**MAPPING FOR THE INFORMATION ECONOMY:
A CASE STUDY FOR CANADA**

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MAPPING FOR THE INFORMATION ECONOMY:
A CASE STUDY FOR CANADA

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in partial fulfilment of the requirements for
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Abstract

The Industrial Revolution and resource-based industries have fuelled Canada's economic growth since Confederation. The primary role of geographers and cartographers over that period was to map the land-water mass and analyse spatial interactions that supported an economic system based on primary industry and resource extraction. Geographic and cartographic methods need to evolve to respond to the demands of an information economy in the 21st century. In particular, the Internet has transformed the way many of us learn, work and play. Through a geographer's or cartographer's lens the Internet can be treated in a manner similar to other, more familiar, network problems such as transportation and hydrology, albeit using unfamiliar data collection methods. The main objective of this thesis is to apply classic geographic and cartographic methods to map and explore spatial relationships of the Internet's infrastructure. Non-Euclidean and Euclidean frameworks are explored and implemented to develop a virtual distance projection of Canada, maps based on points, lines, or surfaces, and quantitative network analysis methods. The maps and analysis indicate that the location of traditional Canadian heartlands and hinterlands have not changed due to the Internet. Heartlands have a high concentration of Internet content providers, a supporting infrastructure that provides a high degree of accessibility and connectivity when compared to the hinterlands. The "death of distance" in cyberspace is more myth than fact and the potential exists for a "digital divide" between traditional heartland-hinterland Canadian regions in an information-economy.

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Table of Contents

Abstract	-iii-
Acknowledgements	-iv-
Table of Contents	-v-
List of Tables	-vii-
List of Illustrations	-viii-
List of Appendices	-ix-
Chapter 1 - Introduction	1
1.1 Maps and Mapping	1
1.1.1 Research topic	1
1.1.2 Thesis objectives	1
1.1.3 Representation of space and time	3
1.1.4 Paradigm shifts - evolving economies and geographical thought ...	5
1.2 Visualisation methodologies	10
1.2.1 Physical and information space categories	10
1.2.2 Traditional cartography	11
1.3 Research constraints	12
1.3.1 Research scope and application	12
1.3.2 External constraints	14
1.4 Summary	14
Chapter 2 - Literature Review	16
2.1 Canada's Heartlands and Hinterlands	17
2.2 The Internet in Canada	21
2.2.1 Context and history	22
2.2.2 Network topology	25
2.2.3 Internet statistics for Canada	26
2.2.4 Potential Internet data sources to map	29
2.3 Cartography and Networks	30
2.3.1 Euclidean cartographic methods	31
2.3.2 Non-Euclidean cartographic methods	33
2.3.3 Cybercartography	34
2.4 Scientific Visualization	36
2.5 Geography and Networks	36
2.5.1 Gravity model	38
2.5.2 Network analysis	39
2.6 Internet Map Gallery	44

2.6.1 Point and density surface maps	45
2.6.2 Line maps	52
2.6.3 CyberCartography	55
2.7 Conclusion	64
Chapter 3 - Data Collection, Preparation and Exploration	66
3.1 - Primary data	67
3.1.1 Network routing from a central point	67
3.1.2 Network timing from a central point	69
3.2 Secondary data sources	84
3.2.1 Canadian Internet addresses	84
3.2.2 Network topology of Canada	87
3.3 Conclusion	90
Chapter 4 - Spatial Structure of the Canadian Internet	91
4.1 - Non-traditional space	91
4.1.1 Virtual distance calculation	91
4.1.2 Virtual distance projection	97
4.2 - Traditional Euclidean space - a cartographic approach	101
4.2.1 Domain name locations - point map	101
4.2.2 Dot density map of Internet addresses	103
4.2.3 Line map of network topology	106
4.3 - Traditional Euclidean space - a network analysis approach	108
4.3.1 Topology of the Canadian Internet	108
4.3.2 Connectivity matrix	110
4.4 Conclusion	116
Chapter 5 - Conclusion	118
5.1 The vision and personal observations	118
5.2 Objectives	119
5.2.1 Non-Euclidean projection based on time	120
5.2.2 Euclidean representation, points, density and lines	123
5.2.3 Network analysis	124
5.3 Heartland – Hinterland	127
Bibliography	130
Appendices	135

List of Tables

Table 2-1 Internet connection capacities	25
Table 2-2 Internet penetration rates by Census Metropolitan Area	28
Table 2-3 nslookup to carleton.ca	48
Table 3-1 Blocked Ping Request	71
Table 3-2 Traceroute analysis summary	73-74
Table 3-3 Ping script	78
Table 3-4 Statistical summary of transmission times (ms)	79
Table 3-5 Sample Domain Name Registration	86
Table 4-1 Virtual Distance	93
Table 4-2 T-matrix and D-matrix for Canadian Census Metropolitan Areas	113

List of Illustrations

Figure 1-1 Thesis Workflow	2
Figure 1-2 Time-Space Convergence	6
Figure 2-1 Heartland and Hinterland Regions of Canada	19
Figure 2-2 Information and Communications Technology Clusters	20
Figure 2-3 The ARPA Network	23
Figure 2-4 Proportion of Canadian Households that use the Internet	28
Figure 2-5 Chief Red Sky's Migration Map	35
Figure 2-6 Dot Map of .ca Internet Domain Names	46
Figure 2-7 Location of IP Address Allocations in Britain	50
Figure 2-8 IP Address Density Surface for Britain	51
Figure 2-9 USENET traffic 1993	53
Figure 2-10 London Subway "Tube" Map	54
Figure 2-11 Conceptual Line map of bandwidth	56
Figure 2-12: Visualization Study of the NSFNET	57
Figure 2-13 United States view of the Mbone network	58
Figure 2-14 Warriors of the Net	60
Figure 2-15 Internet Visualisation - Colours classified according to node address	62
Figure 2-16 Scientific Visualisation of the .ca domain	63
Figure 3-1 Traceroute Ottawa to Victoria via Chicago	70
Figure 3-2 Traceroute Ottawa to Victoria, Canadian route	70
Figure 3-3 Internet Transmission Times, Northern and Southern Canada	80
Figure 3-4 Physical Distance vs Time	81
Figure 3-5 Physical Distance vs Traceroute Distance	82
Figure 3-6 The UUNet backbone in Canada	88
Figure 3-7 CANet 3 Traffic Map and Graphs	89
Figure 4-1 Traceroute and Physical Distance vs. Virtual Distance	95
Figure 4-2 Southern Canada - Traceroute and Physical Distance vs. Virtual Distance ..	96
Figure 4-3 Rubber sheeting process for map re-projection	98
Figure 4-4 Canada - Virtual Space	100
Figure 4-5 Dot map of .ca registrations	102
Figure 4-6 Density map of .ca registrations in Canada	104
Figure 4-7 Density map of .ca registrations in the Quebec City to Windsor corridor ..	105
Figure 4-8 Line map of CANet	107
Figure 4-9 Topology schematic of CANet 3 and UUNet	109
Figure 4-10 Canada Internet Connectivity (T-Index)	115

List of Appendices

Appendices List	135
Appendix A – Ping test results	136
Appendix B - Lambert Conformal Conic projection for Canada	140
Appendix C - Combined CANet 3 and UUNet Connectivity matrix: C1	141
Appendix D - CANet 3 and UUNet Connectivity matrix: C2= C1*C1	142
Appendix E - CANet 3 and UUNet Connectivity matrix: C3= C1*C2	143
Appendix F - CANet 3 and UUNet Connectivity matrix: C4= C1*C3	144
Appendix G - CANet 3 and UUNet Connectivity matrix: C5= C1*C4	145
Appendix H - T-matrix for CANet 3 and UUNet	146
Appendix I - D-matrix for CANet 3 and UUNet	147
Appendix J - Gravity Model Calculations	148
Appendix K - Digital Archive of Data, References and Thesis on Compact Disc	(back pocket)

Chapter 1 - Introduction

1.1 Maps and Mapping

1.1.1 Research topic

A theme common in geographic studies is the appropriate representation and analysis of space within the context of time. Geographic and cartographic methodologies are typically applied to classic portrayals of issues in physical or human geography. The aim of this research is to adapt geographic methodologies and associated cartographic portrayal to an information-economy. Information-based economies are dependent on communication infrastructures that are quick, reliable and widely available.

Communication technologies have evolved over the centuries; however, the space – time compression associated with Internet-based information and services challenge classic geographic thought and associated cartographic representation. Traditional geographic and cartographic methodologies are assessed in terms of their appropriateness to mapping the Internet and applied to the spatiality of the Internet-based information-economy.

1.1.2 Thesis objectives

The general aim of this thesis is to explore techniques to map the Internet using a subset of Canada's Internet infrastructure as an example. More specifically, the research focuses on applying known geographic and cartographic methodologies, based on both non-Euclidean metrics and Euclidean metrics, to the problem of mapping the infrastructure of Canada's Internet, as outlined in Figure 1-1.

Non-Euclidean methods borrow from aboriginal mapping, that places a greater value on the route rather than geographic shape. Based on primary data collection of Internet transmission times, from a major Canadian network, virtual distance is calculated and

used to contort a map of Canada into an Internet temporal projection.

Euclidean metrics form the basis of a more traditional Western cartographic process based on points, lines and surfaces to map Internet points, point density derivatives and routes based on Internet address co-ordinates and Internet Service Provider topology maps.

Network analysis methods, traditionally used in hydrology and transportation applications, are adapted to assess how connected and accessible Canadian communities are to the Internet.

The results are assessed in terms of Canada's traditional heartlands and hinterlands, and recommendations for further work are presented.

1.1.3 Representation of space and time

Geographic methodologies assess absolute and relative location to respond to the question, "why are spatial distributions structured the way they are?" (Abler, 1971, p. 59), within the context of society's priorities of the day. From the early Greeks, through medieval times, colonialism, the period of evolutionary determinism and computerized spatial statistics, geographic thought and cartographic representation of space and time have been, and continue to be, dynamic. Well defined distance metrics provide a basis for most geographic interpretation and associated cartographic representation of space. As industrial societies shift to an information-based economy, however, geographic methodologies need to evolve as well in order to identify how the supporting infrastructure's, the Internet's, spatial distribution pattern and intensity varies. Since the 1950s new concepts of relative location have been employed to create new kinds of

relative and elastic space in order to communicate human behaviour based on concepts that are germane to the map reader, for instance time and cost (Abler, 1971).

Traditional Western cartographic portrayal of landscape is based upon Euclidean space, in which a linear and a well-defined relationship exists between space and time, and in which "the shortest distance between two points is a straight line" (Abler, 1971, p.73). Throughout history, maps based on the earth's geodesy served mercantile and industrial civilisations well. Navigational charts and topographic and thematic maps typically retain either geographic shape or distance (Campbell, 1991). These maps are useful tools when transportation cost is a function of navigable geographic distance.

Internet-based communities such as interactive web sites, newsgroups, discussion forums, billboards and the like may be described as "virtual communities". Compared to other forms of communication the Internet is a very quick method to access data, information and knowledge. As such, Cairncross (1997) argues that the Internet brings the "death of distance", with the implication that the geographer's role in an information economy is minimal. "A gradual withering away of the 'tyranny of space' (Warntz, 1967, quoted in Lowe and Moryadas, 1975, p. 53) implies that Euclidean concepts of space are slowly becoming irrelevant and should be replaced by other geometries which will enable spatial analysts to deal more realistically with how man behaves in space" (Lowe and Moryadas 1975, p. 53). Conversely Kitchen (1998) contends that communication has been and continues to be spatially dependent due to clusters of technical capacity, human expertise and physical hardware at communication nodes and communication lines between and amongst the heartland nodes to the hinterland. Despite the significance of

communication in an information-based economy, geographic methodologies that explore the spatial implications of the knowledge-based economy and ways of portraying that economy are in the early stages of evolving to meet this challenge.

Nevertheless, as technology shrinks our world, perspectives on distance are challenged and modified from the absolute to the relative.

"The spaces in which people live are much more psychological than absolute. If we are concerned, as we often are, with explaining spatial interaction, what is important is not how far interacting places are from each other in absolute space, but rather how far the people at the two places think they are apart" (Abler, 1971, p. 75).

1.1.4 Paradigm shifts - evolving economies and geographical thought

The economic model for industrialised countries has shifted from an industrial base to an information base. Modified from Abler (1971) to include the Internet, Figure 1-2 is a graphical view of time-space convergence between London, England and Edinburgh, Scotland. Abler outlines the work of Janelle's (1968) measurement of relative space of our "shrinking world" by monitoring the rate at which places approach one another in time distance. The diagram is one view of relative space, as our world shrinks due to continual improvements in transportation and communications. The phenomenon is consistent with the "urban implosion" effect whereby transportation corridors reduce travel time between large cities and tend to bypass rural communities, which remain relatively isolated with no significant improvement in time-distance to market. During the Industrial Revolution and subsequent period dominated by resource or industrial economies, access to physical resources, human resources and manufactured products was a function of physical distance. Indeed classic geographic thought on access to

resources as a function of distance is derived from the works von Thünen (1826) as outlined by Wallace (1990), whereby close physical proximity to a market is the prime competitive advantage.

“These varied technological improvements in the movement and communications industries have had significant impact on the reduction of time required for human interaction in space. In turn, this impact has made "distance" a time-biased concept. How much ‘distance’ is too far away has varied through time” (Lowe and Moryadas, 1975, p. 50). Similarly, in an information economy digital resources need to be accessed in a cost effective manner, although the preferred unit of measure is time. We ask ‘how long it will take to download a file?’, not ‘how far away is that file?’. In some instances distance is used in an Internet setting, particularly when transferring large volumes of data or software (>100 Megabytes). For example, corporations that distribute software create copies of their content in different cities on “mirror sites” and clients are requested to download from the closest geographic location in order to minimise transmission time.

Traditional resource, manufacturing, and service economies use maps to measure geographic distance with traditional spatial and temporal metrics. Information economies, on the other hand, are based on data flowing in networks that have non-traditional spatial and temporal metrics. Historically, many urban centres were located at the junction of transportation corridors, typically where navigable waterways met, with subsequent industrial and transportation infrastructure development that built and sustained a diverse economy. Similarly, information ports are located where networks connect and the subsequent database development and professional support services

reach a critical mass to become “Technopoles” (Conference Board of Canada, 1997; Castells and Hall, 1994). As ports of the industrial economy grew the indicators of location theory were of bricks and mortar, and were obvious to observe. The infrastructure of the information economy, however, is less easy to observe because the servers, switches, and wires are not visible as they are located in existing office space and follows existing rights of way. Any building, with appropriate electrical supply and ventilation, can host computer servers. The wires and fibre optics that form the basis of national backbones follow existing telephone, electrical, rail and highway rights of way. Given that a virtual port can be located wherever there are adequate connections, wires, and expertise, does this affect traditional spatial organisation associated with well established cores and peripheries? Conversely traditional core-periphery dichotomies can simply be reinforced as core areas capitalise on this new market that reinforce heartland versus hinterland disparity as articulated by McCann (1987) and applied to the Internet by Zook (2000b) .

Data have been transmitted across Canada for many years since the advent of the telegraph in 1846 between Hamilton and Toronto. However, “By today’s standards telegraphy was slow, inflexible and inaccessible” (Canada Science and Technology Museum, 2002). The magnitude and degree of that accessibility pales in comparison to current communications technologies, namely cellular telephones, wireless personal digital assistants (PDAs), corporate networks and the land-based infrastructures of switches, wires and fibre-optics for telephone switching systems and distributed networking technologies that are otherwise known as the “Internet”.

The commonly used term the “Internet” (upper-case I) represents the computer space created by integrating many dissimilar networks at a global level by means of the Transmission Control Protocol and Internet Protocol (TCP/IP) (the definite article *the* refers to the TCP/IP protocol). Less common are other networks, “internet” (lower-case i), that are connected by other protocols that are specific to those internal networks (Pfaffenberger, 1994). The Internet is composed of hardware and standards for protocols and computer languages. The information may be published and accessed via various sub-components of the Internet including the World Wide Web for hypertext, newsgroups, telenet, electronic mail and file transfer protocol (ftp) sites.

The Internet has become the tool of choice for distributing digital information. The vast majority of households that regularly access the Internet from home use e-mail and browse the World Wide Web. About 57% of Canadian households search for medical and health-related information, 37% for electronic banking, and about 31% use it to find employment (Statistics Canada, 2001). With respect to the availability of personal computers and Internet access, Canada leads the world with 258 Internet users per 1,000 inhabitants and 330 personal computers per 1,000 inhabitants (Industry Canada, 2001).

Internet access is made possible through primarily commercial Internet Service Providers (ISP) which provide Internet access to individuals and organisations based on a particular geographic area or user community. Depending on the location, the number of ISPs and their respective capacity to deliver service, can range from no ISP in the region, to one small ISP with limited infrastructure, to an area that has access to many large ISPs and supporting infrastructures. While service is not uniform across the country, the

Internet has greatly extended the availability of a range of information to more people, over a larger area than with more conventional data distribution methods. Maps can be developed to portray spatial relationships associated with connectivity and accessibility to the Internet.

1.2 Visualisation methodologies

1.2.1 Physical and information space categories

The challenge addressed in this thesis is the representation and analysis of the Internet's infrastructure by adapting existing geographic and cartographic methods. Literature from a geographer's or cartographer's perspective is quite sparse, but there is a body of literature starting to develop in the computer science visualization community. However, Staple (1995) developed an explicit link between cartography and computer network visualisation based on the notion of "information space", arguing that the information space of the Internet, or cyberspace, can be mapped to indicate the relationship between virtual communities. In essence, Staple's paper challenged the geography community to develop maps of the Internet. While the paper helped provide a catalyst for this work it did not explore the physical space of Internet infrastructure or how to adapt existing geographic analytical methods to the problem. Since 1995 a body of literature has been developing from various research communities: geographers, cartographers, computer scientists, and the telecommunications sector, that explore methods to graphically display networks within a spatial framework.

This paper will focus on methodologies to portray the infrastructure of the Canadian Internet, not the ethereal mapping of information space. Notwithstanding that research constraint, the book “Mapping Cyberspace” (Dodge and Kitchin, 2001) deserves honourable mention as the definitive work on information space and approaches the problem from a social perspective by exploring social interactions, impacts and associated spatial representations.

1.2.2 Traditional cartography

Traditional cartography maps the worlds of physical and human geographies, but it has not been applied to a “virtual world” that comprises electronic networks. The art and science of traditional cartography is based on the graphic communication of a well-defined matrix, as defined by the earth’s geoid and mapped using Euclidean geometry (Campbell, 1991; Dent, 1999; Muehrcke, 2001). Mapping the Internet, or “virtual space”, poses interesting challenges for traditional cartography. The landscape of the Internet is non-Euclidean in nature, composed of dynamic, non-planar, bi-directional data flows; in multiple dimensions, n-dimensional; whereas traditional cartography is based on Euclidean metrics. The current landscape of the Internet lacks many of the elements associated with traditional geographic data collection methods, including surveying and remote sensing, and cartographic representation based on a known North, geodesy, projection, and scale.

There are several cartographic methods and categories of maps that are suitable for mapping networks (Campbell, 1991; Dent, 1999; Muehrcke, 2001). For example, the areal distribution of websites can be symbolised by dots on a map. Network connectivity

is mapped using line maps and linear symbology. An early Canadian example includes a series of paper maps depicting aspects of communications including: microwave routes, television, radio, tropospheric scatterwave, land and submarine cables (National Atlas of Canada, 1967). Using visualization tools, line map symbology can be dynamic, in real time, with maps driven by a database on a web site that further facilitate data exploration and analysis. More dramatic interpretations of network access can be achieved with value-by-area contiguous cartograms or maps derived from graph theory (Abler, 1971; Campbell, 1998; Lowe, 1975).

1.3 Research constraints

In order to define a manageable research topic, the scope of this thesis is constrained by several factors. These constraints are either a matter of choice to focus research and apply research methodology to develop maps using manageable data sets, or are imposed by external factors. The following sections outline the rationale for these choices and list the external constraints.

1.3.1 Research scope and application

The scope of this research is limited to a subset of Canada's Internet national carriers, using static mapping processes. Geographic extent, scale, granularity and mapping methods were assessed and defined in order to manage data volumes, while providing enough data to implement network mapping methods for the Internet in Canada.

The geographic extent will focus on Canada, within a global context as required. As such, network connectivity will be measured for Canadian locations and relevant routes

to the United States. Canadian locations are limited to those cities and towns that are connected to the two national networks that are used as a data source. Connectivity for United States locations that provide a gateway into Canada will not be calculated.

Given the geographic extent is Canada and the representation of those maps is limited to 8½" x 11" paper, maps of Canada will be published at a small scale in the order of 1:50 million. The Quebec City, Quebec to Windsor, Ontario corridor has a high concentration of population and infrastructure, and therefore a regional map will be developed.

In order to portray Canada at the appropriate scale and manage data volumes an appropriate network hierarchy is assessed. Networks are hierarchical in nature, from national "backbone" networks to regional, local and institutional networks. The thesis focusses on the first order of network hierarchy which are the backbone networks owned by the major telephony carriers. Mapping the second level and lower is beyond the scope of this thesis. To use a highway analogy, mapping network architecture will be limited to the expressway level. Since this thesis explores geographic concepts at a national level, further work is required to assess regional and local infrastructures.

Computer network mapping is a multidimensional dynamic phenomenon as Internet traffic is highly variable over time and load capacity varies according to national, regional and local networks. Traditional mapping of physical geography networks, for example hydrology, is limited to a finite number of dimensions typically: Cartesian geometry, time and an attribute, such as volume. To prepare traditional static maps a common approach is to hold constant one of these metrics. For example, if volume is the

key message, then it is represented for a certain instant of time or other temporal derivatives, say monthly average. To visualise and map computer networks, based on known two-dimensional geographic and cartographic methodologies, multiple dimensions and temporal measures are held constant.

1.3.2 External constraints

The topology of Canada's Internet infrastructure is required to assess and map connectivity. The topology must be acquired from the respective Internet Service Providers (ISPs), but most ISPs impose confidentiality and security policies that curtail the publication of this information in the public domain. Commercial carriers are reluctant to share the information, citing competitive concerns and security risks. The CA*net (CANARIE Inc. Network) and UUNET (UUNET Technologies Inc.) networks do publish their network maps, and hence these two networks will be used to meet the objectives outlined in this thesis.

