributions. Second, one could compare the telecommunications network with models of graph line patterns. The second approach is adopted here.



(*a*) Point Set (*b*) Nearest Neighbor (*c*) Minimal spanning tree



(*d*) Relative neighbor (*e*) Gabriel graph (*f*) Delaunay triangulation

Figure 7. Models of line patterns

In Figure 7, a variety of models of line patterns are shown in order of increasing connectivity. A minimum spanning tree (MST) is defined as a tree having a set of edges such that the sum of length of all the edges attains the minimum over all trees with the same point set. Scott (1971) gives an iterative approach for building MST by connecting the disconnected segments of the nearest neighbor graph, which is a subgraph of the MST. As telecommunication networks rarely use a tree topology because of a lack of redundancy in a tree, Figure 7(d)(e)(f) show three examples of circuit models.

Gabriel graphs. For a given point set *P*, the *Gabriel graph*, denoted by GG(*P*), is defined by the graph in which $\overline{p_i p_j}$ is an edge of GG(*P*) if and only if the circle having $\overline{p_i p_j}$ as a diameter is an empty circle (Gabriel and Sokal, 1969). Two points p_i and p_j are said to be *Gabriel neighbors* of each other if there is a direct link between them in the Gabriel graph.

Relative neighborhood graph. This is a subgraph of the Gabriel graph. A relative neighborhood graph, denoted by RNG(*P*), is defined as a geometric graph in which RNG(*P*) has an edge between p_i and p_j if and only if

$$d(p_i, p_j) \le \min_{k(\neq i,j)} \{\max\{ d(p_i, p_k), d(p_k, p_j)\}\}$$

(Toussaint, 1980). In other words, $\overline{p_i p_j}$ is an edge of RNG(*P*) if and only if there is no other point of *P* in the interior of the intersection of the two disks, one with center at p_i and the other centered at p_j, with the same radius $d(p_i, p_j)$. The relative neighborhood graph has the ability to extract perceptually relevant structures from sets of points

Delaunay triangulation. This is a geometric dual graph of Voronoi diagram, and can be constructed by joining those pairs of points p_i and p_j whose Voronoi regions have an edge in common. A Delaunay triangulation of a point set forms a space-exhaustive, contiguous tessellation of the planar space, and it is *locally and globally equiangular* (Okabe, et al, 1992). All circumcircles of delaunay triangles are empty circles. It is interesting to note that the Delaunay graph DG(P) of a point set P contains many other graph models as its subgraphs. Figure 8 shows a Delaunay graph and its four subgraphs for easy comparison. These graphs forms a family of models for line patterns.

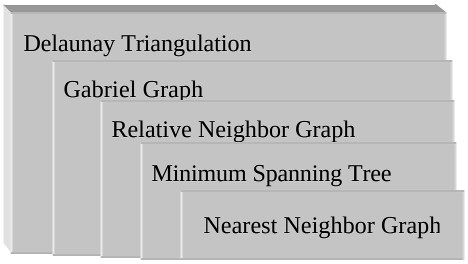
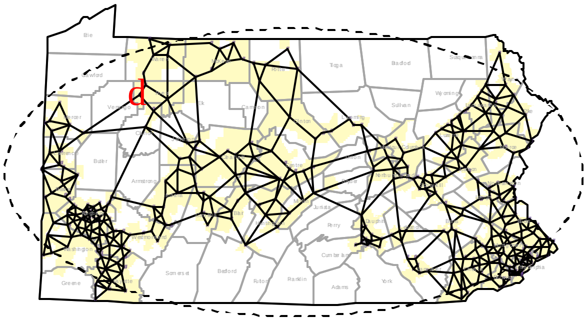


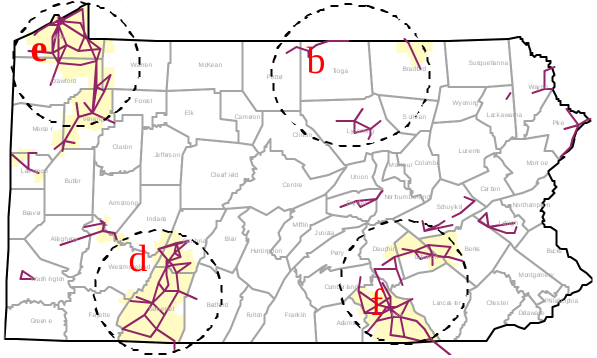
Figure 8. The Relationship between Delaunay graph and Its Subgraphs.

In any pattern of demand, there may be locations of demand that are spatially arranged in such a way that they are better connected by some network topologies than by others. There is an indication that natural connectivity has been used in practical network design. For example, Bell Atlantic has confirmed that the Gabriel graph model of their wire centers in Pennsylvania (Figure 9a) is remarkably similar to the current topology of the inter-office network. Topologies, which are either less dense, such as relative neighbor graphs, or more dense, such as the Delaunay triangulation, would not be appropriate models of the network topology.

Figure 9b shows the best fit of models in figure 7 to each cluster of inter-office networks of GTE. Once such a model is developed, interesting questions of spatial hierarchies, subgraphs of clustered locations, or areas of under-or over-connectivity can be determined.



(a) Bell Atlantic Inter-office networks



(b) GTE Inter-office Networks

Figure 9. Geography of Network Connectivity Patterns

5. Discussion

The central theme of this paper has been to argue for the use of a quantitative approach to the measurement of spatial properties of telecommunications networks. This approach suggests several ways to measure the effectiveness and connectivity of the telecommunications infrastructure.

A geographical study of telecommunications infrastructure can significantly improve our understanding of the use of telecommunications networks and the resulting implications for the developing cyber communities. It is argued that cyberspace has a multi-layered organization and that at lower, physical levels the telecommunications networks are not uniformly distributed in space. In turn, these inequities at the physical level result in fundamental, spatial differences in terms of the impact of cyberspace for society at large. Furthermore, the analytical tools of geographical information science provide the appropriate methodology for modeling the telecommunications infrastructure.

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