1.4 Summary

This chapter has introduced the main objectives of the thesis, namely to map a subset of Canada's Internet infrastructure and assess community connectivity to the Internet. Representation of space and time is introduced within the context of fundamental industrial, resource and information economic drivers, and how transportation and communication technologies affect space-time compression. The emergence and widespread adoption of the Internet in Canada as a communications and data transfer technology further contributes to space-time compression. The challenge is

to adapt geographic and cartographic methodologies to visualize spatial variations associated with the Internet. The problems associated with the cartographic representation of non-Euclidean Internet space have been introduced. More traditional Euclidean metrics of points, surfaces and lines will be used to symbolise Internet addresses, the density of those addresses, and network linkages. Network analytical techniques based on graph theory, drawn from the disciplines of hydrology and transportation, are applied to assess how connected and accessible selected Canadian communities are via the Internet. The spatial distribution of Canada's information economy heartlands and hinterlands is compared with those from the industrial economy.

The next chapter is a literature review that examines more fully the sub-fields relevant to this thesis, namely the heartland-hinterland model, the Internet, cartography and networks, geography and networks, and concludes with a gallery of Internet maps.

Chapter 2 - Literature Review

The research focuses on applying known geographic and cartographic methodologies to the problem of mapping the infrastructure of Canada's Internet, within the context of the heartland-hinterland dichotomy, Euclidean and non-Euclidean metrics, and network analysis. These objectives are built upon literature from six main areas: an overview of Canadian heartlands and hinterlands, a survey of the Internet in Canada, cartographic representation of networks, scientific visualization, relevant geographic methodologies and concludes with a gallery of existing Internet maps. The chapter starts by reviewing the spatial distribution of Canada's heartlands and hinterlands as the economy evolves from a resource and industrial base to an information economy. The second section, 'The Internet in Canada', outlines the relevance of the Internet to an information society, a brief history of the Internet and network topology, Canadian Internet statistics, and concludes with a sub-section on methods to measure Internet dynamics. The third section, 'Cartography and Networks', reviews cartographic representation of networks using dot maps, dot density maps, line maps, alternative cartographic perspectives, and other efforts to map the Internet are noted. Scientific visualization is outlined in the fourth section. Subsequently, 'Geography and Networks', discusses network analysis methods that can be applied to the Internet. Methods are primarily borrowed from transportation geography and include the gravity model and graph theory. The final section provides examples of recent efforts to map the Internet. Given the dynamic nature of World Wide Web links, literature that is referenced to a web resource has been archived to a compact disc, CD, indexed by author. The CD will facilitate the viewing of

multimedia presentations, by removing download time constraints, and will archive related literature as the links listed in the bibliography will inevitably change and cease to work.

2.1 Canada's Heartlands and Hinterlands

Cairncross (1997) argues that rapid communications and the Internet have brought “the death of distance”. If this hypothesis is true, and if an information economy is strong, then regional disparity will presumably decay over time. If not true, then, from a core-periphery perspective, the information economy has the potential to be one more force that will increase regional disparity. Or, the truth may lie somewhere in the middle. Canada's economic cores and the resource peripheries also described as the heartland-hinterland dichotomy are studied in McCann (1987) and by Bone (2002). This thesis will create representations of the Internet infrastructure within the context of Canada's heartlands and hinterlands.

McCann (1987) defines the heartland and hinterland¹ dichotomy as follows:

“Heartlands usually develop in areas which possess favourable physical qualities and grant good accessibility to markets; they display a diversified profile of secondary, tertiary and quaternary industries; they are characterized by a highly urbanized and concentrated population which participates in a well-integrated urban system; they are well advanced along the development path and possess the capacity for innovative change, and they are able to influence and usually control - through the metropolis - economic, social and political decisions of a national importance. Hinterlands are characterized by the obverse: an

¹ McCann's ed. (1987) book *Heartland and Hinterland - A Geography of Canada* provides literature from a variety of authors from both a regional and central perspective, from 1750 to the early 1980s. Much of this section is borrowed from that work. The heartland-hinterland dichotomy is synonymous with metropolis-hinterland, core-periphery, centre-periphery or centre-margin model.

emphasis on primary resource production; scattered population and weakly integrated urban systems; limited innovative capacity; and restricted political prowess. The heartland-hinterland model has been defined by John Friedmann as a 'general theory of polarized growth' which is applicable at all geographic scales: international, national, or provincial" (McCann, 1987, p. 4).

Canada's heartland and hinterland areas as identified in 1987 are indicated in Figure 2-1. The heartland areas are well known to Canadians and include: the national industrial heartland along the Windsor - Quebec City corridor, and the regions of Edmonton - Calgary, Vancouver-Victoria and Halifax - Saint John. Interestingly, Industry Canada (2001) notes three similar regions that have a concentration of information and communications technology industries (Figure 2-2) as:

1. Toronto/Ottawa/Montreal triangle
 - i. 300,000 computer professionals
 - ii. Population approaching 10,000,000
 - iii. Advanced infrastructure, concentration of technologies, research institutes
 - iv. Strong transportation infrastructure
 - v. Integrated into United States core regions
2. Vancouver/Edmonton/Calgary triangle
 - i. 100,000 computer professionals
 - ii. Population approaching 4,000,000
 - iii. Concentration of technologies and academic programs
 - iv. Transportation links to Asia
 - v. Integrated into United States West Coast core
3. The Atlantic Provinces are mentioned, although similar data were not provided.

The spatial distribution of information and communication technology industries in 2001 is similar to the spatial distribution of Canada's industrial economy as represented

by McCann (1987) for 1987 and previous Canadian economic epochs. In and of itself this fact is not terribly surprising. However, spatial distributions were expected to change in response to the development an information economy based on the Internet.

A quick comparison of these maps (Figures 2-1 and 2-2) indicates that the Internet's key stakeholders are located in the traditional heartlands of Canada. Wallace (2002, p. 93) notes that the two fastest growing industrial sectors between 1989 to 1998 (professional, scientific, technical; and management, administration and other support) were disproportionately attracted to census metropolitan areas (CMAs) and even at lower levels of the urban hierarchy "despite the potential of modern telecommunications to distribute earning opportunities in knowledge based industries more widely". In an information economy the heartland - hinterland dichotomy represents a spatial "digital divide" at a national scale.

2.2 The Internet in Canada

Mapping for the information economy is a complex problem that is most easily approached by defining an appropriate subset of the communications infrastructure. Currently, the information economy transmits data and information via electronic networks that may, or may not, be connected to the Internet. These networks range in size and accessibility from a home office composed of a few computers and a printer, non-accessible defence networks, corporate Intranets, to the sum of all public networks that are inter-connected via the Internet. To provide a national view of the infrastructure, a subset of Internet space will be analysed and mapped at a national scale. An alternative is to map at a larger scale, for example a university network, but the results would be

difficult to interpret within the context of heartland-hinterland geography. Chapter 3 describes data based on the CANet and UUNet networks as a representative subset of Canada's Internet, which are analysed further in Chapter 4. The following sub-sections outline the Internet's history, topology, and statistics, and conclude with a sub-section on measurement tools that are unique to the Internet.

2.2.1 Context and history

Originally the Internet was a product of the Cold War, to develop a highly redundant network to link computers in the United States together. The Internet started as a research project of the Advanced Research Projects Agency (ARPA). The first ARPA network, created in 1969, was a small number of leased telephone lines used to interconnect four ARPA sites (Dodge, 2001) (Figure 2-3). By the 1980s, the original ARPA network term, "ARPANet," no longer applied. As network membership expanded considerably beyond the original ARPA sites, the network became increasingly called "the Internet," to indicate an inter-network of connected government agencies, and later private industries (Hafner, 1999).

Geographic regions and communities of interest are now connected by corporate, government, military, academic and regional networks that are linked together by "backbone" networks. Backbone networks are high-speed links that provide the core infrastructure for a myriad of widely distributed networks that support these communities.

“The Internet is an international network of networks that allows different computer users to share information and communicate interactively....The Internet’s most powerful feature is that it allows computers and networks to communicate openly and effectively, regardless of make, architecture, speed, manufacturer, connection, or resources” (Information Highway Advisory Council, 1997).

The building of Canada’s Internet infrastructure began in the late 1980s with the establishment of various regional networks. In June, 1990, a number of universities and research institutions and federal and provincial governments collaborated to establish a national computer communications network called CA*net. CA*net leased transmission lines from telecommunications common carriers in Canada such as Bell Canada. CA*net became the Internet backbone in Canada for public and private research institutions by interconnecting regional networks in all ten provinces and linking them to the Internet backbone in the United States. CA*net operated at an initial speed of 56 Kbps (kilobits per second) (Information Highway Advisory Council, 1997).

In 1993, CANARIE Incorporated, a jointly-funded program of industry and government, was established to stimulate research into high-bandwidth network facilities and applications. Since 2000 CA*net has been operational at speeds of a Gigabyte per second (1,000,000,000 bytes per second) (CANARIE, 2001) using optical technologies. Network terminology and capacities are noted in Table 2-1. A transfer rate of one megabit per second (1 Mbps) is equivalent to 128 pages of text per second (Moss and Townsend, 2000).

2.2.2 Network topology

A network-based analysis of the Internet's topology does share similarities with more traditional geographic applications including those in hydrology and transportation. The physical infrastructure of the Internet is composed of nodes (points) and routes (links). The nodes are the large centralized switches that route traffic to and from destinations.

Network Term	Capacity per second	Capacity Bytes per second
56 K	56.6 Kb	56,600
T1/E1/D1 (Data Service 1)	1.544 to 2 Mb	1,544,000
T3/DS3 (Data Service 3) (28 T1s)	44.21 Mb	44,210,000
OC3c/STM1 (Optical Carrier 3) (100 T1s)	155 Mb	155,000,000
OC12c (Optical Carrier 12) (4 OC3s)	620 Mb	620,000,000
OC48c (Optical Carrier 48) (4 OC12s)	2.5 Gb	2,500,000,000
OC192 (Optical Carrier 192) (4 OC48s)	9.6 Gb	9,600,000,000
Table 2-1 Internet connection capacities		

Routes are bi-directional connections between the nodes. In terms of network analysis bi-directional links are symbolized by two lines that flow in opposite directions. Referring to the 1969 diagram of the Internet, Figure 2-3, the nodes of the network are represented by circular symbols (labelled by their installation order), the lines are communications links and the square boxes are actual computers (labelled by model name) connected to the network. Of particular interest to geographers are network perspectives on granularity (level of detail), generalization, symbolization of flow and scale. It is difficult to imagine the appearance of one full topology map of the Internet depicting all of the current Internet switches, transmission lines and computer servers without some form of extreme generalization as will be evident from illustrations of networks later.

2.2.3 Internet statistics for Canada

This section cites Internet statistics to provide an overview of the relevance of the Internet to Canadians and to identify regional differences of Internet adoption. As networks and the use of network-based technology mature the delivery of products and services over the “net” has evolved from a research and development community to a very broad public infrastructure that is as critical as any other infrastructure or utility. Geographers have long assumed the role of mapping infrastructure and have adapted to changing notions of space and time.

“Canada’s sets of networks that provide the Internet infrastructure are as important as any other national infrastructure program. Canada has a strong tradition of infrastructure building, from the critical nation-building era of railroads to today’s efforts to ensure citizen connectivity.”

For Canada to generate jobs, growth and wealth, it must have a leading, knowledge-based economy that creates new ideas and puts them to work for Canadians. To do this, it is essential to connect Canadians to each other, to schools and libraries, to governments, and to the marketplace – so they can build on each other's ideas and share information.” (Government of Canada, 1999)

The Internet has grown extensively in Canada; initially the spread of e-mail, still the most popular Internet service, fuelled this growth. Soon after, the World Wide Web attracted new users to the Internet. The proportion of households that use the Internet has increased from 29% in 1997 to over 51% in 2000 (Figure 2-4). Growth is occurring in “all provinces and municipalities”, and those that were lagging behind are catching up (Figure 2-4 and Table 2-2) (Statistics Canada, 2001).

Provinces with the highest average incomes, Ontario, Alberta and British Columbia, have the highest rate of penetration and exceeded the national average in 1999 (Statistics Canada, 2001). In 2000 Nova Scotia and PEI increased their penetration rates to exceed the national average. Access to the Internet has become commonplace for many and still out of reach for others. To meet the federal objective to “Connect Canadians” (Government of Canada, 1999) the spatial distribution of the underlying infrastructure is required as a planning tool for infrastructure development and for consumers to assess levels of service in a manner that is analogous to cellular telephone coverage maps.

	1997	1998	1999	2000
Canada	29.4	35.9	41.8	51.3
Halifax	38.8	50.2	52.4	64.1
Québec	23.6	28.6	33.9	50.3
Montréal	24.0	31.6	39.1	46.6
Ottawa*	55.4	55.3	60.7	65.2
Toronto	37.6	42.0	48.5	57.9
Kitchener	34.8	42.4	43.7	52.7
Hamilton	30.4	41.2	43.1	54.9
St Cath.-Nia.	26.0	29.3	34.4	46.0
London	31.7	40.4	45.9	59.2
Windsor	25.5	26.8	33.6	47.5
Winnipeg	33.0	37.9	42.1	53.9
Calgary	40.3	52.8	60.1	65.2
Edmonton	35.7	43.9	48.8	59.5
Vancouver	35.5	45.7	49.7	60.0
Victoria	39.5	48.5	56.4	59.1
Top 15 CMAs	33.9	40.4	46.2	55.5
Other Households	23.2	30.0	36.1	44.7
Other CMAs			40.9	51.5
All CMAs			45.9	55.2

Table 2-2 Internet penetration rates by Census Metropolitan Area.
(Statistics Canada, 2001)

2.2.4 Potential Internet data sources to map

Moss and Townsend (2000) identify three classes of data sources to map the spatial distribution of the Internet's infrastructure, their respective strengths and weaknesses. The first class of data is the number of computers that are directly connected to the Internet, also known as hosts. Such information is available from Matrix Information and Directory Service (MIDS, 2002) or the Internet Software Consortium (2002). The location of hosts and their counts provides a technical view of the Internet as it counts all computers which are connected to the Internet. Host counts fail to differentiate between types of computers that are connected (Moss and Townsend, 2000) and treat large corporate machines in the same manner as a desktop system, both of which are connected to the Internet. Thus a large corporation that only has one point of entry to the Internet will have a smaller host presence on the Internet than a small office that has a few personal computers directly linked to the Internet.

An alternative measure is domain names, i.e. Internet addresses like `www.carleton.ca`. Domain names are more representative of a social phenomenon (e.g. number of corporations), rather than a technical one (e.g. number of buildings) (Moss and Townsend, 2000). Domain names do not account for the size of a corporation; therefore `microsoft.com` is equal to `myfishinghole.com`. Zook (2000a) provides an analysis of using host and domain counts as Internet indicators.

The third source of infrastructure information is the routing of the backbone networks that traverse the country along traditional right of ways such as railway lines, highways and telephone lines (Moss and Townsend, 2000). This information is available either directly from the Internet Service Provider or from third parties including Boardwatch Magazine's Directory of Internet Service Providers (Boardwatch, 2002). "The backbone analysis was the most complete and accurate of these three analyses because the data set involved was more limited and manageable with existing analytic techniques"(Moss and Townsend, 2000, p. 9).

2.3 Cartography and Networks

This section outlines various cartographic methods to map network(s). The initial sub-section (2.3.1) provides a synopsis of types of maps including dot, density, and line maps, all based on Cartesian geometry. A fundamental characteristic of cartography is the cardinal directions (North, South, East, West) which provide a framework to use Euclidean geometry. In Euclidean geometry parallel lines do not meet, the shortest distance between two points is a straight line and there are three dimensions (x,y,z) (Muehrcke, 2001, p. 6).

The subsequent section (2.3.2) is devoted to techniques based on non-Euclidean space. While Euclidean concepts provide a valuable framework to conceptualise space, other perspectives of space are also valuable. Non-Euclidean maps are the basis for mental maps whereby perspectives on space and time can include egocentric pathways, shortcuts, Euclidean measures, direct and indirect

experiences (Muehrcke, 2001, pp. 6-7). If we accept the premise that time is a proxy measure for distance, or time is distance in a virtual world, then Euclidean geometry assumptions are not necessarily valid when transporting data across the Internet. Data may flow along networks that may cross and meet at nodes, cross and not meet at nodes (analogous to aeroplane flight paths), the route may be circuitous and there are infinite dimensions.

The final section on cartographic methods (2.3.3) outlines the potential of multi-media to communicate the Internet's infrastructure.

2.3.1 Euclidean cartographic methods

Several cartographic methods are suitable for mapping discrete and interpreted aspects of the Internet's infrastructure. Discrete phenomena include point locations of computers, switches and linear features that connect those points.

Dot distribution maps, also called areal-frequency maps or just dot maps, have been in use since 1863 to record locations and variations in spatial density (Campbell, 1998; Dent, 1999; Muehrcke, 2001). Symbols, typically dots of a consistent diameter, are placed at precise locations and the map communicates spatial density by the number of dots and their spatial patterns. A dot may represent one object at a location, say a house, or a dot may represent many objects. One dot to one object maps are intuitive to understand but have the potential to be misleading if the dot size is incorrect for the scale of the map, or

due to human non-linear perception of density. The dot size can be determined by iteratively changing the size of the dot until the dots begin to touch and slightly overlap in those areas where the density is greatest (Dent, 1999). If a dot equals more than one object many types of dot maps can be created as outlined in Dent (1999, p. 162). Clusters of dots are a simple visual indicator of the density of the phenomena being mapped.

The visual portrayal of the spatial variations of points can be enhanced by the creation of a density surface or dot density map. A dot density map visualizes the density of dots per unit area. In the ArcMap GIS software by ESRI, the dot density map development process is defined by specifying a diameter to search an area around a point location. Points within that search area are counted and then divided by the area to arrive at a density value which is then applied to the respective cell in a raster image (ESRI, 2001).

Lines are used on maps for a variety of purposes. Their functions range from map elements of border, neatline, and labels to the symbolization of borders, linear features and flow (Dent, 1999, p. 247). When applied to an Internet environment lines indicate backbone connections between nodes, nodes typically located in urban environments. If the bandwidth of backbone connections is known then line thickness and colour can represent these aspects (Dent, 1999; Muehrcke, 2001). Lines may have arrows in order to construct a flow map that will portray a phenomenon's direction and, in conjunction with line weight, the amount of data moving across network(s). The visualisation of network

connectivity using line maps provides a point of reference to quickly assess network connectivity from a qualitative perspective. Additionally, these maps serve as a basis to derive quantitative connectivity measures based on network topology.

2.3.2 Non-Euclidean cartographic methods

This section outlines alternative perspectives on cartographic representation by linking indigenous people's mapping methods with the visualization of Internet routes and connections.

The geography of the Internet can be described in terms of both real and virtual space (Dodge, 2001; Staple, 1995). Virtual space or cyberspace is an imaginary world derived from user-driven perspectives or, in geography parlance, mental maps. Staple (1995) passionately argues that cyberspace offers rich new material for geographers and cartographers whose trade is intrinsically based on western world perspectives and priorities. Malcolm Lewis, quoted in Staple, points out that traditional North American Indian maps “differed from post-Renaissance European maps in two fundamental respects; geometrical structure and the selections and ordering of information content” (Staple, 1995, p. 4). “Cartography becomes less of a gridded stage on which life takes place and more a model of how the spiritual world and physical world interact. Abstractions such as coordinate systems are rejected in favour of more concrete representations” (Woodward and Lewis, 1998, p. 538). European maps have a projective geometry based on a co-ordinate system. Indian maps are topologically structured

“conserving connectivity between the parts, but distorting distance, angles and, hence shape” as in Figure 2-5 (Woodward, 1998, p. 82). Australia’s indigenous people’s sense of geography was similar: “Aboriginals were wanderers, [they did] not imagine territory as a block of land hemmed in by frontiers but rather as an interlocking network of ‘lines’ or ‘ways through’”. Thus as one Aboriginal explained: “All our words for ‘country’...are the same as the words for ‘line’ (Staple, 1995, p. 4). Simply put “the route is everything” (Staple, 1995, p. 4). Therefore it may be more appropriate to portray a feature's shape based on time rather than distance. A map's projection could be based on a temporal metric rather than geodesy.

2.3.3 Cybercartography

Cybercartography is a term that has been in use since 1997 to describe the application of a wide variety of media technologies for the creation, analysis and portrayal of maps. Central to cybercartography are multimedia techniques, but cybercartography also includes telecommunications technologies to access distributed data sources in order to build highly interactive maps which have the capacity to visualize multi-dimensional phenomena (Taylor, 1999).

Cybercartography products may not stand alone as traditional paper or Internet based maps do, or perform spatial analysis, but are well suited for education or communications purposes using entertainment, “edutainment” (Taylor, 1999, p. 319).

2.4 Scientific Visualization

Mapping the flow of data on computer networks has traditionally been within the realm of computer science, not geography, and the cartographic process has typically not been applied to network visualisation. Computer scientists have embraced scientific visualisation to meet the challenges of mapping computer networks unencumbered by predefined earth metrics and they pioneered the mapping of the knowledge-based economy (Becker, 1995; Cheswick, 1998; Cox, 1995; Cox, 1996; Zook, 2000a).

Scientific visualisation uses mathematical models to develop graphical representations of data, which may or may not incorporate geography and associated cartographic representation. Cartographic elements of border, title, scale, and georeferenced location and legend are not used in these attempts to visualise networks. Typical network visualisations show the interconnections of the hardware, which is the basis of a knowledge-based economy, yet they fall short of communicating the information in a manner that is meaningful to the average user.

2.5 Geography and Networks

The geography of an efficient and equitable Internet infrastructure serves an information economy by substantially increasing utilities associated with time and place by means of space-time compression.

"Utility is the capacity of a commodity or a service to satisfy some human want." "Transportation enhances the ability of goods to satisfy human wants by making goods available not only where they are needed but when they are needed. This results in time utility" (Wilson, 1954, p. 7).

"Place utility is the added economic value of a commodity created by transporting it from the place or area in which it has little or no usefulness or value to a place in which it has a greater usefulness or utility" (Wilson, 1954, p. 5).

Wilson's (1954) comments remain valid in 2002, albeit with a greater emphasis on services rather than products or commodities. These utilities can be further quantified in a network environment through the use of network analysis (graph theory) and gravity models.

Network analysis focuses on the existing structures, formed by the nodes and their linkages (Taaffe et al., 1996). Network analysis is derived from two distinct branches. Network hydrology methodology was pioneered by Horton to quantify overland water flow (Singh, 1992, p.83). Transportation and communications network topologies are based on the branch of mathematics known as 'graph theory'.

The gravity model is based on the forces of population and distance which affect flows and subsequent linkages between cities. The volume of movement (flow) is a function of supply and demand (population). Accessibility may be defined as the ease with which a specific location can be reached from a given point, a function of supply and demand. Relative accessibility introduces comparisons between those entities (Lowe and Moryadas, 1975). Gravity model concepts can be explored to estimate the accessibility to and connectivity of communication infrastructures.

2.5.1 Gravity model

The gravity model provides a simple construct and method to assess two obvious factors: interaction between any two points is directly proportional to population of those points, and inversely proportional to the distance between those points (Abler et al., 1971, p. 221; Lowe and Moryadas, 1975, p. 196), whereby:

$$I_{ij} = f\left(\frac{M_i M_j}{d_{ij}}\right)$$

where: I_{ij} = the number of interactions between places i and j during some time period,
 d_{ij} = the distance between places i and j, and
 M = some measure of the size or mass of the interacting places.

Lowe and Moryadas (1975) refer to I_{ij} as the “Interaction Energy Factor” or IEF. The relationship between the IEF and some independent variable can be assessed using a scatter plot and trend line. More elaborate gravity model equations incorporate several independent variables with parameters estimated with simple multiple regression techniques.

The application of the gravity model is explored in this thesis as a potential measure of Internet connectivity between selected census metropolitan areas.

2.5.2 Network analysis

This section reviews network analysis methods that are derived from two mathematical fields, topology² and graph theory. The structure of this section is a synthesis of work drawn primarily from Taaffe et al. (1996, pp. 249 - 286) and Campbell (1998, pp. 207 - 211), interspersed with references to several other works. In particular, Taaffe et al. (1996) provide a clear explanation on network theory, albeit with a transportation focus. Abler et al. (1971), Haggett and Chorley (1969), and Lowe and Moryadas (1975) also provide extensive information based on the application of graph theory to transportation or hydrology problems. Muehrcke et al. (2001) provide an overview of the characteristics of connectivity from a cartographic perspective. Wheeler and Kelly (1999) apply network analytical methodology to the Internet environment in the United States to assess urban connectivity based on backbone topology, and their work is reviewed further in section 2.6.5.

Both Campbell (1998, p. 207) and Haggett et al. (1969, p. 5) quote K. J. Kansky's (1963) geography definition of network: "a set of geographic locations interconnected in a system by a number of routes". This definition can be also be applied in this thesis; to assess Internet connectivity and accessibility of Canadian cities. Network analysis is based on graph theory that abstracts network topology and provides mathematical methods to quantify that topology. The relative location of objects and the connections between those objects define topology; geographic location and distance are not

² The application of network topology to transportation can be traced back to Euler's classic riddle of the seven bridges of Königsberg in 1735 (Lowe and Moryadas, p. 81, 1975)

considered. Topology is a branch of mathematics concerned with the properties of geometrical figures that remain unchanged when they are transformed by bending, stretching, shrinking, or twisting. Hence, topology focuses on relative positions and continuity. The abstraction eliminates geographic elements in order to focus on the structure of those relationships to calculate accessibility and connectivity (Campbell, 1998).

"One way to obtain a somewhat sophisticated understanding of networks is to recognise a certain isomorphism, as between different types of networks, and to focus our attention upon their fundamental characteristics, such as their configuration, connectivity and structure, ignoring such nitty-gritty questions as whether a highway is a divided one with U-turns prohibited" (Lowe and Moryadas, 1975, p. 78).

Typically, a topological graph is derived from a geographic map. Maps portray settlements, as points, or nodes, and transportation routes as lines, which can be abstracted into a series of nodes and lines that do not have geographical reference. The building blocks of graphs are nodes and lines, although different definitions and interpretations exist as the method has been applied to a variety of disciplines. "One of the complications in applying graph theory to the analysis of network structure is the very confused and overlapping terminology. Lines are commonly referred to as 'links', 'edges', 'sides', 'arcs', 'segments', 'branches', 'routes' or 'one-cells'; while points are described as 'nodes', 'vertices', 'junctions', 'intersections', 'terminals' or 'zero-cells'" (Haggett, 1969, p. 6). The following terms will be used here: *node* for a place or point, a *link* begins at one node and ends at another node, a *path* is a series of links along a series of nodes.

The choice of a proper network analysis formula depends on the classification of the network as being planar or non-planar. Planar networks are those where links are on the same plane and, if they cross, they intersect at a node, for example a rural road crossing. In a non-planar network links cross on different planes, and therefore do not intersect; for example aeroplane routes. The Internet is an undirected, non-planar network. "The backbones are undirected because traffic may flow in both directions on linkages and are nonplanar networks because linkages may cross without a node" (Wheeler et al., 1999, p. 331).

Topology is initially represented in the form of an abstract diagram, which is subsequently used to define a matrix that in turn will be used in matrix algebra calculations to quantify connectivity. The abstract diagram sets the stage to perform calculations that can assess a network as a whole, while the matrix can be used to measure components of that network.

A whole network can be assessed for connectivity, "the degree of connection between all vertices" using three measures (Taaffe, 1996, p. 250). Given the Internet mapping context, only formulae for an undirected nonplanar network are noted. Based on the number of nodes (N) the first whole network measure calculates the potential minimum, $e_{\min} = (N-1)$, and potential maximum, $e_{\max} = N(N-1)/2$, number of linkages between nodes. The second measure is the diameter of the network which simply counts the maximum number of links, hops, between the two most distant points or nodes. The third whole network measurement is the gamma index, γ , which is simply the ratio between the actual number of lines in a given network and the maximum number of lines, $\gamma = e_{\min} /$

$e_{\max}$. The gamma index is used to evaluate the relative connectivity of a network against a classification system. Networks can be classified as minimally connected as a "spinal configuration", or as a dense, highly connected "delta" network or as an intermediate "grid" network (Taaffe, 1996, p. 253).

Whole network measures are useful to compare networks within a geographic region. When comparing the networks between regions the values may also reflect the geographic shape of that region and infrastructure development in general. For example, the United States is roughly rectangular in shape with a corresponding settlement and infrastructure development pattern. Conversely, Canada's settlement pattern is somewhat linear, constrained by large northern physiogeographic areas that are sparsely populated. Even though both countries have prosperous free market economies, one would expect networks in the United States to tend towards delta networks due to many (cross) connections across the rectangle, while Canadian networks tend to be more linear along an east-west axis and probably classified as spinal at a national scale.

The internal spatial structure of network(s) can be derived using matrix algebra to quantify spatial relationships. This thesis focuses on the network measures that provide an analytical assessment of regional connectivity and associated spatial patterns. Graph theory provides a mathematical structure to quantify connectivity measures.

The first step is to build an $n \times n$ connectivity matrix from the abstract graph whereby the number of rows and columns in the matrix equal the number of nodes in the network. Each cell in the matrix contains either a zero or one. If a direct linkage exists between nodes then a one is inserted, if not, then a zero is inserted. For transportation network

analysis a node is not considered to be connected to itself, in other words, one does not leave home to drive home. Similar logic is applied to Internet network analysis by Wheeler et al. (1999).

The first measure of a region's connectivity is the "degree of the node" (Taaffe et al., 1996, p. 256) which simply counts the number of *direct links*, or one step connections, to reach each of the other nodes. The degree of the node is calculated by summing either a row or column for a particular node and it is directly related to the accessibility of that node. The phrase "you can't get there from here" denotes a low degree of accessibility, in marked contrast to the phrase "all roads lead to Rome" (Lowe and Moryadas, 1975, p. 84).

The second measure of connectivity assesses *indirect linkages* between nodes and is known as the *T-index* derived from a Total Accessibility Matrix (Taaffe et al., 1996). The original connectivity matrix, C^I , is powered to the diameter of the network. Recall that the diameter of the network is the maximum number of links between the two most separated nodes. By powering the C^I matrix by the network's diameter the resulting matrix C^P should have no zeros in it. The numeric value in the cells represent the potential number of direct and indirect linkages between the nodes. The greater the number the more connected that node is. By summing either a row or a column one arrives at a composite connectivity index for that node and can compare that value with other nodes in the matrix.

The third measure of connectivity is a measure of the one *shortest path* between nodes and is known as the Shimbel distance or *D-matrix*. "The elements of the *D-matrix*

indicate the ‘distance’ (in number of linkages) of the shortest path between all pairs of nodes in a network” (Taaffe et al., 1996, p. 268). The *D*-matrix is calculated by recording the minimum number of linkages between nodes. Consider the original connectivity matrix, C^1 , in which each cell has either a one or zero in it. The cells that contain a “one” represent nodes that are connected in one link. If the cell contains a zero then the nodes are connected in more than one link and the minimum number of links needs to be calculated by multiplying the matrices. Consider a second connectivity matrix which is the square of the original, $C^2 = C^1 * C^1$; new cells in C^2 that have non-zero values in them indicate that these nodes can be connected in two links, and therefore a 2 is transferred to the *D*-matrix for these nodal pairs. The multiplication process continues with the *D*-matrix populated at each step until C^1 has been powered to the diameter of the network, $C^1, C^2, C^3, \dots, C^p$, and no non-zero values exist in any cell. Row or column sums indicate the shortest number of links to each of the other nodes. The node with the lowest value is the most accessible node in the network (Taaffe et al., 1996, p. 270).

The analytical techniques used in network analysis have been applied to the Internet by Wheeler and Kelly (1999) to assess urban connectivity in the United States. This thesis shall employ the same techniques to assess and map Canadian urban connectivity and accessibility.

2.6 Internet Map Gallery

The following section provides selected examples of Internet mapping categorised as point maps, density surface maps, line maps, cartograms, cybercartography and non-geo-referenced diagrams from the scientific visualization community.

2.6.1 Point and density surface maps

Several authors (Brooks, 1997; Dodge and Shiode, 1998) have developed point maps of the Internet domain name locations. An organization reserves a domain name, web address, that is relevant to their business, trademark or marketing strategies. For example Carleton University has registered carleton.ca with the Canadian Internet Registration Authority ("CIRA"). The registration file contains georeferencing information (postal address, latitude and longitude) that can be mapped as discrete points.

Brooks (1997) used registry information from CANet, the predecessor to CIRA, to map .ca domain locations according to the latitude and longitude field that clients submitted to CANet during the registration process. The map symbolizes each domain name with a dot and provides a general picture of domain name locations in Canada (Figure 2-6).

Data quality and virtual address issues are evident. The most striking error is the linear series of points located east of Ellesmere and Baffin Islands due to client's confusion of latitude and longitude when registering. If the co-ordinates are reversed then these points lie within the Windsor to Quebec City corridor. The map also indicates many points within the United States. Canadian domain name registrations located in the United States can be attributed to either erroneous data or corporate offices registering "branch plant" addresses for Canada, for example yahoo.ca or microsoft.ca.

Based on data from Réseaux IP Européens (RIPE), the domain registration authority for Europe (including the United Kingdom), Dodge and Shiode (1998) plotted blocks of internet protocol addresses by postal addresses. The internet protocol (IP) address is a unique number of the form 123.255.255.123 (four sets of numbers, maximum of eight bites = $2^8 = 0-255$, separated by a period) that precisely identifies the location of an Internet host, i.e. a computer that is directly connected to the Internet (Pfaffenberger, 1994). Typically the number is not published as people prefer to remember domain names rather than numeric strings. System administrators create lookup tables that match a domain name, say www.carleton.ca, to a specific IP number, say 134.117.1.60, that, in this case, identifies a specific Carleton University computer.

Institutions are assigned blocks of IP numbers to administer within their domain. Referring to the following text box, a query is initiated from Natural Resources Canada (cosmos1.ccrs.nrcan.gc.ca) to two Carleton University websites, the main Carleton University website (www.carleton.ca) and Carleton's library (www.library.carleton.ca). The "nslookup" command is invoked to ascertain what the IP number is at each of the Carleton University sites (Table 2-3). Note that the initial digits of the IP number are the same. This high level hierarchy represents a block of IP numbers.

Dodge and Shiode (1998) mapped the allocation of 10,183 IP blocks for Britain and symbolized each allocation with a dot (Figure 2-7). Allocation units represent widely varying numbers of potential IP address. The term potential is used because while an organisation may have retained the right to a block of addresses, that does not imply they

```
C:\>nslookup www.carleton.ca
Server:  cosmos1.ccrs.nrcan.gc.ca
Address: 132.156.47.211

Non-authoritative answer:
Name:    temagami.carleton.ca
Address: 134.117.1.60
Aliases: www.carleton.ca

C:\>nslookup www.library.carleton.ca
Server:  cosmos1.ccrs.nrcan.gc.ca
Address: 132.156.47.211

Non-authoritative answer:
Name:    library1.library.carleton.ca
Address: 134.117.10.100
Aliases: www.library.carleton.ca
```

Table 2-3 nslookup to carleton.ca

Note: the nslookup is from a server at the Canada Centre for Remote Sensing, Natural Resources Canada (cosmos1.ccrs.nrcan.gc.ca) to the Carleton University main web site (www.carleton.ca) and the Carleton University Library (www.library.carleton.ca). The nslookup query returns the IP numeric address and the original name of that computer server (temagami and library1, respectively).

have allocated that address to a host. The 10,183 allocation units have 43.85 million potential IP addresses. Therefore, since each dot represents an allocation unit of variable size a continuous density surface was created using the number of IP addresses as a form of a Z (elevation) value for each point (Figure 2-8).

The key limitation associated with mapping blocks of IP ownership is the inability to ascertain how many of the IPs are actually being used. Given that an organization can register a large block with one application and Britain has a population of 57.8 million (National Statistics, 2002), it stands to reason that many of the potential 43.85 million IP addresses are not being used. The procedure to geocode the IP addresses to a postal address was not described in Dodge and Shiode (1998), but it would require detailed base maps and probably a significant amount of effort to integrate the data sets.

Brooks (1997) approached the problem by using domain names as a measure of Internet providers. This solution starts to provide a link between the hardware of the infrastructure and a commitment to build content for that IP address. Domain names are registered one at a time and are a better indicator of content development than ranges of IP addresses.

2.6.2 Line maps

Line maps are commonly used to map the topology of the Internet backbone networks. Topological maps indicate connectivity, hierarchy, and routing between an origin and a destination (Dodge, 2000, p.108; Muehrcke, 2001) and can be represented as lines or be conceptual in nature.

Figure 2-9, produced by Brian Reid and reported in Dodge (1999), maps traffic flows on USENET worldwide network, May 1993. The thickness of the lines is proportional to the traffic flow and small arrows indicate direction (Dodge, 1999). According to Reid the hardest part of the project was “devising a technique that could be used to collect usable data, and finding something that had mathematical validity in the middle of the noise” (Dodge, 1999). The issue of data availability has become acute due to Internet privatisation since Reid’s efforts. Reid’s maps suffer from dense over-plotting at a global scale and indicate the limits of line maps to map network topology.

Probably the most familiar example of a transportation network represented in topologically correct graph terms is "The Tube Map" of the London subway system. "The Tube Map" has been maintained since 1933 (London Underground Limited, 2002) (Figure 2-10). Such a topological "map" or graph shows relative location of a station (node) and rail-line (link). "Such a graph shows topological position only, the location of a node is reckoned in terms of position on the graph, regardless of its position in the real world" (Abler, 1971, p. 256).

An interesting example of a quantitative traffic flow map is provided by the map of Inter-regional Backbone Bandwidth for the United States (New York University, 2000) (Figure 2-11). Unfortunately, New York University did not publish background information with the map. Notwithstanding this limitation, the map successfully applies flow mapping techniques to aggregate traffic flows based on census regions to provide a quantitative representation, visualized based on line thickness, of traffic between geographic regions. An unexplained anomaly is the apparent lack of direct linkages between New York (Middle Atlantic) and Los Angeles (Pacific).

2.6.3 CyberCartography

Line maps of complex networks, when presented in two dimensions, tend to be quickly overloaded. Hence to provide appropriate views of network topologies multimedia techniques are employed (Cox, 1992; Munzner, 1996). One frame of the animation is provided in Figure 2-12. The visualization study of the NSFNET provides a good example of an animated line map using cybercartographic “edutainment” principles, as defined by Taylor (1999, p. 316).

Munzer (1996) developed interactive 3D maps of the global topology of another Internet network, the Multicast Backbone, or MBone, network. The screen capture (Figure 2-13) is overloaded with lines, but interactive visualisation allows the user to zoom to a regional level to discern the network lines. "The interactive 3D maps permit an immediate understanding of the global structure unavailable from the data in its original form as lines of text with only hostnames and IP addresses. Data visualization techniques such as grouping and thresholding allow further analysis of specific aspects of the

Figure 2-13 United States view of the Mbone network
(Munzner, 1996)

MBone topology" (Munzer, 1996). The portrayal helps analysts visualize, assess and optimise the topology of the network.

An excellent example of “edutainment” is the “Warriors of the Net” movie that explains how the Internet works with creative animations, sound effects and vocal variety (Ericsson Medialab, 1999) (Figure 2-14). While the movie is not cartographic in nature, it uses innovative practices that can be applied to cybercartography including the application of “friendly” concepts to complex technology, video symbology, vocalisation and complementary music. The only boundary is the cartographer’s imagination.

2.6.4 Scientific visualisation

Figure 2-15 is an example of scientific visualisation of over 100,000 network nodes, or addresses. The abstract explosion of lines is a picture of the "tin cans and string of the Internet," creating a non-geographical map of the Internet. The centrally located green-blue mass is "the magnetic north of the Internet," at the MCI switching facilities in the Chicago area (Cheswick, B. and H. Burch, 1998). The networks that make up the Internet are probed with traceroute like requests to develop a mathematical network with an arbitrary unit distance, “pookie” that are positioned in the diagram to form a tree-like network of paths (Cheswick, B. and H. Burch, 1998; Jiang, 1999). Overall, the graphic shows data relationships that are lost in numeric expressions and have the *potential* to provide early warnings about congested areas, market opportunities, and growth. “The early results looked like a peacock smashed into a windshield. Though you could pick out the major ISPs and some interesting details around the edges, the map was not very useful” (Cheswick, B. and H. Burch, 1998).

Unfortunately, it is impossible to identify location and answer questions from a geographic perspective, for instance; “Where am I in relation to other locations?” Cheswick and Burch (1998) note the “data cries for interactive visualization tools: 3D might be great [or] make a time-lapse movie of the growth of the Internet [which is] already interesting: it writhes and squirms and such.” Cybercartographic techniques based on three or four dimensions would substantially improve the utility and visual impact of this data set.

Figure 2-16 provides a similar type of visualization for Canada’s .ca domain. One could better appreciate the utility of these pictures if traditional cartographic labels, bounding box, north arrow and scale can be incorporated perhaps using emerging cybercartographic presentation techniques.

2.6.5 Network analysis

The definitive work that applies network analysis concepts to the Internet’s topology is that of David Wheeler and Morton O’Kelly (1999). By applying network analysis techniques, outlined earlier, they analysed the accessibility of 30 United States cities to the Internet by calculating the total accessibility matrix (T-matrix) and the Shimbel distance matrix (D-matrix). When appropriate data are available, they demonstrate that network analysis concepts can be applied to analyse Internet accessibility, although the results can be difficult to interpret given the non-planar and multi-dimensional Internet space.

Cities that enjoy the highest degree of accessibility occur at major network access points that are related to the relative and absolute location of a city, its regional status and concentration of information technologies. Traditional transportation hubs, including New York, Chicago, Dallas and Washington D.C. have high Internet accessibility.

2.7 Conclusion

The literature review has outlined several aspects related to mapping for an information economy from a Canadian perspective. Regional geography in Canada commonly uses the heartland - hinterland model to describe spatial patterns and interactions at a national scale. Mapping of the information economy will also reveal spatial patterns at a national scale and can be compared to Canada's heartlands and hinterlands that were defined during the eras of resource and traditional industry based economies.

Participation in the information economy depends on the level of accessibility to the Internet's physical infrastructure. Canadians have adopted the Internet to the point where it has been identified by the Canadian Government as a fundamental infrastructure. Therefore, the spatial distribution of Internet indicators are required to assess accessibility to the infrastructure. Two indicators of the Internet are domain names and backbone topology.

Various cartographic methods will be employed to portray these measures including Euclidean measures of points, lines, and surfaces and non-Euclidean representations of relative space.

Graph theory analytical techniques have been used by geographers to quantify hydrology and transportation problems, and has been applied to assess Internet connectivity and accessibility to urban areas in the United States. This technique will be applied to Canada.

A simple gravity model will be defined and used to calculate the interaction energy factor between Canada's census metropolitan areas. Interaction energy factors will be compared to the graph theory analysis for each area.

Chapter 3 - Data Collection, Preparation and Exploration

Research goals include mapping physical infrastructure of the Internet in Canada and assessing the degree of Internet connectivity through an exploration of spatial patterns using Euclidean and non-Euclidean metrics (Figure 1-1). To meet these goals data were collected from both primary and secondary sources.

This chapter describes data collection, data pre-processing operations and data exploration that provide a foundation for mapping operations in subsequent chapters. In these areas, the Internet domain brings challenges to geography and cartography. In addition to the multidimensional and temporal issues discussed in Chapter 2, the Internet has unique data collection opportunities and constraints. The Internet architecture is composed of distributed and redundant networks that are publicly accessible – seemingly a fertile ground to harvest data for geographic exploration. However, widespread commercialization of Internet services has dramatically reduced access to sources of data that measure the Internet, including domain names and the physical networks of wires and switches that make up the Internet infrastructure. Government or scientific agencies are no longer able to collect and disseminate these data as a public good. Similarly, the multitude of private sector network providers that provide those network infrastructures typically do not publish data that they deem to be proprietary or confidential (Moss and Townsend, 2000, p. 3).

Therefore, as a primary source of data collection, readily available software tools are employed that can probe or explore those portions of the Internet that are publicly accessible. Secondary sources of data are obtained from those network providers that choose to publish their network information architecture. This chapter outlines data preparation and exploration before geographic and cartographic techniques are applied in Chapter 4. Data preparation includes parsing out incomplete entries, transferring data from a publication to a digital format suitable for further analysis and assigning attributes to geographic locations. Summary statistics are used to explore the raw data in order to identify which variables are suitable for map creation. Preliminary findings are presented in this chapter as a prerequisite to the data manipulation and exploration methods that follow.

3.1 - Primary data

3.1.1 Network routing from a central point

Various diagnostic tools are used by system administrators to assess Internet connectivity (King, 2001; Pfaffenberger, 1994). The tools “ping” and “traceroute” are used to diagnose network connections. The ping utility was named after the sound that sonar makes when locating an object via an echo (Muuss, 2000). Ping is available on many operating systems, including UNIX and Windows, and is invoked by typing “ping” followed by the server name that is of interest. The program sends out packets of data to that server and times the round-trip time in milliseconds. Several parameters can be

defined during the query including the number of pings to send in a session, the size of the data packets and how long to wait for a response.

The “traceroute” utility builds on ping’s functionality by recording the path data packets take via various servers from origin to destination. The command line version of traceroute is included in UNIX (traceroute) and Windows (tracert) operating systems. Query results are presented in a tabular format. Some variations of traceroute have a graphical interface that present the query results in the form of a map. Graphical traceroute programs use a map interface in an attempt to link respective internet protocol addresses to latitude and longitude with various degrees of success. Commercial products include Neotrace, (www.neoworx.com – since bought out by McAfee.com), Visualroute (www.visualroute.com) and GeoBoy (www.ndgsoftware.com). The route is often surprising and is hardly intuitive from a traditional geographical perspective.

In order to verify that the times recorded between various cities by the ping script are comparable, network hierarchies are assessed. The “traceroute” utility was used to assess the route to each location. The first consideration is to attempt to have all test sites, ping targets, accessible from the same level of Canada’s Internet hierarchy. Most universities are accessible from the CANet infrastructure and also accept, i.e. do not block, ping requests. Traceroute analysis confirms which universities are directly connected to CANet and, if not, alternate routes are identified. The traceroute program “Visual Route” provides both tabular and map-based analysis of these connections (Figure 3-1 and Figure 3-2). These figures are particularly interesting as they demonstrate the dynamic nature of the Internet. Both instances were initiated from Ottawa to Victoria. In the first

case the route was through Chicago, at 6:32 PM; two hours later, at 8:22 PM, the second route was within Canada via Montreal. This behaviour is consistent with published network maps noted later in this chapter.

This test was repeated twice for each site with quantitative and qualitative results summarised in Table 3-3. Consistent results were obtained for all cities with the exception of Victoria, Whitehorse and Yellowknife. For these locations three tests were conducted and the one that recorded routing information was used. While this is far from statistically rigorous, it does meet the objective to confirm routing behaviour and gross estimates of the geographic distance a traceroute request covers. All links from Carleton University, Ottawa, were routed through the Ontario network, ONet, via Toronto, regardless of destination, i.e., including those points that are east of Ottawa.

3.1.2 Network timing from a central point

As discussed in Chapter 2, distance can be expressed as the time it takes to travel that distance. In order to calculate transmission times a simple sampling methodology was developed to collect temporal data based on the ping utility from a cross section of Canada's Internet. From the Carleton University server in Ottawa, Ontario, Canada, a computer script pinged 14 servers located in Federal, Provincial and Territorial capital cities across Canada. Preliminary tests were directed to government servers although some of these blocked access to the ping program. An example of a blocked ping request is noted in Table 3-1.

```
C:\>ping www.gov.nf.ca
```

```
Pinging www.gov.nf.ca [209.128.28.10] with 32 bytes of data:
```

```
Request timed out.
```

```
Request timed out.
```

```
Request timed out.
```

```
Request timed out.
```

```
Ping statistics for 209.128.28.10:
```

```
    Packets: Sent = 4, Received = 0, Lost = 4 (100% loss),
```

```
Approximate round trip times in milli-seconds:
```

```
    Minimum = 0ms, Maximum =  0ms, Average =  0ms
```

Table 3-1 Blocked Ping Request

Also, it was difficult to establish whether or not the provincial government servers were connected to comparable levels of the Internet, based on the analysis of Traceroute results. Therefore the data collection script was changed to test university sites in capital cities that do not block ping requests which are connected to CANet3 (Table 3-2).

There are four criteria to note when using this method. An initial criterion is to choose a set of web sites that share a common connectivity level of service; in other words they are on the same level of hierarchy. Otherwise, temporal variations related to intermediate network providers, “middlemen”, will be interpreted as “virtual distance”. Consider the analogy of taking a vacation by car. One may travel via an expressway or choose the scenic route. While both routes will take you to the destination, their travel times are not comparable. The architecture of CANet is publicly available and has connections to most Canadian cities providing a common hierarchy to base temporal measurements on. In southern Canada CANet connects to all of the eleven communities tested. The three northern Canadian communities are connected by a variety of service providers and the hierarchy common with a national hierarchy was not possible. Therefore this criterion was only satisfied in southern Canada. The research constraints section in Chapter 1 proposed a rationale to limit scope of the thesis in order to simplify the exploration and analysis of geographic methodologies based on a subset of Internet space. Since the northern communities are not connected via CANet3, regional networks were used in order to include these areas.

Table 3-2 Traceroute analysis summary					
City and Institution	CANet connection status	Physical Distance (km) ¹	Trace-route Distance (km) ²	# of hops	Notes
St. John's, NF Sir Wilfred Grenfell College, Memorial U.	Yes	1800	2635	11	Ottawa to Mississauga to Ottawa to Montreal to Fredericton to Halifax to St. John's
Halifax, N.S. Dalhousie U.	Yes	975	1725	11	Ottawa to Mississauga to Ottawa to Montreal to Fredericton to Halifax
Charlottetown, PEI U. of PEI	Yes	1000	1900	11	Ottawa to Mississauga to Ottawa to Montreal to Fredericton to Halifax to Charlottetown
Fredericton, NB U. of New Brunswick	Yes	715	1435	10	Ottawa to Mississauga to Ottawa to Montreal to Fredericton
Quebec City, PQ U. of Quebec	Yes	380	1112	10	Ottawa to Mississauga to Ottawa to Montreal to Quebec City
Ottawa, ON Carleton University	Yes, but not applicable	0	0	1	Traceroute to and from Carleton U., as a control sample
Toronto, ON U. of Toronto	Yes	360	1073	11	Ottawa to Mississauga to Ottawa to Toronto.
Winnipeg, MN U. of Manitoba	Yes	1700	2705	12	Ottawa to Mississauga to Ottawa to Montreal to Winnipeg
Regina, SK U. of Regina	Yes	2225	3215	13	Ottawa to Mississauga to Ottawa to Montreal to Winnipeg to Regina
Edmonton, AB U. of Alberta	Yes	2840	4210	14	Ottawa to Mississauga to Ottawa to Montreal to Winnipeg to Regina to Calgary to Edmonton
Victoria, B.C. U. of Victoria	Connection ends at Vancouver	3560	4710	15	Ottawa to Mississauga to Ottawa to Montreal to Winnipeg to Vancouver to Victoria. Final leg, Van. - Vic., by BCnet
Whitehorse, YK YK Net	No	4075	5185	16	Ottawa to Montreal to Toronto to Calgary to Whitehorse (probably via Edmonton)
Continued on next page...					

Table 3-2 Traceroute analysis summary (continued)					
City and Institution	CANet connection status	Physical Distance (km) ¹	Trace-route Distance (km)	# of hops	Notes
Yellowknife, NWT city.yellowknife.nt.ca	No	3050	6430	16	Ottawa to Montreal to Calgary to Burnaby B.C. to Whitehorse to Yellowknife
Iqaluit, NU city.iqaluit.nu.ca	No	2050	6430	19	Ottawa to Montreal to Calgary to Burnaby B.C. to Whitehorse to Yellowknife. Iqaluit server is located in Yellowknife.
Note 1: Source National Atlas of Canada, 2001					
Note 2: Measured as the "crow flies"					

The second criterion for consideration is that the candidate web sites must respond to a ping request. Typically this is true but some site administrators block access to the ping request as a security precaution. In response to increasing security threats posed by malicious hackers, system administrators have responded with a variety of precautions, including blocking ping requests (King, 2001). A large volume of ping requests can be used to initiate a denial of service attack against a server by overloading that system. Most sites that connect via CANet do respond to ping requests and a subset of those sites was used for this test. In northern Canada, government sites that respond to ping requests, or their respective Internet service provider's site, were used.

The third criterion of concern is the centralising nature of a ping request. A ping request is initiated from one server, typically a server with which one has a computer account, to query many other servers. In this case the computer account was located in Ottawa; hence data are collected from a central place resulting in an Ottawa-centric view of the world. From a computer science perspective this is a one-to-many relationship. A

more comprehensive approach would be to measure from many locations to many other locations, or a many-to-many relationship. However, the analysis of non-spatial many-to-many relationships is significantly more complex than a one-to-many relationship. Computer accounts would be required on servers that physically exist in each city to ping between each site and every other site in order to develop an $n \times n$ matrix, where n is the number of sites being tested - in this case a 14×14 matrix. Matrix algebra, probably using complete graph theory, could then be applied to derive indicators that can be mapped, potentially resulting in a three dimensional map with “worm holes”, (e.g., a short tunnel between Toronto and Vancouver that runs beneath Western Canada, hence warping a 3D projection) between cities. It is beyond the scope of this thesis to explore and map a many-to-many relationship.

The final and fourth consideration is variability. Variations of this test were conducted 12 times over a two year period. Some of the results were counter intuitive and others had anomalies that were difficult to interpret. For example, in one test Quebec City and Fredericton were “closer” to Ottawa than Ottawa was. The source of this error was an unspecified temporary network connectivity problem at Carleton University and the data were discarded. Subsequent tests did not display this phenomenon at Carleton University. In another test session Iqaluit and St. John's times would vary by a factor of ten. Again, the high variance was attributed to network instability. However, in all of the tests a general trend emerged that the farther a place was from Ottawa the longer the transmission time. Network variability arises due to time of day, network loading and other variables. While variability was noted in the statistics, the effect was minimised by

many tests with a reasonable sample size of $n=100$, while keeping in mind that the objective is to identify and map general trends.

An issue that cannot be resolved is the collection of comparable data from Canada's territories: Yukon, Northwest Territories and Nunavut. CANet3 does not reach the north but other data sources were used to give some indication of connectivity although not directly comparable with that in southern Canada.

Several parameters that can be set when running the ping utility were described in Chapter 2 and are adjusted to meet the requirements of this test. The first parameter is the number of bytes per request. This was increased from the default of 32 bytes to 2,000 bytes in order to better simulate web traffic characteristics associated with larger packets of data. Hence the parameter "Send buffer size" was changed (-l 2000). Given the larger data request the maximum allowable time for the request to process, the timeout period, was increased to 100,000 milliseconds (-w 100000). The third parameter is the number of ping requests to send out, which was set to 100, (-n 100), as a representative sample size. A separate test was run with a sample size of $n = 1,000$, although the results were not substantially different from a smaller $n = 100$ sample size. Since these tests do put a small load on the host's server it is more acceptable net etiquette to minimize the effects of this action. The script to collect the data is noted in Table 3-3.

While the data were collected on various dates a decision was made to only use the data from December 28, 2001. Previous data collection efforts tested times to provincial government servers. Unfortunately over the data collection period some sites stopped accepting ping requests, and therefore the data collection script was modified to test,

primarily, university sites connected to CANet. Therefore previous data based on government sites are not directly comparable with data from university sites and should not be mixed and risk producing a misleading map. The results of the December 28, 2001 test are on the CD in the file ping100.txt and an abridged version in Appendix “A”.

Intuitively the mean time expressed as distance would be the most suitable measure of Internet virtual distance although various descriptive statistics³ – minimum, maximum, mean, variance and standard deviation – were calculated for each sample site to explore the data for other patterns that can potentially be mapped, summarised in Table 3-4. In Figure 3-3 the average transmission time from Ottawa is plotted for each location, moving across the country from west to east, and the vertical bars indicate +/- one standard deviation. Similarly, Figure 3-4 indicates time and distance as a scatter-plot with a linear best fit trend line, associated linear equation and r^2 value. Physical distance versus traceroute distance is plotted in Figure 3-5 with a trend line, equation and r^2 value. The graphs include the northern locations of Yellowknife, Whitehorse and Iqaluit that are not connected to CA*net, and hence correlation is marginal for physical distance (km) vs. time (ms) ($r^2 = 0.511$) and increases for physical distance (km) vs. traceroute distance (km) ($r^2 = 0.737$). If the northern points are not included correlation increases substantially to ($r^2 = 0.969$) and ($r^2 = 0.979$) respectively. Transmission time is highly correlated to physical distance and traceroute distance between two points on the same network.

³ Statistical analysis is limited to descriptive statistics. Regression model assumptions (normal distribution, multicollinearity, heteroscedasticity, autocorrelation, linearity) have not been assessed and may be violated (Lee, 1993).

Table 3-3

Ping script to query response times from Canadian Universities and Territories.

```

rem ping script Canadian Universities and Northern Canadian Capital
Cities.
rem
rem NF - Memorial, Sir Wilfred Grenfell College - St. John's
ping -l 2000 -w 100000 -n 100 www.swgc.mun.ca >> ping100.txt
echo
rem NS - Dalhousie - Halifax
ping -l 2000 -w 100000 -n 100 www.dal.ca >> ping100.txt
echo
rem NB - University of New Brunswick - Fredericton
ping -l 2000 -w 100000 -n 100 www.unb.ca >> ping100.txt
echo
rem PE - University of PEI - Charlottetown
ping -l 2000 -w 100000 -n 100 www.upei.ca >> ping100.txt
echo
rem QC - Universite du Quebec - Quebec City
ping -l 2000 -w 100000 -n 100 www.uquebec.ca >> ping100.txt
echo
rem ON - Carleton University - Ottawa (Ottawa <-> Ottawa as a control
ping -l 2000 -w 100000 -n 100 rideau.carleton.ca >> ping100.txt
echo
rem ON - University of Toronto - Toronto
ping -l 2000 -w 100000 -n 100 www.utoronto.ca >> ping100.txt
echo
rem MB - University of Manitoba - Winnipeg
ping -l 2000 -w 100000 -n 100 www.umanitoba.ca >> ping100.txt
echo
rem SK - The University of Regina - Regina
ping -l 2000 -w 100000 -n 100 www.uregina.ca >> ping100.txt
echo
rem AB - University of Alberta - Edmonton
ping -l 2000 -w 100000 -n 100 www.ualberta.ca >> ping100.txt
echo
rem BC - University of Victoria - Victoria
ping -l 2000 -w 100000 -n 100 www.uvic.ca >> ping100.txt
echo
rem YK - YKNet - Whitehorse
ping -l 2000 -w 100000 -n 100 yknet.yk.ca >> ping100.txt
echo
rem NT - City of Yellowknife
ping -l 2000 -w 100000 -n 100 city.yellowknife.nt.ca >> ping100.txt
echo
rem NU - City of Iqaluit
ping -l 2000 -w 100000 -n 100 www.city.iqaluit.nu.ca >> ping100.txt

```


Table 3-4 Statistical summary of transmission times (ms)								
between Ottawa and...	URL	N sample attempted	N response	Min.	Max.	Mean	Var.	Std. Dev.
St. Johns	www.swgc.mun.ca	100	100	1221	1362	1242	185	14
Halifax	www.dal.ca	100	100	1202	1232	1225	39	6
Charlottetown	www.upei.ca	100	100	1211	1382	1232	426	21
Fredericton	www.unb.ca	100	99	1211	1252	1222	46	7
Quebec City	www.quebec.ca	100	100	1201	1302	1219	122	11
Ottawa	www.carleton.ca	100	100	1191	1221	1203	33	6
Toronto	www.utoronto.ca	100	100	1201	1362	1218	420	20
Winnipeg	www.umanitoba.ca	100	100	1221	1572	1245	1381	37
Regina	www.uregina.ca	100	100	1221	1312	1244	95	10
Edmonton	www.ualberta.ca	100	100	1251	1352	1260	140	12
Victoria	www.uvic.ca	100	100	1261	1302	1275	44	7
Whitehorse	yknet.yk.ca	100	100	1342	1523	1366	520	23
Yellowknife	city.yellowknife.nt.ca	100	100	1372	2774	1448	25642	160
qaluit	city.iqaluit.nu.ca	100	100	1331	1872	1353	2858	53

Correlation decreases if the points are not located on the same network due to the cumulative effects of factors not related to distance, for example: variable network speed / latency, switches between networks and dynamic routing.

This test was based primarily on the CA*net network with nominal difference (250 ms) between the highest transmission time (1450 ms) and the smallest (1200 ms). While the difference is not great, it is based solely on times gathered from one high speed network designed for Canada's research and development (R&D) community requirements for high bandwidth applications. The ping test places a very small load (2,000 bytes per request) in relation to the capacity of CA*net and the R&D applications which use it. Notwithstanding the capacity of CA*net, transmission time is a function of distance, that only increases as other lower capacity networks are added to reach locations outside of CA*net service.

There may also be a relationship between distance and variance due to network instabilities over long distances, but this observation was not consistent and could be attributable to other factors, including network loading, latency and switching at key infrastructure hubs in Toronto and Winnipeg. Variance is also attributed to Internet "weather storms" (Paxon, 1997), consideration of which are beyond the scope of this work.

Preliminary data preparation and analysis indicates that mean transmission time, with CANet network as the prime data source is co-related to physical distance and traceroute distance. Therefore mean transmission time will be the basis for subsequent virtual distance calculations to represent Canada in terms of virtual Internet space.

3.2 Secondary data sources

3.2.1 Canadian Internet addresses

In order to develop a dot map and dot density map of registered Internet sites in Canada a data collection and filtering operation was conducted.

Internet addresses, or Uniform Resource Locators (URLs), are registered with a central registration body. In Canada this was the function of CDNNet until December 31, 2000. As part of registering a name for a web site the latitude and longitude information was included. On January 1, 2001 the .ca domain registry function was undertaken by the Canadian Internet Registration Authority ("CIRA"). Unfortunately CIRA no longer provides a central access point for URL latitude and longitude. The CDNNet information was in the public domain as a series of text files, one text file for each registered URL. These files were downloaded from the CDNet File Transfer Protocol (FTP) site before December 31, 2000, and pre-processed in preparation for the development of a dot map of URLs registered in Canada.

The following process was adapted from Brooks (1999) to develop the dot map of .ca URL registered sites in Canada:

1. Downloaded 58,690 .ca addresses from the Canadian registrar in 1999 as a series of individual text files. Each file is organised as a series of fields, with the "Location" field stating latitude and longitude co-ordinates (Table 3-5)
2. Each of 58,690 text files were concatenated into one large text file.

3. The large text file was filtered (parsed) for lines that contain latitude and longitude information using the scripting language “awk”. The command *awk '/Location/' out.txt* extracted all lines of text that began with the word “Location”. That line contains latitude and longitude, which is output and stored in another text file, in this case “out.txt”.

4. In a spreadsheet the data were processed further:
 - Records that did not have a numeric value for a latitude and a longitude entry were deleted.
 - Entries that obviously confuse latitude with longitude are reversed.
 - Entries that fell outside the Canada’s bounding co-ordinates, [east of St.John’s (47 34N, 52 43W), south of Point Pelee (41 57N, 82 31W), west of Yukon-Alaska meridian (141W) and north of the 85th latitude)] were deleted.
 - Entries that fell south of the 49th parallel and west of 95th meridian, i.e., south of the western provinces, were deleted.

5. After data preprocessing, the sample, *n*, was 16,818 points, which represents 29% of the original population, *N*, of 58,690. Of the original population, 38,000 points were removed by the first filter, when the latitude and longitude fields were blank. The remaining 3,872 points were removed by subsequent parsing operations described above. The 16,818 georeferenced points were then for mapping and interpretation.

Table 3-5 Sample Domain Name Registration

Subdomain: ottawa-airport.ca
 Date-Received: 1997/03/26
 Date-Approved: 1997/04/02
 Date-Modified: 1997/10/31
 Organization: Ottawa MacDonald-Cartier International Airport Authority
 Type: Non-Profit Corporation, Federally Incorporated
 Description: Company managing the Ottawa Airport
 Admin-Name: Robert Louiseize
 Admin-Title: Administrator
 Admin-Postal: Ottawa MacDonald-Cartier International Airport
 50 Airport Road
 Gloucester, Ontario
 K1V 9B4
 Canada
 Admin-Phone: +1 (613) 248-2000
 Admin-Fax: +1 (613) 248-2003
 Admin-Mailbox: administrator@ottawa-airport.ca
 Tech-Name: Michel L'Ecuyer
 Tech-Title: Director
 Tech-Postal: Ottawa MacDonald-Cartier International Airport
 50 Airport Road
 Gloucester, Ontario
 K1V 9B4
 Canada
 Tech-Phone: +1 (613) 248-2010 ext 1124
 Tech-Fax: +1 (613) 248-2003
 Tech-Mailbox: support@ottawa-airport.ca
 Location: 45 26 24 N / 75 41 42 W
 Net-Provider: UUNET Canada
 Forwarder: UUCP: uunet.ca <postmaster@uunet.ca>;
 NS1-Hostname: ns.uunet.ca
 NS2-Hostname: ns2.uunet.ca
 NS3-Hostname: auth01.ns.uu.net
 Location: 43 40 12 N / 79 22 12 W
 Net-Provider: other
 NS1-Hostname: nsws2.e-mediagroup.com
 NS2-Hostname: ns.datafirm.net

3.2.2 Network topology of Canada

In order to assess a region's connectivity using network analysis it is necessary to ascertain the number and type of links that a region has with other regions. Connectivity information was derived from maps published by two networks that have a major presence in Canada. UUNet (Figure 3-6) and CANet (Figure 3-7) have points of presence throughout southern Canada. The inset map in Figure 3-6 is a more detailed view of the linkages noted in the main map for southern Ontario, particularly in the "golden horseshoe" region between St. Catharines and Toronto. The diagram or map of CANet (Figure 3-7) is a screen capture from an interactive application on their web site to monitor CANet3 network statistics using a map of Canada as a background. The on-line dynamic map attempted to communicate information at several levels. The static screen capture is very "busy" with explanatory text, navigation menus and linkages between many network "clouds". While the on-line dynamic map provides a graphical view of network statistics for computer science professionals, the ambitious representation is heresy for cartographers.

Unfortunately other backbone network Internet service providers do not publish network maps. Typically these are not published for competitiveness or security reasons as cited earlier. Thus major carriers including Bell Canada Sympatico, AT&T and Rogers are not included in this study. However, the UUNet / CANet sample is sufficiently broad in scope to explore cartographic representation and geographic interpretation of Canada's Internet network topology.

Figure 3-6 The UUNet backbone in Canada.
(Source: <http://www.uunet.ca>)

3.3 Conclusion

Chapter 3 described the collection, preparation and exploration of data for subsequent analysis. Internet data collection brings a set of challenges that most geographers are unaccustomed to. While the Internet is open for exploration, data collection is problematic due to the privatisation of the backbones and security measures; similarly, analytical methods to map the Internet are in their infancy, so data requirements have not been articulated in order to provide standardised data sets that support geographic representation of the Internet. Referring to the gallery of Internet maps in Chapter 2, the more outstanding visualisation and analytical efforts took place in the mid 1990s before the privatisation of the Internet. The combination of public domain data and research interest in the emerging World Wide Web led to several projects which produced interactive, multi-dimensional maps. Continued privatisation of Internet has, and will continue to, reduce the amount of data available for geographers to explore this space.

Notwithstanding these constraints, sufficient data have been collected to explore techniques to map the infrastructure and assess connectivity. Data processing and exploration of summary statistics were required in this chapter to guide the author, and reader, to the analytical techniques explored and implemented in Chapter 4.

Chapter 4 - Spatial Structure of the Canadian Internet

The objectives of this thesis are to explore techniques to map the Internet by applying known geographic and cartographic methodologies, as outlined in the workflow diagram Figure 1-1, based on non-Euclidean metrics and Euclidean metrics and network analysis.

Non-Euclidean methods borrow from aboriginal mapping, that place a greater value on the route rather than geographic shape, to construct a temporal projection map of Canada based on primary data collection of Internet transmission times.

Euclidean metrics form the basis of a more traditional Western cartographic process based on points, lines and areas and are used to map Internet points, point density surfaces and linear features of the networks.

Network analysis methods, traditionally used in hydrology and transportation applications, are adapted to assess how connected Canadian communities are to the Internet. This chapter presents these findings, which are further discussed in Chapter 5.

4.1 - Non-traditional space

4.1.1 Virtual distance calculation

Native Americans' primary method of transportation was to navigate rivers and lakes by canoe. In Chapter 2 a review was conducted of virtual space, or mental maps, and absolute geographic space. For the navigator of waterways, "the route is everything" (Staple, 1995) and similarly Internet navigators, perhaps unknowingly, argue that "the route is [also] everything", in terms of connection speed. The speed of a connection is

dependent on the route that data take and the capacity of that route. Just as Abler (1971) contends that a nation's geography may be measured in time, the geography of the Internet can also be measured using time. Using the time to connect between servers in various cities, maps using non-Euclidean projections of non-absolute space can be created.

This section will calculate virtual distance from time and discuss data collection and representation issues in northern Canada. Virtual distance is used as a proxy for time in order to create a map of Canada from a Lambert Conformal Conic projection to a projection based on virtual distance from Ottawa.

In Chapter 3 the collection of temporal data using the ping program was described and the routes those ping requests took were assessed using the traceroute program. The temporal data are used as a basis for the virtual distance each test site is from Ottawa. The means of the time measurements, $N=100$ per site, between Ottawa and the various regions were noted in Table 3-4 and they are used to calculate virtual distance in Table 4-1. As the ping request originated in Ottawa, the Ottawa travel time is used as a control so that the virtual distance to Ottawa is assumed to be zero and Ottawa to Ottawa ping times are normalized to zero. Times to other regions are standardized to this control by subtracting the Ottawa mean of 1203 ms from their respective times. The standardized times are then multiplied by a constant of 25 so as to estimate real world distance in kilometres. The constant of 25 approximates virtual distance to physical distance between Ottawa and Toronto, and Ottawa and Quebec City.

Table 4-1 Virtual Distance						
Ottawa and..	Location number on Figure 4-3	Mean (ms)	Less Ottawa Mean of 1203 (ms)	Virtual Distance (km) - Product of the normalized mean and a constant of 25	Actual straight line physical distance (km)	Trace-route Distance (km)
St. John's	14	1242	39	967	1800	2635
Halifax	13	1225	22	541	975	1725
Charlottetown	12	1232	29	719	1000	1900
Fredericton	11	1222	19	476	715	1435
Quebec City	10	1219	15	383	380	1112
Ottawa	9	1203	0	0	0	0
Toronto	8	1218	15	381	360	1073
Winnipeg	7	1245	41	1037	1700	2705
Regina	6	1244	41	1019	2225	3215
Edmonton	5	1260	57	1425	2840	4210
Victoria	4	1275	72	1803	3560	4710
Whitehorse	1	1366	162	4058	4075	5185
Yellowknife	2	1448	245	6124	3050	6430
Iqaluit	3	1353	150	3748	2050	6430

The relationship between virtual distance (transmission time), physical distance and traceroute distance is further quantified in Figure 4-1. The exponential trend-line indicates a positive correlation between virtual distance and physical or traceroute distance. Physical distance is defined as the straight line distance between Ottawa and the other locations. Traceroute distance is the straight line distance along traceroute paths, as dictated by a ping request, between Ottawa and the test locations, as recorded in Chapter 3. Virtual distance is more strongly correlated to traceroute distance ($r^2 = 0.7422$) than physical distance ($r^2 = 0.5088$). This observation is expected as traceroute distance represents the actual path the ping request takes. The longer the electronic path (regardless of physical distance between cities), the longer one would expect the delay to be. Similar to the transportation of goods, ping requests include an initialization time required to leave the local networks and pass through firewalls when entering and leaving Internet space (similar to loading a truck, driving in city traffic, before driving down the highway). Similarly ping requests to locations close to Ottawa include a lag time that forms a higher proportion of total travel time than for locations further away.

A visual inspection of the southern test sites graph and table indicates that the points form a near linear pattern (Figure 4-2). When the northern points are not included in the virtual distance regression analysis, the traceroute distance correlation ($r^2 = 0.9809$) and physical distance correlation ($r^2 = 0.9325$) improve substantially. This observation is consistent with one of the four sampling conditions noted in Chapter 3, that direct comparisons can only be made between network points that are accessible via the same level of network hierarchy. To properly assess more than one network a more elaborate

data collection and analysis exercise would be required to develop and process an $n \times n$ matrix.

4.1.2 Virtual distance projection

A map projection of Canada is developed that is based on time, commonly referred to as virtual distance (Dodge, 2001; Kitchen, 1998; Staple, 1995). Virtual distances derived from time, noted in Table 4-1, are used as ground control points to stretch a map of Canada that originally was in a Lambert Conformal Conic projection at a scale of 1:30M. The Lambert Conformal Conic projection is used by the Atlas of Canada to represent Canada (Atlas of Canada, 2001). The Lambert Conformal Conic projection is conformal (scale is the same in every direction, meridians and parallels cross at right angles) and the distortion of shape and distance is minimized (United States Geological Survey, date not specified).

The virtual distances are plotted as control points on a map along a line between Ottawa and the respective site. Figure 4-3A notes the actual location of the geographic points and Figure 4-3B notes the respective points according to virtual distance. The fourteen control points are located at federal, provincial and territorial capital cities (Table 4-1). Due to the limited number of control points in the far north, another three points (15, 16, 17) are included to retain some shape. The three additional points are located in a manner that roughly extrapolates from the temporal measures that were observed for the territorial capitals. A representation of Canada using virtual distance is created by reprojecting the location of the sample points from their respective geographic locations to their virtual locations. A process known as “rubber sheeting” using image analysis software from PCI Geomatics is employed to stretch the map according to the

virtual distance control points. Rubber sheeting is commonly used in image analysis to fit a remotely sensed image to ground control points. The rubber sheeting is based on the nearest neighbour algorithm which assigns a value in the new map based on the nearest value in the old map. The nearest neighbour algorithm is commonly used to rubber sheet line work. It is applicable to both discrete and continuous value types, while bilinear and cubic algorithms are only applicable to continuous data (ESRI, 2001). The resulting map of Canada in terms of virtual space, Figure 4-4, indicates the relative temporal, or virtual, distance of locations from Ottawa. The process can be repeated to create different geographic views depending on one's perspective. For example, a southern perspective may ignore the northern points and reproject based on the bounding box of Victoria, Edmonton, Windsor and St. John's. At a regional scale, Canadian technology clusters (Toronto/Ottawa/Montreal or Vancouver/Edmonton/Calgary) (Industry Canada, 2001) can be assessed for temporal variations associated with network latencies.

Depending on network capacity and network load the relative position of cities will vary. For example, major urban centres typically enjoy high bandwidth and are "close" to each other. However, as peak hour usage between urban centres approaches network capacity, service variability and delays increase, thus forcing cities to "drift apart" as virtual distance increases. A series of these maps could be animated in order to visualize traffic dynamics over time.

Figure 4-4 Canada - Virtual Space

The outstanding issue associated with this methodology is the centralized nature during data collection, i.e. the data were based on requests originating from Ottawa. However, this type of analysis is valid if the central point is coincident with one's location and geographic perspective. Later in this chapter heartlands are identified and the ping methodology could be used from those heartlands to ascertain relationships with the periphery or Internet hinterland.

4.2 - Traditional Euclidean space - a cartographic approach

4.2.1 Domain name locations - point map

A common cartographic method to represent discrete phenomena is the plotting of dots on a map. Adapting and refining Brooks' (1997) work (Figure 2-6), a dot map (Figure 4-5) was developed from the 18,343 Canadian web site addresses derived from the .ca registry in Chapter 3. A cursory examination indicates .ca web addresses cluster in urban areas, similar to Figure 2-6. Alternatively stated, there is a visual relationship between density of .ca web addresses and population. Typically URLs are in the same location as the computer server that delivers web pages, e-mail and the like to the Internet, albeit some URLs may be "aliased" to another server or a server may have multiple URLs. These errors of omission and commission are negligible when mapping spatial patterns at a national scale.

4.2.2 Dot density map of Internet addresses

From the previous Internet domain location or address registration dot map a dot density map of Canada was created (Figure 4-6). As noted in the methodology section, Chapter 2.3.1, the dot density map indicates the relative density of URLs.

An ordinal classification of URL density is applied as low, medium and high density. A ratio or interval level of measurement could not be obtained for two reasons. First, the data cleaning exercise eliminated over 40,000 points of 58,000; therefore an absolute number would be misleading. Second, during the GIS analysis process the density calculation was based on a less-than-intuitive number of URLs per 30 square kilometres. This rather odd spatial unit was chosen to balance processing time with cartographic representation at a national scale.

Nevertheless, the map does provide a good indication of the relative density of Internet servers in Canada. Dark areas indicate high URL concentrations, grey a medium density and white no URLs are registered. A similar map (Figure 4-7) provides a more detailed view of the Windsor to Quebec City corridor.

URL density follows heartland-hinterland patterns familiar to Canadian geographers (McCann, 1987).

4.2.3 Line map of network topology

As cited in Chapter 3, some Internet infrastructure providers publish their network topology. Published sources can be aggregated to produce line maps for more than one network. For example, the CANet3 website has an interactive interface to visualize near-real-time network loads (ARDNOC, 2001). From this site a line map of CANet is created (Figure 4-8). Note that network topology is maintained in order to assess a point's connectivity level, i.e., how well connected that point is to other points. The line map in Figure 4-8 is rather busy as a result of the requirement to maintain network topology and relationships to other regional and international sets of networks that are symbolized with amorphous clouds. Adding another network to the map would increase the map's complexity and would not help the reader assess the level of connectivity between points. The cartographic methods of simplification or generalisation are not well suited to assessing connectivity by mapping a hierarchy of regional, national and international networks as lines on a map that are topologically correct. Many lines from different networks would cross one another without necessarily connecting. Line maps have limitations to symbolise multiple infrastructures at varying scales, while retaining complex network topologies. Graph theory is better suited for network analysis and subsequent cartographic portrayal.

Canada - CANet3 topology
August 2001

Scale 1:35 000 000

Projection: Lambert Conformal Conic

Source: www.canet.ca

Figure 4-8 Line map of CANet

Adapted from Figure 3-7

(Canarie Advanced Research and Development Network Operations Center, 2001.

URL: <http://www.canet3.net/stats/map.html>)

4.3 - Traditional Euclidean space - a network analysis approach

4.3.1 Topology of the Canadian Internet

Figure 4-8 portrays one network, CANet, in a more cartographically correct manner than Figure 3-7, but does not resolve the problem of assessing and visualising more complex problems. To assess a location's connectivity, network analysis methods are used to quantify connectivity and accessibility, which in turn can be visualized on a map.

Transportation geography, a geography based on a network infrastructure of lines, summarises network connectivity with analysis tools such as graph theory. By applying transportation geography methodologies to the Internet, the topologies of more than one network can be mapped.

Network analysis is well suited to the problem of assessing accessibility and connectivity as described in Chapter 2. Using the line maps of various Internet service providers a city's connectivity and accessibility can be calculated. The methods are scalable so multiple networks can be added to the calculation for complete analysis of a location's connectivity. The main constraint is data availability.

This section implements network analysis methods to map the combined topologies of the CANet3 and UUNet networks. The network maps that are available from CANet3 and UUNet are summarised in a combined network topology schematic in Figure 4-9. Other infrastructures (networks, or, networks of networks) are symbolized as clouds and the switches that control traffic between infrastructures are noted. From this diagram a

matrix of connectivity between cities is built (Appendix C).

4.3.2 Connectivity matrix

Graph theory provides several measures to assess connectivity and accessibility for each node on a network based on topology abstracted from maps or other publications, and matrix algebra techniques. From an initial connectivity matrix, “C matrix”, a Total Accessibility Index, “T-matrix”, and a Shimbeld distance index, “D-matrix”, are derived.

From the abstracted topology diagram (Figure 4.9) a connectivity matrix (C1) of 40 by 40 nodes was derived, noted in Appendix C, and the spreadsheet is also available on the compact disc (CD). The first 40 by 40 connectivity matrix (C1) indicates how many potential direct links there are from each Canadian city to other cities and networks connected to UUNet and CANet3. Multiple links between locations are similarly recorded; for example there are four links between Vancouver, Seattle, Pacific rim and Western USA. Zero values indicate the respective locations cannot be connected in one link.

The last column and row are the sums of the respective row and column that indicate how connected a city is to other cities, networks and major hubs in the United States that are one link away. For example Toronto has 34 ways to make such connections, whereas Victoria has only two ways to connect in one link.

The matrix is only valid for Canadian cities. Connections between these Canadian cities and networks other than UUNet or CANet3, or cities outside of Canada (in the United States), are included to assess how well the Canadian cities are connected. The

matrix is not valid for networks other than UUNet or CANet3 or for cities in the United States, as their complete topologies were not included.

In order to connect all cities and networks to one another the “diameter” of the combined networks is calculated. From a visual inspection of Figure 4-9 the minimum number of hops, or links, to connect the two furthest locations – Victoria, British Columbia, and Moncton, New Brunswick – is five. While Moncton is closer to Victoria than Halifax in geographic distance, Moncton is one Internet network link further away than Halifax since traffic is routed via Halifax. Therefore the matrix is multiplied five times until all points are connected (Appendices D to G). The final connectivity matrix, C5, does not have any zeroes as all points are connected. A short interpretation accompanies each matrix (C1, C2, C3, C4, C5) in each appendix and on the CD.

The connectivity matrices are then used to develop the T-matrix and D-matrix. “The T-matrix is a measure of the total direct and indirect connections to a node on a network. The D-matrix, or Shimbel distance, is a measure of the shortest path between nodes in a network” (Wheeler, 1999).

The "Total accessibility matrix" (T) analysis of the connectivity matrix calculation is adapted from Taaffe (1996) and Wheeler (1999), as follows:

1. Develop a topology diagram (Figure 4-9).
2. Determine direct connections between nodes and populate the connectivity matrix with ones (direct link) and zeros (no direct link) accordingly. Relevant United States gateways are included (Seattle, Chicago, New York) in order to

weight Canadian gateways accordingly (Vancouver, Winnipeg, Toronto, Montreal) and linkages to other networks are included.

3. Determine the network's "diameter". In this case the maximum number of hops between nodes is five. This was determined by a visual examination of the topology diagram. Power the matrix by the diameter value, according to the methods outlined in Chapter Two.

4. Sum the resulting matrices to form the final T-matrix,

$$T = C1+C2+C3+C4+C5.$$

The procedure is computationally intensive for a large matrix, and therefore the computer program MatLab was used to multiply and add the matrices.

The T-matrix, Table 4-2, demonstrates that Toronto has 897,000 ways to connect to Canadian cities (including itself), other networks and major United States hubs in five links, whereas Victoria has 9,000 ways to connect in five links. Hence Toronto is more *connected* to the Internet than Victoria.

Similarly the D-matrix was calculated with the results presented in Table 4-2, using the methods outlined in Chapter 2. According to the D-matrix Toronto can connect to all Canadian cities, other networks and major United States hubs in 68 links, whereas Victoria requires 145 links. Toronto is more *accessible* than Victoria.

Table 4-2 T-matrix and D-matrix for Canadian Census Metropolitan Areas			
City	T-matrix	D-matrix	Population* (thousands)
Toronto	897,000	68	4881.4
Montreal	799,000	78	3511.8
Ottawa	443,000	93	1106.9
Halifax	248,000	105	359.2
Hamilton	244,000	104	680.6
Winnipeg	182,000	81	684.8
Quebec City	181,000	111	693.1
Calgary	178,000	90	971.5
Regina	120,000	94	198.1
Vancouver	100,000	107	2078.8
Fredericton	82,000	109	81.3
Peterborough	66,000	105	102.4
Barrie	66,000	105	148.5
Windsor	61,000	104	313.8
Kitchener-Waterloo	61,000	106	431.7
Moncton	35,000	143	117.7
Edmonton	25,000	121	956.8
St. Catharines	22,000	142	393.1
Saskatoon	17,000	115	230.5
London	11,000	140	426.3
Victoria	9,000	145	318.8
(* Statistics Canada, 2001)			

The T-index values are classified by standard deviation and plotted on a map of Canada, Figure 4-10. The results are interpreted in Chapter 5.

4.3.3 Correlation to other independent variables

Correlation analysis assessed the relationship between each location's census metropolitan area population (Table 4-2) and the T and D matrices. The Pearson correlation coefficient between population and the associate T-value is 0.885 (p-value = 0.05), and between population and the D-value is -0.589 (p-value = 0.05). A very probable strong positive relationship exists between population and the T-value or a location's connectivity. Similarly a location that enjoys good connectivity should be highly accessible, a hypothesis supported by the fact that the D-value has a negative correlation with population. The higher the population, the lower the D-value, i.e. it takes fewer links, hops, to reach this location.

4.3.4 Gravity model calculation and correlation to T-index

A simple gravity model, as outlined in section 2.5.1, was applied to calculate the "Interaction Energy Factor" (IEF), for pairs of locations. The IEF between two cities is calculated by multiplying the population of the cities and dividing by the distance between them. For example the IEF between Montreal and Ottawa is 108 which is the population of Ottawa (1,106,900) times Montreal (3,511,800) divided by distance (190 km). The calculations of the IEF for each city pair are itemized in Appendix "J". The Montreal-Toronto (59), Toronto-Ottawa (34) and Ottawa-Montreal (108) triangle exhibit

relatively large IEFs. Vancouver-Victoria has the largest IEF at 152, although the model fails to take into the account Victoria's location on an island.

Correlation between IEF and the T-index for each city pair is relatively low at $r^2 = 0.32$. The gravity model could be refined and adjusted further to increase the correlation with connectivity and accessibility. The numerator could be based on parameters other than population, for example the number of computer professionals, high technology companies, or number of domain names for each area. Depending on the availability of data, other independent variables can be used with parameters or constants estimated using multiple regression.

4.4 Conclusion

This chapter has outlined several methods to visualize and evaluate the Internet from a geographer's perspective. Concepts and techniques are borrowed from aboriginal perspectives, image analysis and transportation geography techniques to create non-conventional projections of virtual distance, traditional cartographic techniques and measurements of Internet connectivity and accessibility.

A map to represent the virtual space of the Internet was developed based on two networks. While the map has an Ottawa-centric view, it serves to explain the concept of developing a projection based on transmission time. Many variations of this map can be made to represent one's own perspective, change over time, interactive and animated display or multi-dimensional data.

A traditional dot map representing one dot per domain name was developed and indicates concentrations in the expected areas. These concentrations are further represented by way of a national and regional density map. If current data were available, more effort could be applied to filter and geographically code the data, by applying latitude and longitude in order to indicate the absolute numbers of domain names per unit area. The dot and dot density maps provides an overview of domain name concentrations that are coincident with Canada's traditional heartlands.

Network topologies are extracted from Internet service provider literature to produce more cartographically correct maps. These maps were in turn used to develop a topology diagram to develop the first connectivity matrix and ascertain the network diameter which are used to assess connectivity and accessibility using graph theory techniques. The T-matrix indicates how connected an area is to the Internet, the larger the number the more ways to connect. The D-matrix, or Shimmel distance, is a measure of accessibility, the number of direct links between locations. Locations that can be accessed with fewer links are more accessible, therefore the lower the D-matrix the more accessible is a location. These results are further discussed in the concluding chapter.

Chapter 5 - Conclusion

The concluding chapter outlines: the vision and personal observations; reviews the objectives, associated literature, results, limitations of those results and how the results could be improved with further work; and concludes by discussing the concept of heartland and hinterland in the information economy.

5.1 The vision and personal observations

The catalyst for this work on mapping the Internet was based on the observation that computer scientists, using scientific visualization methods, were attempting to map the physical infrastructure and information spaces of the Internet. As Canada's economy evolves from a natural resources and industrial base to an information services model, various geographic questions come to mind, for instance: "What patterns can be mapped in an information economy?" "Are the spatial patterns of an information economy different from Canada's classic heartlands and hinterlands?", "What is the role of a geographer in an information economy?", "Are new spatial analysis and cartographic methodologies required or can existing ones be adapted?". This paper has taken an evolutionary approach by adapting known geographic and cartographic methods, and by borrowing relevant methods from other disciplines, in an attempt to further bring geographic analytical methods and cartographic portrayal to the spatial exploration, representation and analysis of the information economy.

This Master's thesis was completed on a part-time basis over a period of five years. When initiated in the fall of 1997 very little literature was available to help define the

problems that this research would address. At that time Staple's (1995) paper provided a rationale that geography, as a discipline, would rise to the challenges of the information age. Over the period 1997 - 2002 other researchers published works around themes that adapted geographic methods to the Internet by either:

- mapping the Internet's physical infrastructure (Boardwatch, 2002; Brooks, 1997; Cheswick, 1998; Dodge and Shiode, 1998; Matrix, 1998; Moss et. al. 2000; New York University, 2000; Wheeler and O'Kelly, 1999; Zook(a), 2000), or,
- mapping the information space or Internet virtual communities (Dodge and Kitchin, 2001; Jiang and Ormeling, 1999; Kitchen, 1998;), or,
- analysing economic and spatial variations (Cairncross, 1997; Cukier, 1999; Conference Board of Canada, 1997; Estabrooks, 1997; Organisation for Economic Co-operation and Development, 1998; Staple, 1997; Zook(b), 2000).

These papers helped the objectives of this Master's thesis evolve the vision of mapping for the information economy.

5.2 Objectives

The objectives were to explore techniques to map the Internet using a subset of Canada's Internet infrastructure as an example. The research focuses on applying known geographic and cartographic methodologies to the problem of mapping the infrastructure of Canada's Internet, as outlined in the workflow diagram Figure 1-1, based on non-Euclidean metrics and Euclidean metrics.

Non-Euclidean methods borrowed from aboriginal mapping and spatio-temporal geography to create a map of Canada using a temporal or virtual distance projection.

Euclidean metrics based on points, surfaces and lines and were used to map the physical infrastructure of the Internet in Canada. Internet addresses co-ordinates and Internet Service Provider topology maps provided data to map point addresses, associated relative densities and networks.

Network analysis methods, traditionally used in hydrology and transportation applications, were adapted to assess how connected Canadian communities are to the Internet. Measures of connectivity are correlated with population and gravity model interaction energy factor.

5.2.1 Non-Euclidean projection based on time

The first objective was to explore alternative or non-Euclidean projections to represent the Internet's multi-dimensional space. Initial thoughts included three dimensional maps with high speed connections symbolized with "worm holes" tunnelling beneath the surface of the map; also multi-media were considered as a method to animate data flow. While these methods are visually appealing, they are also complex and not readily adaptable by other geographers or cartographers to build upon more classic methodologies documented over the years. Thus, an underlying objective was the adaption of existing methods, which can also be viewed as a constraint to the research process. The constraint took the form of limiting research to the use and evolution of classical geographic and cartographic methods.

A second constraint, common to most research, was the availability of data. A primary source of data collection includes the network diagnosis tools ping and traceroute to respectively measure time and routes from one location to many others. Network topology information is limited due to the privatization of much of the Internet's backbone infrastructure.

The initial attempt to build maps for an information economy was to explore spatio-temporal patterns, or in Internet parlance, "virtual distance". The rationale for associating time with distance was two-fold: when accessing information on the Internet a primary concern is the time it will take for the files to load on a local computer, and, secondly, a body of western literature speaks to the measure of distance in terms of time (Abler, 1971). Most intriguing are the works of Woodward and Lewis (1998) on indigenous peoples' maps which portray alternative perspectives on space and time, whereby "the route is everything" (Staple, 1995), and, as a result, geographic shape need not be retained. The combination of representing distance with time and not retaining geographic shape resulted in the production of a map of Canada projected according to Internet transmission time from Ottawa to provincial and territorial capitals. The process is based on a one (Ottawa) to many (provincial and territorial capitals) ping request, and therefore, has an Ottawa-centric projection. The map indicates that connectivity both between and within southern Canadian heartlands, is relatively greater than connectivity, to, and within, the North. From an Internet infrastructure perspective, urban areas within the heartlands are enjoying a spatio-temporal implosion, while rural and hinterland areas are relatively less connected.

The Ottawa-centric, temporal projection map is but one of many possible perspectives using this method, that can be easily repeated and adapted by geographers and cartographers. Other perspectives can be built by changing the location of the originating ping request(s) (e.g. from the north for a circumpolar view); location of receiving ping requests to assess regional inter-urban connectivity (e.g. in the Windsor - Quebec City corridor an analysis of rural centres: Peterborough, Trenton, Tweed, Trois Rivières etc.); or to assess continental or global connectivity – in order to assess if connectivity is appropriate to one's virtual community and, if not, mitigation measures can be assessed and applied. Further work is required to construct a many to many matrix of time from n origins to n destinations, for example from each Canadian federal, provincial, and territorial capital to every other said capital. A computer account or some other co-operative arrangement would be required in each city to issue the ping requests from and store the collected data. At a global level early examples of these co-operative data collection arrangements, to pool ping or traceroute results have emerged, but none cover Canada at this time. In the Canadian capital example the data would be stored in a 14×14 matrix (since there are 14 Canadian capitals at various jurisdictions), perhaps over time (t), to form a data cube ($14 \times 14 \times t$). Potential analytical methods include network analysis based on graph theory, temporal or four dimension geographic information systems, and multimedia visualization. Multiple international, national, and regional network dimensions could be added to the multidimensional “cube” to generate temporal virtual distance vectors using principal components analysis.

5.2.2 Euclidean representation, points, density and lines

The second objective was to map portions of Canada's Internet infrastructure using standard cartographic methods. As outlined earlier a significant constraint to this effort was data availability. In particular, network topologies and the database of .ca registrations ceased to be publically available.

The registry of Canadian internet domain names, “.ca”, includes several fields for location, including street address, city, latitude and longitude. Registrations that included valid latitude and longitude information were mapped as points on a small scale map of Canada. The effort replicated and improved upon Brooks' (1997) work by applying more rigorous filters to validate the data. Co-ordinate validation was a process of deleting those entries that did not have an entry, or the entry was not located in Canada, or reversing those entries that had confused latitude with longitude. After the validation process 16,818 of the original 58,690 registrations were available to map as point locations. Given the large sample size in relation to the population the results can be confidently considered to be indicative of the distribution of internet registrations in Canada. Typically the physical address of an internet address is associated with the location of a corporation, government or internet service provider. This location may have many internet addresses for internet sites, or conversely, the address may represent an office that has contracted access to their content to an off-site location. These discrepancies tend to negate each other. To further visualize potential trends a density surface was created from the dot map data to indicate the relative concentration of internet addresses for Canada and the Windsor to Quebec City region. Internet addresses

are a good indicator of the spatial distribution of the Internet's infrastructure and, by association, the infrastructure of an information economy. Concentrations are high in traditional heartland areas, with little or no discernible change from the heartland - hinterland maps of resources and industry generated by McCann in 1975. If the .ca registrations were available on a continuous basis a greater effort could be applied to matching the address fields in the registrations to latitude and longitude.

The CA*net network topology was used to construct a near cartographically correct line map that indicates the CA*net backbone and connections to regional networks. The intent was to include more than one network on the topology map. However, it became clear that the map would quickly become too busy to symbolize more than one network's topology, as topologically significant lines cannot be aggregated.

5.2.3 Network analysis

Wheeler and O'Kelly (1999) mapped Internet connectivity in the United States using network analysis methods. Building on their work and methodology from numerous other sources (Abler et. al., 1971; Dodge and Shiede, 1998; Haggett and Chorley, 1969; Lowe and Moryadas, 1975; Moss and Townsend, 2000; Moss et. al. 2000; New York University, 2000; Taaffe, Gauthier and O'Kelly, 1996; Zook(a), M., 2000) Internet connectivity and accessibility were calculated and mapped for Canada. UUNet and CANet network topologies were represented as an "abstract" schematic to develop a connectivity matrix (C1). The first connectivity matrix (C1) indicates the number of one step links between cities. The second connectivity matrix (C2) indicates the number of two step links exist between cities and so on. The process of matrix multiplication

continues until the diameter of the network is reached whereby all cities are connected. From the connectivity matrices (C1, C2, C3, C4, C5) a Total Accessibility index (T-matrix) and Shimbeld Distance index (D-matrix) are derived.

The T-matrix, for each location, provides a measure of connectivity and represents the total number of potential direct and indirect linkages between that location and all locations. The higher the T-matrix value, the more connected a location is. Toronto is the most connected city with 897,000 ways to get to all locations in five steps or less. Montreal (799,000) and Ottawa (443,000) rank second and third respectively. Hamilton ranks fifth, 244,000 due to its proximity and interaction with Toronto. Halifax is a regional centre for Atlantic Canada, which is reflected in a T-matrix value of 248,000, by supporting linkages from central Canada to the Atlantic region. Moncton, New Brunswick promotes information technology as part of its business development (Greater Moncton Economic Commission, 2002). However, based on the network analysis in this thesis Moncton does not enjoy a high level of connectivity (35,000) because it is at the end of a spoke served by the regional Halifax hub at the country's geographic periphery. Victoria, British Columbia, is the least connected with 9,000 potential ways to get to all locations, including itself, in five steps or less, due to its peripheral location at the edge of the country, plus it is on an island, and served by only one of the two networks being studied.

The D-matrix, or Shimbeld distance, is a measure of accessibility counted as the number of linkages via the shortest path to all other cities. The lower the number the more accessible a location is. While Toronto (68) and Montreal (78) rate first and second

as the most accessible (D-matrix) and connected cities (T-matrix), Winnipeg rose to third spot in terms of accessibility (81) replacing Ottawa for third spot. Referring to Figures 3-6, 3-7, and 4-10, Winnipeg is almost located at the geographic centre of North America. “Winnipeg has become a significant grain centre on the American continent, the financial, commercial, wholesale and manufacturing centre of the middle west, owing to its geographical position and its tremendous railway facilities” (City of Winnipeg, 2002). Telephone and data transmission lines tend to follow rail rights of way and it stands to reason that Winnipeg’s classic cross-road geographic position contributes to the topology of Canada’s networks and Winnipeg’s connectivity and accessibility to the Internet.

Correlation analysis assessed the relationship between each location's census metropolitan area population (Table 4-2) and the T and D matrices. There is a strong positive relationship between population and the T-value or a location's connectivity. Similarly, the higher the population, the lower the D-matrix, i.e. it takes fewer links, hops, to reach this location. Edmonton is a notable exception to these trends, with a relatively large population yet ranks 17th for connectivity (T-matrix = 25,000) and accessibility (D-matrix = 121) of the 21 cities studied. The anomaly is function of Edmonton’s dependence on Calgary as an entry point to the national infrastructure based on existing transportation patterns, effectively placing Edmonton at the end of the line in northern Alberta.

A simple gravity model, as outlined in section 2.5.1, was applied to calculate the "Interaction Energy Factor", IEF, for each location. Correlation between IEF and the

T-index is relatively low at $r^2 = 0.32$. Further work is required to explore methods to calibrate a gravity model using other independent variables (computer professionals, concentration of technologies, research institutions, transportation connectivity and accessibility) and constants based on multiple regression techniques. Consideration of nodal and route hierarchies (Lowe and Moryadas, 1975, pp. 102-109) in relation to gravity model is also required.

Suggested further work in the application of network theory to mapping the Internet infrastructure would incorporate: other global, continental and national networks; routing Canadian points via the United States; and incorporating bandwidth capacity when assessing connectivity and accessibility. Referring to Figure 4-9, Vancouver's rank would increase if links to the western United States and Asia, and the subsequent domino of links that cascade from there, were included in the calculation. The same holds true for Toronto's links to Chicago and Montreal's to New York.

Related to bandwidth, Wheeler and O'Kelly (1999) recommend the incorporation of network latency. By building on the work of Paxon (1997) network latency, Internet "storms" and associated virtual distance elasticity can be mapped using a combination of network analysis and cyber-cartographic methods.

5.3 Heartland – Hinterland

This thesis has developed Canadian maps based on virtual distance, URL dots, URL dot density and analytical network analysis of connectivity and accessibility. Each method has approached the visualization and spatial analysis of the Internet in Canada

from different perspectives, including time as a measure of virtual distance, commercial representation with domain name registrations and measures of connectivity and accessibility based on network topology. Based on this visual and analytical exploration one concludes that Canada's heartland remains the bastion of power in an information economy. The Canadian heartland - hinterland regions of the information economy (Figure 4-10) have evolved little from the same regions as the industrial economy (Figure 2-1). This conclusion is consistent with Wheeler and O'Kelly's (1999) analysis of United States cities; "Cities traditionally important in transportation networks and information flows - New York, Chicago, Dallas, and Washington, D.C. - are near the top of the accessibility hierarchy."

While the heartland maintains predominance, participation in the information economy via the Internet is far more elastic than traditional industrial or resource based economies. The dot map (Figure 4-5) and density maps (Figures 4-6 and 4-7) indicate participation by many hinterland communities. This is especially evident along the coastlines in the Maritimes where, one assumes, many tourist operations are using the Internet to advertise their services. Similar patterns emerge north of Toronto in "cottage country", between Edmonton and Calgary, and the interior of British Columbia. The Internet has the potential to reduce virtual distance, to subsequently modify our spatial perspectives.

The risk of a digital divide at national, inter-urban and intra-urban scales remains. This thesis has visualized the dichotomy at a national scale. Further work is required to assess potential dichotomies within urban areas. Similarly, "urban implosion" effects

need to be assessed whereby corridors between large cities tend to bypass rural communities. A potential way to represent urban implosion would map the T or D index as z values on a digital elevation model. Locations that are most accessible and connected could reside in “valleys” with connecting links symbolized by “rivers” from which a dendritic pattern of regional connections would emanate.

Governments are responsible for infrastructure and have for many years used infrastructure projects to leverage economic growth. The Canadian Government has identified Internet connectivity as a priority. While the physical infrastructures of docks, tracks and highways are tangible, with visible impact, the underlying infrastructure of an information economy is less visible and rather anonymous. Therefore it is more incumbent than ever for governments, and other groups, to monitor accessibility and connectivity to the Internet, the supporting infrastructure of the information economy. The information can be presented using readily understood communication methods, without technical obfuscation. Maps remain an ideal tool to communicate the infrastructure of the information economy using geographic analysis to synthesize the data and present it using professional cartographic art and science expertise – a key role for geographers and cartographers in an information economy.

Yes, the tyranny of space is slowly withering away as “you can (usually) get there from here” at a reasonable cost. Peripheral areas, due to either geography or topology, do not enjoy levels of connectivity and accessibility that the core, heartland areas have. The information economy and the Internet have developed many more roads to travel on, but most roads still lead to the traditional heartlands.

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Appendices

Appendix A - Abridged results of 'ping' test

Appendix B - Lambert conformal projection parameters for Canada

Appendix C - Combined CANet 3 and UUNet Connectivity matrix: C1

(Note: Appendices C to J are also recorded on the CD, in the data directory, in the spreadsheet Appendix-C-J.xls – the paper copy is difficult to read)

Appendix D - CANet 3 and UUNet Connectivity matrix: $C2 = C1 * C1$

Appendix E - CANet 3 and UUNet Connectivity matrix: $C3 = C1 * C2$

Appendix F - CANet 3 and UUNet Connectivity matrix: $C4 = C1 * C3$

Appendix G - CANet 3 and UUNet Connectivity matrix: $C5 = C1 * C4$

Appendix H - T-matrix for CANet 3 and UUNet

Appendix I - D-matrix for CANet 3 and UUNet

Appendix J - Gravity Model Calculations

Appendix K - Digital Archive of Data, References and Thesis on Compact Disc

Note: The root directory on the CD contains the following:

- 'cd-directory-list.jpg' is a listing of the files and their paths,
- 'data' directory contains data and subsequent calculations,
- 'references' directory contains replications of web references noted in the bibliography (to simplify access to web resources if the address changes and to quickly read large multimedia files)
- "thesis" directory contains the Master's thesis in Adobe "portable document format" (pdf) version 4. The Adobe Acrobat reader is available from <http://www.adobe.com>

Appendix A – Ping test results

Sample of data collected on December 28, 2001. The abbreviated results include the first of one-hundred responses and summary statistics for each test site. The summary statistics are calculated by the ping utility automatically after the hundred requests have been received.

Pinging galaxy.swgc.mun.ca [198.165.18.3] with 2000 bytes of data:

Reply from 198.165.18.3: bytes=2000 time=1242ms TTL=115

Ping statistics for 198.165.18.3:

Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 1221ms, Maximum = 1362ms, Average = 1241ms

Pinging www.compusult.nf.ca [198.165.107.139] with 2000 bytes of data:

Reply from 198.165.107.139: bytes=2000 time=1272ms TTL=244

Ping statistics for 198.165.107.139:

Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 1242ms, Maximum = 1482ms, Average = 1264ms

Pinging IS.dal.ca [129.173.1.52] with 2000 bytes of data:

Reply from 129.173.1.52: bytes=2000 time=1212ms TTL=243

Ping statistics for 129.173.1.52:

Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 1171ms, Maximum = 1252ms, Average = 1202ms

Pinging www.unb.ca [131.202.3.39] with 2000 bytes of data:

Reply from 131.202.3.39: bytes=2000 time=1202ms TTL=243

Ping statistics for 131.202.3.39:

Packets: Sent = 100, Received = 94, Lost = 6 (6% loss),

Approximate round trip times in milli-seconds:

Minimum = 1191ms, Maximum = 1232ms, Average = 1129ms

Pinging atlas.cs.upei.ca [137.149.3.1] with 2000 bytes of data:

Reply from 137.149.3.1: bytes=2000 time=1201ms TTL=53

Ping statistics for 137.149.3.1:

Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 1192ms, Maximum = 1372ms, Average = 1210ms

Pinging Panoramix.UQSS.quebec.ca [192.77.51.2] with 2000 bytes of data:

Reply from 192.77.51.2: bytes=2000 time=1202ms TTL=243

Ping statistics for 192.77.51.2:

Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 1181ms, Maximum = 1272ms, Average = 1196ms

Pinging rideau.carleton.ca [134.117.1.17] with 2000 bytes of data:

Reply from 134.117.1.17: bytes=2000 time=1181ms TTL=253

Ping statistics for 134.117.1.17:

Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 1171ms, Maximum = 1262ms, Average = 1182ms

Pinging info.utcc.utoronto.ca [128.100.132.30] with 2000 bytes of data:

Reply from 128.100.132.30: bytes=2000 time=1192ms TTL=243

Ping statistics for 128.100.132.30:

Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 1172ms, Maximum = 1212ms, Average = 1191ms

Pinging spica.cc.umanitoba.ca [130.179.16.50] with 2000 bytes of data:

Reply from 130.179.16.50: bytes=2000 time=1212ms TTL=242

Ping statistics for 130.179.16.50:

Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 1201ms, Maximum = 1613ms, Average = 1226ms

Pinging sue.cc.uregina.ca [142.3.100.15] with 2000 bytes of data:

Reply from 142.3.100.15: bytes=2000 time=1222ms TTL=241

Ping statistics for 142.3.100.15:

Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 1211ms, Maximum = 1262ms, Average = 1224ms

Pinging duff-5.ucs.ualberta.ca [129.128.5.42] with 2000 bytes of data:

Reply from 129.128.5.42: bytes=2000 time=1232ms TTL=240

Ping statistics for 129.128.5.42:

Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 1222ms, Maximum = 1272ms, Average = 1237ms

Pinging www.uvic.ca [142.104.5.64] with 2000 bytes of data:

Reply from 142.104.5.64: bytes=2000 time=1252ms TTL=238

Ping statistics for 142.104.5.64:

Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 1241ms, Maximum = 1292ms, Average = 1254ms

Pinging yknet.yk.ca [199.247.146.2] with 2000 bytes of data:

Reply from 199.247.146.2: bytes=2000 time=1462ms TTL=237

Ping statistics for 199.247.146.2:

Packets: Sent = 100, Received = 97, Lost = 3 (3% loss),

Approximate round trip times in milli-seconds:

Minimum = 1392ms, Maximum = 1533ms, Average = 1414ms

Pinging city.yellowknife.nt.ca [216.108.3.57] with 2000 bytes of data:

Reply from 216.108.3.57: bytes=2000 time=1382ms TTL=108

Ping statistics for 216.108.3.57:

Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 1342ms, Maximum = 1692ms, Average = 1378ms

Pinging webhosts.city.igaluit.nu.ca [199.247.51.199] with 2000 bytes of data:

Reply from 199.247.51.199: bytes=2000 time=1332ms TTL=238

Ping statistics for 199.247.51.199:

Packets: Sent = 100, Received = 100, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 1312ms, Maximum = 1362ms, Average = 1327ms

Appendix B - Lambert Conformal Conic projection for Canada

Lambert Conformal Conic projection parameters:

1st standard parallel	49 degrees North
2nd standard parallel	77 degrees North
central meridian	95 degrees West
latitude of projection's origin	49 degrees North
false easting (metres)	0
false northing (metres)	0

Data are referenced to the North American Datum of 1927 (NAD 27).
Spheroid is Clarke 1866

Connectivity matrix - C1

The first connectivity matrix (C1) indicates the number of one step links from each Canadian city to other cities and networks connected via UUNet and CANet3. If there is more than one, one step, link between locations, then that number is entered, for example there are 4 links between Vancouver and Seattle. A city is assumed to be connected to itself and is arbitrarily given a value of 0.

The last column and row sum these cells and indicate how connected a city is to other cities, networks and major hubs in the United States that are one step away. For example Toronto has 33 ways to connect to Canadian cities, other networks and major United States hubs in one link, whereas Victoria has 1 way to connect in one step. Zero values indicate the respective locations can not be connected in one step.

The matrix is only valid for Canadian cities. Connections between these Canadian cities and networks other than UUNet or CANet3, or cities outside of Canada (in the United States), are included to assess how well the Canadian cities are connected. The matrix is not valid for the other listed networks or United States cities as their topologies were not assessed. The matrix has 40 rows and 40 columns.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Total
Victoria	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
Vancouver	2	1	0	4	4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	12	
Seattle	3	0	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	6	
Calgary	4	0	4	1	0	1	2	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	12	
Edmonton	5	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3		
Regina	6	0	0	0	2	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	8	
Saskatoon	7	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
Winnipeg	8	0	1	0	0	0	2	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	8	
Chicago	9	0	0	0	2	0	0	0	1	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	
Toronto	10	0	0	0	1	0	1	0	1	4	0	1	1	1	0	1	4	0	3	6	0	0	0	0	3	2	0	0	0	0	1	1	1	1	0	0	0	0	0	0	33	
Peterborough	11	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
Barrie	12	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
Waterloo	13	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
London	14	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
Windsor	15	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Hamilton	16	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	
St. Catherine	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
Ottawa	18	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	9		
Montreal	19	0	0	0	0	0	0	0	1	0	6	0	0	0	0	0	0	0	4	0	2	1	3	0	5	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	23	
Quebec City	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	
Fredericton	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	
Halifax	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	12
Moncton	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
New York	24	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	
Washington	25	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
BCnet	26	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
NETERA	27	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
SRNet	28	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
MRNet	29	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
Onet	30	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
SureNet	31	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
WedNet	32	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
NRC	33	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
CRC	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
ARDNOC	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
RISQ	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
NB_ECN	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
UPEI	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
Memorial	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
DALnet	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
C1		1	12	6	12	3	6	2	8	7	33	2	2	2	2	5	1	9	23	5	3	12	2	8	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

BCnet (Vancouver, British Columbia), Netera (Calgary, Alberta), SRNet (Saskatoon, Saskatchewan), MRNet (Winnipeg, Manitoba), Onet (Mississauga, Ontario), SureNet (Ontario), WedNet (Windsor, Ontario), NRC (Ottawa, Ontario), CRC (Ottawa, Ontario), ARDNOC (O

Connectivity matrix - C2

The second connectivity matrix (C2) indicates the number of potential two step links from each Canadian city to other cities and networks connected to UUNet and CANet3. The matrix $C2 = C1 * C1$.

The last column and row sum these cells and indicate how connected a city is to other cities, networks and major hubs in the United States that are two steps away. For example Toronto has 279 ways to connect to Canadian cities (including itself), other networks and major United States hubs in two steps, whereas Victoria has 12 ways to connect in two steps. Zero values indicate the respective locations can not be connected in two steps or less.

The matrix is only valid for Canadian cities and has 40 rows and 40 columns.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Total
Victoria	1	1	0	4	4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	
Vancouver	2	0	36	4	5	4	10	2	0	9	5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	8	0	1	0	0	0	0	0	0	0	0	0	0	0	85	
Seattle	3	4	4	18	17	5	2	0	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	62	
Calgary	4	4	5	17	28	4	1	1	11	4	10	1	1	1	0	1	4	0	3	6	0	0	0	0	0	3	2	4	1	2	0	1	1	1	1	0	0	0	0	0	118	
Edmonton	5	1	4	5	4	3	2	0	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	26		
Regina	6	0	10	2	1	2	10	2	1	10	4	1	1	1	0	1	4	0	3	8	0	0	0	0	3	2	0	2	0	2	1	1	1	1	0	0	0	0	0	74		
Saskatoon	7	0	2	0	1	0	2	2	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	11		
Winnipeg	8	1	0	4	11	2	1	0	10	4	12	1	1	1	0	1	4	0	7	6	2	1	3	0	8	2	1	0	2	0	1	1	1	1	0	0	1	0	0	90		
Chicago	9	0	9	2	4	2	10	1	4	21	3	4	4	4	0	4	16	0	12	25	0	0	0	0	12	8	0	2	0	1	4	4	4	4	0	0	0	0	0	164		
Toronto	10	0	5	1	10	1	4	1	12	3	10	1	1	0	2	0	4	24	28	12	6	18	0	30	0	0	1	1	1	0	0	0	0	3	3	6	0	0	0	279		
Peterborough	11	0	0	0	1	0	1	0	1	4	1	2	1	1	0	1	4	0	3	6	0	0	0	0	3	2	0	0	0	0	1	1	1	1	0	0	0	0	0	35		
Barrie	12	0	0	0	1	0	1	0	1	4	1	1	2	1	0	1	4	0	3	6	0	0	0	0	3	2	0	0	0	0	0	1	1	1	0	0	0	0	0	35		
Waterloo	13	0	0	0	1	0	1	0	1	4	0	1	1	2	0	2	4	0	3	6	0	0	0	0	3	2	0	0	0	0	0	1	1	1	1	0	0	0	0	35		
London	14	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4		
Windsor	15	0	0	0	1	0	1	0	1	4	0	1	1	2	0	2	4	0	3	6	0	0	0	0	3	2	0	0	0	0	0	1	1	1	1	0	0	0	0	35		
Hamilton	16	0	0	0	4	0	4	0	4	16	0	4	4	4	0	4	17	0	12	24	0	0	0	0	12	8	0	0	0	0	0	4	4	4	4	0	0	0	0	133		
St. Catherine	17	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5		
Ottawa	18	0	0	0	3	0	3	0	7	12	24	3	3	3	0	3	12	0	27	18	8	4	12	0	29	6	0	0	0	0	3	3	3	3	0	0	4	0	0	193		
Montreal	19	0	1	0	6	0	8	1	6	25	28	6	6	6	0	6	24	0	18	93	9	3	7	6	18	12	0	0	0	1	6	6	6	6	4	4	0	1	3	3	332	
Quebec City	20	0	0	0	0	0	0	0	2	0	12	0	0	0	0	0	0	8	9	13	5	6	6	10	0	0	0	0	0	0	0	0	0	0	0	2	0	3	3	82		
Fredericton	21	0	0	0	0	0	0	0	1	0	6	0	0	0	0	0	0	0	4	3	5	3	3	2	5	0	0	0	0	0	0	0	0	0	0	0	1	0	1	36		
Halifax	22	0	0	0	0	0	0	0	3	0	18	0	0	0	0	0	0	12	7	6	3	26	0	15	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	94	
Moncton	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	6	2	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	24	
New York	24	0	0	0	3	0	3	0	8	12	30	3	3	3	0	3	12	0	29	18	10	5	15	0	34	6	0	0	0	0	0	3	3	3	3	0	5	0	0	214		
Washington	25	0	0	0	2	0	2	0	2	8	0	2	2	2	0	2	8	0	6	12	0	0	0	0	6	4	0	0	0	0	0	2	2	2	2	0	0	0	0	66		
BCnet	26	1	0	4	4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	12			
NETERA	27	0	8	1	1	1	2	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	18		
SRNet	28	0	0	0	2	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	6		
MRNet	29	0	1	0	0	0	2	1	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	8		
Onet	30	0	0	0	1	0	1	0	1	4	0	1	1	1	0	1	4	0	3	6	0	0	0	0	3	2	0	0	0	0	1	1	1	1	0	0	0	0	0	33		
SureNet	31	0	0	0	1	0	1	0	1	4	0	1	1	1	0	1	4	0	3	6	0	0	0	0	3	2	0	0	0	0	1	1	1	1	0	0	0	0	0	33		
WedNet	32	0	0	0	1	0	1	0	1	4	0	1	1	1	0	1	4	0	3	6	0	0	0	0	3	2	0	0	0	0	1	1	1	1	0	0	0	0	0	33		
NRC	33	0	0	0	1	0	1	0	1	4	0	1	1	1	0	1	4	0	3	6	0	0	0	0	3	2	0	0	0	0	0	1	1	1	1	0	0	0	0	33		
CRC	34	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	9		
ARDNOC	35	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	9		
RISQ	36	0	0	0	0	0	0	0	1	0	6	0	0	0	0	0	0	4	0	2	1	3	0	5	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	23		
NB_ECN	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3		
UPEI	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	12	
Memorial	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	12	
DALnet	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	12	
C2		12	85	62	118	26	74	11	90	164	279	35	35	4	35	133	5	193	332	82	36	94	24	214	66	12	18	6	8	33	33	33	33	9	9	23	3	12	12	12		

BCnet (Vancouver, British Columbia), Netera (Calgary, Alberta), SRNet (Saskatoon, Saskatchewan), MRNet (Winnipeg, Manitoba), Onet (Mississauga, Ontario), SureNet (Ontario), WedNet (Windsor, Ontario), NRC (Ottawa, Ontario), CRC (Ottawa, Ontario), ARDNOC (Ottawa, Ontario)

Connectivity matrix - C3

The third connectivity matrix (C3) indicates the potential number of three step links from each Canadian city to other cities and networks connected to UUNet and CANet3. The matrix $C3 = C1 * C2$.

The last column and row sum these cells and indicate how connected a city is to other cities, networks and major hubs in the United States that are three steps away. For example Toronto has 5087 ways to connect to Canadian cities (including itself), other networks and major United States hubs in three steps, whereas Victoria has 85 ways to connect in three steps. Zero values indicate the respective locations can not be connected in three steps or less.

The matrix is only valid for Canadian cities and has 40 rows and 40 columns.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Total
Victoria	1	0	36	4	5	4	10	2	0	9	5	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	8	0	1	0	0	0	0	0	0	0	0	0	0	85		
Vancouver	2	36	40	157	203	43	15	4	74	30	57	5	5	5	0	5	20	0	19	30	2	1	3	0	20	10	36	9	10	0	5	5	5	5	0	0	1	0	0	0	860	
Seattle	3	4	157	34	49	21	43	9	11	42	31	1	1	1	0	1	4	0	3	10	0	0	0	0	3	2	4	35	2	4	1	1	1	1	0	0	0	0	0	476		
Calgary	4	5	203	49	62	34	90	15	28	107	138	11	11	10	2	10	40	4	54	98	12	6	18	0	60	20	5	45	1	11	10	10	10	10	3	3	6	0	0	1201		
Edmonton	5	4	43	21	34	8	13	5	11	14	16	1	1	1	0	1	4	0	3	8	0	0	0	0	3	2	4	9	2	2	1	1	1	1	0	0	0	0	214			
Regina	6	10	15	43	90	13	8	3	56	19	146	5	5	4	2	4	16	4	44	52	16	8	24	0	52	8	10	3	10	1	4	4	4	4	3	3	8	0	0	701		
Saskatoon	7	2	4	9	15	5	3	0	12	6	13	1	1	1	0	1	4	0	7	6	2	1	3	0	8	2	2	1	2	0	1	1	1	1	0	0	1	0	0	116		
Winnipeg	8	0	74	11	28	11	56	12	24	80	147	13	13	12	2	12	48	4	60	165	21	9	25	6	66	24	0	15	1	10	12	12	12	12	7	7	6	1	3	3	1027	
Chicago	9	9	30	42	107	14	19	6	80	24	436	7	7	3	8	3	12	16	109	130	50	25	75	0	134	6	9	6	10	4	3	3	3	3	12	12	25	0	0	1442		
Toronto	10	5	57	31	138	16	146	13	147	436	370	102	102	103	0	103	408	0	421	954	110	46	126	36	443	202	5	11	4	12	101	101	101	101	24	24	28	6	18	18	18	5087
Peterborough	11	0	5	1	11	1	5	1	13	7	102	2	3	1	2	1	4	4	27	34	12	6	18	0	33	2	0	1	1	1	1	1	1	1	3	3	6	0	0	0	314	
Barrie	12	0	5	1	11	1	5	1	13	7	102	3	2	1	2	1	4	4	27	34	12	6	18	0	33	2	0	1	1	1	1	1	1	1	3	3	6	0	0	0	314	
Waterloo	13	0	5	1	10	1	4	1	12	3	103	1	1	0	4	0	0	4	24	28	12	6	18	0	30	0	0	1	1	1	0	0	0	0	3	3	6	0	0	0	283	
London	14	0	0	0	2	0	2	0	2	8	0	2	2	4	0	4	8	0	6	12	0	0	0	0	6	4	0	0	0	0	2	2	2	2	0	0	0	0	0	0	70	
Windsor	15	0	5	1	10	1	4	1	12	3	103	1	1	0	4	0	0	4	24	28	12	6	18	0	30	0	0	1	1	1	0	0	0	0	3	3	6	0	0	0	283	
Hamilton	16	0	20	4	40	4	16	4	48	12	408	4	4	0	8	0	0	17	96	112	48	24	72	0	120	0	0	4	4	4	0	0	0	0	12	12	24	0	0	0	1121	
St. Catherine	17	0	0	0	4	0	4	0	4	16	0	4	4	0	4	17	0	12	24	0	0	0	0	12	8	0	0	0	0	0	4	4	4	4	4	0	0	0	0	0	133	
Ottawa	18	0	19	3	54	3	44	7	60	109	421	27	27	24	6	24	96	12	144	464	72	30	82	24	162	48	0	3	3	7	24	24	24	24	27	27	18	4	12	12	2183	
Montreal	19	1	30	10	98	8	52	6	165	130	954	34	34	28	12	28	112	24	464	378	207	101	330	14	549	56	1	6	8	6	28	28	28	28	18	18	93	3	7	7	7	4111
Quebec City	20	0	2	0	12	0	16	2	21	50	110	12	12	12	0	12	48	0	72	207	36	15	92	12	81	24	0	0	0	2	12	12	12	12	8	8	9	5	6	6	946	
Fredericton	21	0	1	0	6	0	8	1	9	25	46	6	6	6	0	6	24	0	30	101	15	6	34	6	33	12	0	0	0	1	6	6	6	6	4	4	3	3	3	3	429	
Halifax	22	0	3	0	18	0	24	3	25	75	126	18	18	18	0	18	72	0	82	330	92	34	42	52	89	36	0	0	0	3	18	18	18	18	12	12	7	3	26	26	1362	
Moncton	23	0	0	0	0	0	0	0	6	0	36	0	0	0	0	0	0	0	24	14	12	6	52	0	30	0	0	0	0	0	0	0	0	0	0	0	6	2	0	0	0	188
New York	24	0	20	3	60	3	52	8	66	134	443	33	33	30	6	30	120	12	162	549	81	33	89	30	180	60	0	3	3	8	30	30	30	30	29	29	18	5	15	15	15	2497
Washington	25	0	10	2	20	2	8	2	24	6	202	2	2	0	4	0	0	8	48	56	24	12	36	0	60	0	0	2	2	2	0	0	0	0	6	6	12	0	0	0	0	558
BCnet	26	0	36	4	5	4	10	2	0	9	5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	85	
NETERA	27	8	9	35	45	9	3	1	15	6	11	1	1	1	0	1	4	0	3	6	0	0	0	0	3	2	8	2	2	0	1	1	1	1	0	0	0	0	0	0	180	
SRNet	28	0	10	2	1	2	10	2	1	10	4	1	1	1	0	1	4	0	3	8	0	0	0	0	3	2	0	2	0	2	1	1	1	1	0	0	0	0	0	0	74	
MRNet	29	1	0	4	11	2	1	0	10	4	12	1	1	1	0	1	4	0	7	6	2	1	3	0	8	2	1	0	2	0	1	1	1	1	0	0	1	0	0	0	90	
Onet	30	0	5	1	10	1	4	1	12	3	101	1	1	0	2	0	0	4	24	28	12	6	18	0	30	0	0	1	1	1	0	0	0	0	3	3	6	0	0	0	279	
SureNet	31	0	5	1	10	1	4	1	12	3	101	1	1	0	2	0	0	4	24	28	12	6	18	0	30	0	0	1	1	1	0	0	0	0	3	3	6	0	0	0	279	
WedNet	32	0	5	1	10	1	4	1	12	3	101	1	1	0	2	0	0	4	24	28	12	6	18	0	30	0	0	1	1	1	0	0	0	0	3	3	6	0	0	0	279	
NRC	33	0	5	1	10	1	4	1	12	3	101	1	1	0	2	0	0	4	24	28	12	6	18	0	30	0	0	1	1	1	0	0	0	0	3	3	6	0	0	0	279	
CRC	34	0	0	0	3	0	3	0	7	12	24	3	3	3	0	3	12	0	27	18	8	4	12	0	29	6	0	0	0	0	0	3	3	3	0	0	4	0	0	0	193	
ARDNOC	35	0	0	0	3	0	3	0	7	12	24	3	3	3	0	3	12	0	27	18	8	4	12	0	29	6	0	0	0	0	0	3	3	3	0	0	4	0	0	0	193	
RISQ	36	0	1	0	6	0	8	1	6	25	28	6	6	6	0	6	24	0	18	93	9	3	7	6	18	12	0	0	0	1	6	6	6	6	4	4	0	1	3	3	332	
NB_ECN	37	0	0	0	0	0	0	0	1	0	6	0	0	0	0	0	0	0	4	3	5	3	3	2	5	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	36
UPEI	38	0	0	0	0	0	0	0	3	0	18	0	0	0	0	0	0	0	12	7	6	3	26	0	15	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	94	
Memorial	39	0	0	0	0	0	0	0	3	0	18	0	0	0	0	0	0	0	12	7	6	3	26	0	15	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	94	
DALnet	40	0	0	0	0	0	0	0	3	0	18	0	0	0	0	0	0	0	12	7	6	3	26	0	15	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	94	
C3		85	860	476	214	701	116	###	###	###	314	314	283	70	283	###	133	###	###	###	946	429	###	188	###	558	85	180	74	90	279	279	279	279	193	193	332	36	94	94	94	

BCnet (Vancouver, British Columbia), Netera (Calgary, Alberta), SRNet (Saskatoon, Saskatchewan), MRNet (Winnipeg, Manitoba), Onet (Mississauga, Ontario), SureNet (Ontario), WedNet (Windsor, Ontario), NRC (Ottawa, Ontario), CRC (Ottawa, Ontario), ARDNOC (O)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Total
Victoria	1	36	40	157	203	43	15	4	74	30	57	5	5	0	5	20	0	19	30	2	1	3	0	20	10	36	9	10	0	5	5	5	5	0	0	1	0	0	0	0	860
Vancouver	2	40	1629	372	516	247	621	117	191	708	849	62	62	57	10	57	228	20	291	607	69	33	97	6	321	114	40	360	15	74	57	57	57	19	19	30	1	3	3	8119	
Seattle	3	157	372	712	919	215	153	32	339	233	377	32	32	31	2	31	124	4	133	224	20	10	30	0	143	62	157	83	43	11	31	31	31	3	3	10	0	0	0	4821	
Calgary	4	203	516	919	1472	280	319	62	752	704	1820	149	149	140	20	140	556	40	812	1462	250	116	336	36	904	276	203	111	90	28	138	138	138	54	54	98	6	18	18	13683	
Edmonton	5	43	247	215	280	82	108	19	114	143	208	147	16	2	16	64	4	80	134	16	8	24	0	88	32	43	55	13	11	16	16	16	16	3	3	8	0	0	0	2177	
Regina	6	15	621	153	319	108	448	69	252	820	944	151	151	148	8	148	588	16	652	1488	176	76	212	48	698	292	15	133	8	56	146	146	146	44	44	52	8	24	24	24	9617
Saskatoon	7	4	117	32	62	19	69	17	35	94	163	14	14	2	13	52	4	63	173	21	9	25	6	69	26	4	24	3	12	13	13	13	7	7	6	1	3	3	1241		
Winnipeg	8	74	191	339	752	114	252	35	600	668	2134	160	160	149	24	149	592	48	1115	1608	405	191	588	50	1266	294	74	39	56	24	147	147	147	80	60	165	9	25	25	13108	
Chicago	9	30	708	233	704	143	820	94	668	2038	1903	443	443	444	6	444	1760	12	1852	4177	485	205	565	150	1958	872	30	149	19	80	436	436	436	109	109	130	25	75	75	23777	
Toronto	10	57	849	377	1820	208	944	163	2134	1903	13341	472	472	370	206	370	1480	408	4974	6938	2286	1086	3364	252	5880	740	57	169	146	147	370	370	370	421	421	421	421	421	421	421	55313
Peterborough	11	5	62	32	149	17	151	14	160	443	472	105	104	104	2	104	412	4	448	988	122	52	144	36	476	204	5	12	5	13	102	102	102	27	27	34	6	18	18	5401	
Barrie	12	5	62	32	149	17	151	14	160	443	472	104	104	104	2	104	412	4	448	988	122	52	144	36	476	204	5	12	5	13	102	102	102	27	27	34	6	18	18	5401	
Waterloo	13	5	57	31	140	16	148	13	149	444	370	104	104	107	0	107	416	0	427	966	110	46	126	36	449	206	5	11	4	12	103	103	103	24	24	28	6	18	18	5157	
London	14	0	10	2	20	2	8	2	24	6	206	2	2	0	8	0	0	8	48	56	24	12	36	0	60	0	0	2	2	2	0	0	0	0	6	6	12	0	0	566	
Windsor	15	5	57	31	140	16	148	13	149	444	370	104	104	107	0	107	416	0	427	966	110	46	126	36	449	206	5	11	4	12	103	103	103	24	24	28	6	18	18	5157	
Hamilton	16	20	228	124	556	64	588	52	592	1760	1480	412	412	416	0	416	1649	0	1696	3840	440	184	504	144	1784	816	20	44	16	48	408	408	408	96	96	112	24	72	72	20481	
St. Catharines	17	0	20	4	40	4	16	4	48	12	408	4	4	0	8	0	0	17	96	112	48	24	72	0	120	0	0	4	4	4	0	0	0	12	12	24	0	0	0	1121	
Ottawa	18	19	291	133	812	80	632	63	1115	1852	4974	448	448	427	48	427	1696	96	3173	4410	1174	550	1722	164	3583	842	19	57	44	60	421	421	421	421	144	144	464	30	82	82	32091
Montreal	19	30	607	224	1462	134	1488	173	1608	4177	6938	988	988	966	56	966	3640	112	4410	12088	1746	711	1905	660	4752	1908	30	108	52	165	954	954	954	954	464	464	378	101	330	330	59505
Quebec City	20	2	69	20	250	16	176	21	405	485	2286	122	122	110	24	110	440	48	1174	1746	690	304	786	184	1365	220	2	12	16	21	110	110	110	110	72	72	207	15	92	92	12308
Fredericton	21	1	33	10	116	8	78	9	191	205	1086	52	52	46	12	46	184	24	550	711	304	138	375	68	643	92	1	6	8	9	46	46	46	46	30	30	101	6	34	34	5509
Halifax	22	3	97	30	336	24	212	25	588	565	3364	144	144	126	36	126	504	72	1722	1905	786	375	1482	84	2028	252	3	18	24	25	126	126	126	82	82	330	34	42	42	16258	
Moncton	23	0	6	0	36	0	48	6	50	150	252	36	36	36	0	36	144	0	164	660	184	68	84	104	178	72	0	0	0	6	36	36	36	24	24	14	6	52	52	2724	
New York	24	20	321	143	904	88	698	69	1266	1958	5880	476	476	449	60	449	1784	120	3583	4752	1365	643	2028	178	4074	886	20	63	52	66	443	443	443	162	162	549	33	89	89	35816	
Washington	25	10	114	62	276	32	292	26	294	872	740	204	204	206	0	206	816	0	842	1908	220	92	252	72	886	404	10	22	8	24	202	202	202	48	48	56	12	36	36	10174	
BCnet	26	36	40	157	203	43	15	4	74	30	57	5	5	5	0	5	20	0	19	30	2	1	3	0	20	10	36	9	10	0	5	5	5	0	0	1	0	0	0	860	
NETERA	27	9	360	83	111	55	133	24	39	149	169	12	12	11	2	11	44	4	57	108	12	6	18	0	63	22	9	80	3	15	11	11	11	3	3	6	0	0	0	1677	
SRNet	28	10	15	43	90	13	8	3	56	19	146	5	5	4	2	4	16	4	44	52	16	8	24	0	52	8	10	3	10	1	4	4	4	3	3	8	0	0	0	701	
MRNet	29	0	74	11	28	11	56	12	80	147	13	13	12	2	12	48	4	60	165	21	9	25	6	66	24	0	15	1	10	12	12	12	12	7	7	6	1	3	3	1027	
Onet	30	5	57	31	138	16	146	13	147	436	370	102	102	103	0	103	408	0	421	954	110	46	126	36	443	202	5	11	4	12	101	101	101	24	24	28	6	18	18	5087	
SureNet	31	5	57	31	138	16	146	13	147	436	370	102	102	103	0	103	408	0	421	954	110	46	126	36	443	202	5	11	4	12	101	101	101	24	24	28	6	18	18	5087	
WedNet	32	5	57	31	138	16	146	13	147	436	370	102	102	103	0	103	408	0	421	954	110	46	126	36	443	202	5	11	4	12	101	101	101	24	24	28	6	18	18	5087	
NRC	33	5	57	31	138	16	146	13	147	436	370	102	102	103	0	103	408	0	421	954	110	46	126	36	443	202	5	11	4	12	101	101	101	24	24	28	6	18	18	5087	
CRC	34	0	19	3	54	3	44	7	60	109	421	27	27	24	6	24	96	12	144	464	72	30	82	24	162	48	0	3	7	24	24	24	24	27	27	18	4	12	12	2183	
ARDNOC	35	0	19	3	54	3	44	7	60	109	421	27	27	24	6	24	96	12	144	464	72	30	82	24	162	48	0	3	7	24	24	24	24	27	27	18	4	12	12	2183	
RISQ	36	1	30	10	98	8	52	6	165	130	954	34	34	28	12	28	112	24	464	378	207	101	330	14	549	56	1	6	8	6	28	28	28	18	18	93	3	7	7	4111	
NB EGN	37	0	1	0	6	0	8	1	9	25	46	6	6	6	0	6	24	0	30	101	15	6	34	6	33	12	0	0	0	1	6	6	6	4	4	3	3	3	429		
UPEI	38	0	3	0	18	0	24	3	25	75	126	18	18	18	0	18	72	0	82	330	92	34	42	52	89	36	0	0	0	3	18	18	18	12	12	7	3	26	26	1362	
Memorial	39	0	3	0	18	0	24	3	25	75	126	18	18	18	0	18	72	0	82	330	92	34	42	52	89	36	0	0	0	3	18	18	18	12	12	7	3	26	26	1362	
DALnet	40	0	3	0	18	0	24	3	25	75	126	18	18	18	0	18	72	0	82	330	92	34	42	52	89	36	0	0	0	3	18	18									

[illegible]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	T / 1000
Victoria	1	0	1706	537	728	285	646	123	266	747	911	67	67	62	10	62	248	20	310	638	71	34	100	6	341	124	77	377	25	75	62	62	62	62	19	18	31	1	3	3	9
Vancouver	2	1706	5775	7929	11730	2557	2924	561	5492	5366	12155	978	978	921	124	921	3664	248	5323	9184	1576	739	2162	200	5923	1822	1706	1265	646	266	911	911	911	310	310	638	34	100	100	100	
Seattle	3	537	7929	3254	4633	1564	3134	595	1908	3962	5794	442	442	411	64	411	1640	128	2169	4232	558	264	772	60	2397	618	537	1751	196	354	409	409	409	136	136	234	10	30	30	53	
Calgary	4	728	11730	4633	8802	2369	6770	1110	6021	11763	25154	2130	2130	1691	302	1691	7920	600	12285	22728	4194	1926	5732	708	13737	3938	728	2548	412	791	1969	1969	1969	869	869	1566	122	354	354	178	
Edmonton	5	295	2557	1954	2369	639	1132	221	1105	1665	3567	243	243	227	34	227	904	68	1249	2384	356	196	482	48	1385	450	295	590	123	127	225	225	225	83	83	142	8	24	24	25	
Regina	6	646	2624	3134	6770	1132	2560	434	5205	5515	12490	1252	1252	1105	306	1105	4400	608	9571	14678	3904	1792	5472	472	11025	2190	646	510	467	311	1085	1085	1085	699	699	1548	84	236	236	120	
Saskatoon	7	123	561	595	1110	221	434	73	762	912	2519	182	179	28	179	28	179	56	1265	1922	444	209	640	56	1431	314	123	119	74	48	177	177	177	177	177	177	177	177	177	177	177
Winnipeg	8	266	5492	1909	6021	1105	5205	762	5798	11393	27523	2468	2468	2320	324	2320	9228	644	14136	28904	5408	2406	7021	1232	15782	4588	266	1145	311	835	2294	2294	2294	1182	1182	1780	201	616	616	182	
Chicago	9	747	5366	3962	11783	1665	5515	912	11393	11771	61484	2800	2800	2390	902	2390	9412	1788	24608	36616	10594	4997	15356	1280	26698	4692	747	1094	849	753	2346	2346	2346	1973	1973	4332	230	640	640	287	
Toronto	10	911	12155	5794	25154	3667	22490	2519	27523	61484	111076	14389	14389	14021	948	14021	55664	1862	74039	156106	26376	11406	31448	7016	81069	27626	911	2378	1095	2294	13813	13813	13813	5422	5422	7926	1138	3508	3508	997	
Peterborough	11	67	978	442	2130	243	1252	192	2468	2800	14389	685	685	580	212	580	2312	420	5900	8954	2542	1196	3670	324	6868	1152	67	194	157	174	576	576	576	478	478	1028	58	162	162	66	
Barrie	12	67	978	442	2130	243	1252	192	2468	2800	14389	686	685	580	212	580	2312	420	5900	8954	2542	1196	3670	324	6868	1152	67	194	157	174	576	576	576	478	478	1028	58	162	162	66	
Waterloo	13	62	921	411	1991	227	1105	179	2320	2360	14021	580	580	479	219	479	1900	420	5478	7994	2432	1150	3544	288	72	964	416	10	24	26	208	208	208	54	54	88	12	36	36	11	
London	14	10	124	64	302	34	306	28	324	902	948	212	212	219	10	219	890	8	906	2000	244	104	288	72	964	416	10	24	26	208	208	208	54	54	88	12	36	36	11		
Windsor	15	62	921	411	1991	227	1105	179	2320	2360	14021	580	580	479	219	479	1900	420	5478	7994	2432	1150	3544	288	72	964	416	10	24	26	208	208	208	54	54	88	12	36	36	11	
Hamilton	16	248	3664	1640	7920	904	4000	712	9228	9412	55664	2312	2312	1900	840	1900	7586	1667	21796	31840	9690	4576	14104	1152	25556	3784	248	728	608	644	1892	1892	1892	1804	1804	3976	208	576	576	244	
St. Catherine	17	20	248	128	600	88	608	56	644	1788	1892	420	420	420	8	420	1667	18	1804	3976	488	208	576	144	1916	824	20	48	20	52	412	412	412	108	108	136	24	72	72	22	
Ottawa	18	310	5323	2169	12285	1249	9571	1285	14136	24608	74039	5900	5900	5478	908	5478	21796	1804	36194	74990	15240	6746	19692	3632	40746	10844	310	1005	699	1182	5422	5422	5422	3345	3345	4896	584	1816	1816	443	
Montreal	19	638	9184	4332	22728	2384	14678	1822	28904	36616	156106	8954	8954	7994	2000	7994	31840	3978	74990	107491	31655	14910	48768	4480	86578	15952	638	1900	1548	1780	7926	7926	7926	4896	4896	12560	816	2245	2245	799	
Quebec City	20	71	1576	558	4194	356	3804	444	5408	10594	26376	2542	2542	244	2432	9690	488	15240	31655	6389	2871	9143	1774	17044	4816	71	282	192	428	2408	2408	2408	1254	1254	1964	324	837	837	181		
Fredericton	21	34	739	264	1926	168	1792	209	2406	4997	11486	1186	1186	1150	104	1150	4578	208	6746	14910	2871	1239	3634	826	7494	2276	34	132	84	201	1138	1138	1138	584	584	816	148	413	413	82	
Halifax	22	100	2182	772	928	482	5472	640	7021	15356	33148	3670	3670	3544	288	3544	14104	576	19692	48768	9143	3634	10292	3102	21749	7016	100	384	236	616	3508	3508	3508	1816	1816	2245	413	1551	1551	248	
Moncton	23	6	200	60	708	48	472	56	1232	1280	7016	324	324	288	72	288	1152	144	3632	4490	1774	826	3102	2174	4264	576	6	36	48	56	289	288	288	188	188	690	78	138	138	35	
New York	24	341	5923	2397	13737	1385	11025	1431	15782	28698	81069	6668	6668	9422	964	9422	25556	1816	40746	86578	17044	7494	4264	45688	12712	341	1113	753	1340	6356	6356	6356	3774	3774	5324	681	2132	2132	502		
Washington	25	124	1822	816	3938	450	2190	354	4588	4692	27626	1152	1152	948	416	948	3764	824	10944	15652	4816	2276	7018	576	12712	1888	124	362	302	320	944	944	944	896	896	1976	104	288	288	121	
BCnet	26	77	1706	537	728	295	646	123	266	747	911	67	67	62	10	62	248	20	310	638	71	34	100	6	341	124	77	377	25	75	62	62	62	19	19	31	1	3	3	9	
NETERA	27	377	1265	1751	2549	560	610	119	1145	1094	2378	164	194	183	24	183	728	48	1005	1800	282	132	394	36	1113	362	377	278	136	54	181	181	181	60	60	114	6	18	18	20	
SRNet	28	25	646	198	412	123	487	74	311	849	1095	157	157	153	10	153	608	20	699	1548	192	84	238	48	753	302	25	136	19	59	151	151	151	47	47	60	8	24	24	10	
MRNet	29	75	266	354	761	127	311	48	635	753	2294	174	174	162	26	162	644	52	1182	1780	428	201	616	96	1340	320	75	54	59	35	160	160	160	67	67	172	10	28	28	14	
Onet	30	62	911	409	1969	225	1095	177	2294	2346	13813	576	576	474	208	474	1892	412	5422	7926	2408	1138	3508	288	6356	944	62	181	151	160	472	472	472	448	448	968	52	144	144	61	
SureNet	31	62	911	409	1969	225	1095	177	2294	2346	13813	576	576	474	208	474	1892	412	5422	7926	2408	1138	3508	288	6356	944	62	181	151	160	472	472	472	448	448	968	52	144	144	61	
WedNet	32	62	911	409	1969	225	1095	177	2294	2346	13813	576	576	474	208	474	1892	412	5422	7926	2408	1138	3508	288	6356	944	62	181	151	160	472	472	472	448	448	968	52	144	144	61	
NRC	33	62	911	409	1969	225	1095	177	2294	2346	13813	576	576	474	208	474	1892	412	5422	7926	2408	1138	3508	288	6356	944	62	181	151	160	472	472	472	448	448	968	52	144	144	61	
CRC	34	19	310	136	869	83	699	70	1182	1973	5422	478	478	454	54	454	1804	108	3345	4896	1254	584	1816	188	3774	968	19	60	47	67	448	448	448	172	172	486	34	94	94	34	
ARDNOC	35	19	310	136	869	83	699	70	1182	1973	5422	478	478	454	54	454	1804	108	3345	4896	1254	584	1816	188	3774	968	19	60	47	67	448	448	448	172	172	486	34	94	94	34	
RISQ	36	31	638	234																																					

D-matrix

D-matrix for Canadian cities indicates their accessibility to other cities and networks connected to UUNet and CANet3. Each cell represents the fewest links between each location. It is assumed that no links are required to move within a city. The last column and row sum these cells and indicate how accessible a city is to other cities, networks and major hubs in the United States. For example Toronto can connect to all Canadian cities, other networks and major United States hubs in 68 links, whereas Victoria requires 145 links.

The matrix is only valid for Canadian cities. Connections between these Canadian cities and networks other than UUNet or CANet3, or cities outside of Canada (in the United States), are included to assess how well the Canadian cities are connected. The matrix is not valid for the other listed networks or United States cities as their full topologies were not included. The matrix has 40 rows and 40 columns.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	D-Index		
Victoria	1	0	1	2	2	2	3	3	2	3	3	4	4	4	5	4	4	5	4	3	4	4	4	5	4	4	2	3	4	3	4	4	4	4	5	5	4	5	5	5	5	145		
Vancouver	2	1	0	1	1	1	2	2	1	2	2	3	3	3	4	3	3	4	3	2	3	3	3	4	3	3	1	2	3	2	3	3	3	3	4	4	3	4	4	4	4	107		
Seattle	3	2	1	0	1	2	2	3	2	2	2	3	3	3	4	3	3	4	3	3	4	4	4	5	3	3	2	2	3	3	3	3	3	3	4	4	4	5	5	5	5	123		
Calgary	4	2	1	1	0	1	1	2	2	1	1	2	2	2	3	2	2	3	2	2	3	3	3	4	2	2	2	1	2	3	2	2	2	2	3	3	3	4	4	4	4	90		
Edmonton	5	2	1	2	1	0	2	1	2	2	2	3	3	3	4	3	3	4	3	3	4	4	4	5	3	3	2	2	3	3	3	3	3	3	4	4	4	5	5	5	5	121		
Regina	6	3	2	2	1	2	0	2	1	2	1	2	2	2	3	2	2	3	2	2	3	3	3	4	2	2	3	2	1	2	2	2	2	2	3	3	3	4	4	4	4	94		
Saskatoon	7	3	2	3	2	1	2	0	1	2	2	3	3	3	4	3	3	4	3	2	3	3	3	4	3	3	3	3	3	2	3	3	3	3	4	4	3	4	4	4	4	115		
Winnipeg	8	2	1	2	2	2	1	1	0	1	1	2	2	2	3	2	2	3	2	1	2	2	2	3	2	2	2	3	2	1	2	2	2	2	3	3	2	3	3	3	3	81		
Chicago	9	3	2	2	1	2	2	2	1	0	1	2	2	2	3	2	2	3	2	2	3	3	3	4	2	2	3	2	3	2	2	2	2	2	2	3	3	3	4	4	4	96		
Toronto	10	3	2	2	1	2	1	2	1	1	0	1	1	1	2	1	1	2	1	1	2	2	2	3	1	1	3	2	2	2	1	1	1	1	2	2	2	3	3	3	3	68		
Peterborough	11	4	3	3	2	3	2	3	2	2	1	0	1	2	3	2	2	3	2	2	3	3	3	4	2	2	4	3	3	3	2	2	2	2	2	3	3	3	4	4	4	4	105	
Barrie	12	4	3	3	2	3	2	3	2	2	1	1	0	2	3	2	2	3	2	2	3	3	3	4	2	2	4	3	3	3	2	2	2	2	2	3	3	3	4	4	4	4	105	
Waterloo	13	4	3	3	2	3	2	3	2	2	1	2	2	0	1	2	2	3	2	2	2	3	3	3	4	2	2	4	3	3	3	2	2	2	2	4	4	3	4	4	4	4	106	
London	14	5	4	4	3	4	3	4	3	3	2	3	3	1	0	1	3	4	3	3	4	4	4	5	3	3	5	4	4	4	3	3	3	3	3	4	4	4	5	5	5	5	140	
Windsor	15	4	3	3	2	3	2	3	2	2	1	2	2	2	1	0	2	3	2	2	3	3	3	4	2	2	4	3	3	3	2	2	2	2	2	3	3	3	4	4	4	4	104	
Hamilton	16	4	3	3	2	3	2	3	2	2	1	2	2	2	3	2	0	1	2	2	3	3	3	4	2	2	4	3	3	3	2	2	2	2	2	3	3	3	4	4	4	4	104	
St. Catharines	17	5	4	4	3	4	3	4	3	3	2	3	3	3	4	3	1	0	3	3	4	4	4	5	3	3	5	4	4	4	3	3	3	3	3	4	4	4	5	5	5	5	142	
Ottawa	18	4	3	3	2	3	2	3	2	2	1	2	2	2	3	2	2	3	0	1	2	2	2	3	2	2	4	3	3	3	2	2	2	2	2	1	2	2	3	3	3	3	93	
Montreal	19	3	2	3	2	3	2	2	1	2	1	2	2	2	3	2	2	3	1	0	1	1	1	2	1	2	3	3	3	2	2	2	2	2	2	2	2	1	2	2	2	2	78	
Quebec City	20	4	3	4	3	4	3	3	2	3	2	3	3	3	4	3	3	4	2	1	0	2	1	2	2	3	4	4	4	3	3	3	3	3	3	3	2	3	2	2	2	111		
Fredericton	21	4	3	4	3	4	3	3	2	3	2	3	3	3	4	3	3	4	2	1	2	0	1	2	2	3	4	4	4	3	3	3	3	3	3	3	2	1	2	2	2	109		
Halifax	22	4	3	4	3	4	3	3	2	3	2	3	3	3	4	3	3	4	2	1	1	1	0	1	2	3	4	4	4	3	3	3	3	3	3	3	2	2	1	1	1	1	105	
Moncton	23	5	4	5	4	5	4	4	3	4	3	4	4	4	5	4	4	5	3	2	2	2	1	0	3	4	5	5	5	4	4	4	4	4	4	4	4	3	3	2	2	2	143	
New York	24	4	3	3	2	3	2	3	2	2	1	2	2	2	3	2	2	3	2	2	1	2	2	2	3	0	2	4	3	3	3	2	2	2	2	2	3	2	3	3	3	3	96	
Washington	25	4	3	3	2	3	2	3	2	2	1	2	2	2	3	2	2	3	2	2	3	3	3	4	2	0	4	3	3	3	2	2	2	2	2	3	3	3	4	4	4	4	106	
BCnet	26	2	1	2	2	2	2	3	2	3	3	4	4	4	5	4	4	5	4	3	4	4	4	5	4	4	0	3	4	3	4	4	4	4	4	5	4	5	5	5	5	145		
NETERA	27	3	2	1	1	2	2	3	3	2	2	3	3	3	4	3	3	4	3	3	4	4	4	4	5	3	3	3	0	3	4	3	3	3	3	3	4	4	4	5	5	5	5	127
SRNet	28	4	3	3	2	3	1	3	2	3	2	3	3	3	4	3	3	4	3	3	4	4	4	5	3	3	4	3	0	3	3	3	3	3	3	4	4	4	5	5	5	5	132	
MRNet	29	3	2	3	3	3	2	2	1	2	2	3	3	3	4	3	3	4	3	2	3	3	3	4	3	3	3	4	3	0	3	3	3	3	3	3	4	4	3	4	4	4	119	
Onet	30	4	3	3	2	3	2	3	2	2	1	2	2	2	3	2	2	3	2	2	3	3	3	4	2	2	4	3	3	3	0	2	2	2	2	3	3	3	4	4	4	4	106	
SureNet	31	4	3	3	2	3	2	3	2	2	1	2	2	2	3	2	2	3	2	2	3	3	3	4	2	2	4	3	3	3	2	0	2	2	2	3	3	3	4	4	4	4	106	
WedNet	32	4	3	3	2	3	2	3	2	2	1	2	2	2	3	2	2	3	2	2	3	3	3	4	2	2	4	3	3	3	2	2	0	2	2	3	3	3	4	4	4	4	106	
NRC	33	4	3	3	2	3	2	3	2	2	1	2	2	2	3	2	2	3	2	2	3	3	3	4	2	2	4	3	3	3	2	2	2	0	3	3	3	3	4	4	4	4	106	
CRC	34	5	4	4	3	4	3	4	3	3	2	3	3	3	4	3	3	4	1	2	3	3	3	4	3	3	5	4	4	4	3	3	3	3	0	3	3	4	4	4	4	131		
ARDNOC	35	5	4	4	3	4	3	4	3	3	2	3	3	3	4	3	3	4	1	2	3	3	3	4	3	3	5	4	4	4	3	3	3	3	2	0	3	4	4	4	4	130		
RISQ	36	4	3	4	3	4	3	3	2	3	2	3	3	3	4	3	3	4	2	1	2	2	2	3	2	3	4	4	4	3	3	3	3	3	3	0	3	3	3	3	3	116		
NB_ECN	37	5	4	5	4	5	4	4	3	4	3	4	4	4	5	4	4	5	3	2	3	1	2	3	3	4	5	5	5	4	4	4	4	4	4	4	4	4	3	0	3	3	3	147
UPEI	38	5	4	5	4	5	4	4	3	4	3	4	4	4	5	4	4	5	3	2	2	2	1	2	3	4	5	5	5	4	4	4	4	4	4	4	4	3	0	2	2	143		
Memorial	39	5	4	5	4	5	4	4	3	4	3	4	4	4	5	4	4	5	3	2	2	2	1	2	3	4	5	5	5	4	4	4	4	4	4	4	4	4	3	2	0	143		
DALnet	40	5	4	5	4	5	4	4	3	4	3	4	4	4	5	4	4	5	3	2	2	2	1	2	3	4	5	5	5	4	4	4	4	4	4	4	4	3	2	2	0	143		
D-Index		145	107	122	90	121	94	115	81	96	88	105	105	104	140	104	104	142	92	78	111	109	105	143	96	106	145	128	132	119	106	106	106	106	131	133	116	147	143	143	143	4587		

BCnet (Vancouver, British Columbia), Netera (Calgary, Alberta), SRNet (Saskatoon, Saskatchewan), MRNet (Winnipeg, Manitoba), Onet (Mississauga, Ontario), SureNet (Ontario), WedNet (Windsor, Ontario), NRC (Ottawa, Ontario), CRC (Ottawa, Ontario), ARDNOC (Ottawa, Ontario)

	Toronto	Montreal	Ottawa	Halifax	Winnipeg	Quebec City	Calgary	Regina	Vancouver	Fredericton	Edmonton	Saskatoon	Victoria
Population	4881.4	3511.8	1106.9	359.2	684.8	693.1	971.5	198.1	2078.8	81.3	956.8	230.5	318.8
Distance (km)													
Toronto	-	539	399	1857	2099	810	3434	2670	4492	1373	3455	2927	4558
Montreal	-	-	190	1318	2408	270	3743	2979	4801	834	3764	3236	4867
Ottawa			-	1508	2218	460	3553	2789	4611	1024	3574	3046	4677
Halifax				-	3726	912	5042	4297	6119	346	5082	4554	6185
Winnipeg					-	2678	1336	571	2232	3241	1357	829	2298
Quebec City						-	4014	3249	5071	586	4035	3507	5137
Calgary							-	764	1057	4558	299	620	1123
Regina								-	1822	3813	785	257	1888
Vancouver									-	5634	1244	1677	66
Fredericton										-	4598	4070	5700
Edmonton											-	528	1310
Saskatoon												-	1743
Victoria													-
Gravity Model													
Toronto	-	59.00606	33.93962	0.50846	0.758723	5.156681	0.402149	0.135646	0.502895	0.21052	0.391264	0.131332	0.074906
Montreal	-	-	107.679	0.726165	0.414744	33.3886	0.243519	0.078392	0.316723	0.410476	0.237166	0.077301	0.047263
Ottawa			-	0.17484	0.154081	3.625673	0.085185	0.082226	0.108226	0.085822	0.082913	0.027499	0.016132
Halifax				-	0.017718	0.299325	0.013727	0.003854	0.019943	0.243935	0.013307	0.003992	0.002993
Winnipeg					-	0.066182	0.372729	0.416079	0.285751	0.0053	0.355816	0.229681	0.041341
Quebec City						-	0.041791	0.013007	0.05603	0.164093	0.040731	0.01299	0.008373
Calgary							-	0.329716	1.807613	0.003802	10.39732	0.582546	0.245585
Regina								-	0.124051	0.001108	0.307586	0.691336	0.017717
Vancouver									-	0.005324	1.285266	0.17038	152.1399
Fredericton										-	0.003679	0.001131	0.000798
Edmonton											-	0.791087	0.177745
Saskatoon												-	0.024188
Victoria													-
T-Matrix													
Toronto	-	156106	74039	33148	27523	26376	25154	22490	12155	11486	3057	2519	911
Montreal	-	-	74990	46768	28904	31855	22728	14878	9184	14910	2384	1922	638
Ottawa			-	19692	14136	15240	12285	9571	5323	6746	1249	1265	310
Halifax				-	7021	9143	5732	5472	2182	3834	482	640	100
Winnipeg					-	5408	6021	5205	5492	2406	1105	762	266
Quebec City						-	4194	3804	1576	2871	356	444	71
Calgary							-	6770	11730	1926	2369	1110	728
Regina								-	2924	1792	1132	434	646
Vancouver									-	739	2557	561	1706
Fredericton										-	166	209	34
Edmonton											-	221	295
Saskatoon												-	123
Victoria													-