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Government Information Quarterly 23 (2006) 454–479

Government Information Quarterly

Analysis of the urban/rural broadband divide in Canada: Using GIS in planning terrestrial wireless deployment

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Abstract

Millions of Canadians residing in Canada's northern, isolated, rural, and remote communities do not have broadband Internet access. This situation has led to a national "broadband divide." That is, the deployment of wireline broadband is very limited in Canada's northern, isolated, rural, and remote areas because of the significant expense of installation and maintenance of the wired infrastructure needed to reach dwellings in these locations.

Terrestrial broadband wireless technology, on the other hand, does not entail the same kind of physical infrastructure. As a result, there are dramatic changes in how spatial considerations affect the provision of broadband Internet services (BIS) to areas beyond the urban zone. In particular, the spatial question is now focused on assessing the capacity for different technological solutions to reach profitable population bases, and brings to the forefront organizations that are developing non-line-of-sight (NLOS) technologies that would permit wireless Internet access over much greater distances than current solutions.

We begin this paper by establishing the importance of broadband connectivity to Canada's northern, isolated, rural, and remote communities. This discussion comments on the role of the Government of Canada in the provision of broadband connectivity to residents of these communities, and outlines the current regulatory issues that govern wireless services and policy formulation.

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doi:10.1016/j.giq.2006.08.003

The second part of the paper illustrates the use of geographic information system (GIS) approaches in the study of wireless broadband planning and deployment. Case study findings suggest that GIS applications can make a significant contribution to the analysis of wireless deployment planning, to the understanding of the relationships between wireless signal sources and consumers, and to the spatial configuration of terrestrial wireless broadband networks. We conclude the paper by discussing how the GIS approach employed could be used to inform the public policy process with regard to increasing access to broadband Internet services in all regions of the country, and thereby providing the opportunity for all Canadians, regardless of location, to fully participate in the Information Society.

Keywords: Broadband divide; Accessibility; Infrastructure; WiMAX; 802.16; 802.22; GIS; Wireless; Terrestrial wireless; Internet; Accessibility; Spatial analysis; Social equity; Public policy

1. Introduction

We begin this paper by briefly describing broadband and related technologies for the purpose of context. We then define Canada's urban/rural broadband divide and distinguish this concern from issues involving the digital divide. Next, we establish the importance of broadband connectivity to Canada's northern, isolated, rural, and remote communities. This part of the paper considers the role of the Government of Canada in the provision of broadband connectivity to residents of these communities and outlines some of the current regulatory issues affecting wireless services and policy formulation. The second part of the paper discusses the use of geographic information systems (GIS) methods and technologies in terrestrial broadband wireless Internet service planning and deployment. To illustrate our argument, the results of a preliminary, GIS-based study of the potential market that could be served by connecting Canada's northern, isolated, rural, and remote communities to terrestrial broadband wireless technology are presented. We conclude the paper by exploring several policy issues and options arising from our investigation.

2. Broadband

Broadband telecommunications in this paper refers specifically to high-speed Internet access that connects an end-user to the Internet backbone[1] (Industry Canada, 2001). Individuals are typically connected to the Internet through an Internet Service Provider (ISP), where the transfer speeds are faster than dialing to an Internet connection that has a maximum of 56–64 kilobits per second (Kbps) (CRTC, 2004). In many present situations, broadband is being residentially provided in urban areas between 1 and 7 megabits per second (Mbps), which is roughly eighteen times the bandwidth of a dialup connection (Rogers High Speed

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[1] The Internet backbone is the wireline and wireless network infrastructure that links all the parts of the Internet together.

Internet, 2005). In 2002, Canada was above the North American average with 30% of dwellings using broadband (Alcatel, 2004). Internationally, Canada is second to South Korea in terms of broadband penetration (Phillipson, 2004). Drawing a parallel with earlier assessments of how changes in technology are affecting individuals and institutions (Wellar, 1983a), having broadband in a dwelling at the present time represents a major advance in promoting and achieving time-efficient interaction with the Internet's products, processes, and participants.

2.1. Broadband technologies

There are numerous types of broadband technologies that can be classified as either wireline or wireless links (Table 1). Wireline technologies like Digital Subscriber Line (DSL) (Cybertron, 2005) and Cable Modem (Vicomsoft, 2005) are the most commonly known; however, power-line (Tongia, 2004) and fiber optics (St. Arnaud et al., 2005) also exist. Viable alternatives to wireline include fixed wireless (WiMAX Forum, 2004a) and satellite (Industry Canada, 2004a) Some of these technologies are new and emerging, while others are in early development. Table 1 provides a framework for a brief discussion of these broadband technologies in terms of two performance criteria pertinent to remote locations, that is, location of use and range of coverage. Readers interested in detailed discussions of the respective technologies are invited to consult the references.

Each of these technologies has advantages and disadvantages. In the interests of space, we identify a limited selection of features that are relevant to this paper, beginning with DSL in the wireline group. This technology, using high frequencies via unshielded telephone wires (Peden & Young, 2001), is limited spatially because of susceptibility to interference (Czajkowski, 1999). DSL is not well-suited for locations distant (>2 km) from telephone exchanges or central offices (Mitchell, 2004). Cable modems utilize high frequencies within shielded coaxial cable and allow for greater geographic range/coverage than does DSL. However, cable is a shared medium, and signal delay of distant modems can cause transmission collisions with other signals (Dutta-Roy, 2001). Further, cable is not available in most northern, isolated, rural, and remote areas of Canada. The use of power-lines for broadband (PLB or BLP-Broadband over power line) is compromised by issues of interference within and outside the network (Baugh & Matyjas, 2004) and massive investments are required to overcome the problem (Tongia, 2004). Fiber optics, a major part of the Internet backbone, can transport massive

Table 1
Comparison of broadband technologies

	Technology	Primarily location of use	Coverage distance
Wireline	DSL	Urban	7.2 km
	Cable modem	Urban	48 km
	Power line	In development	In development
	Fiber optic	Urban	120 km
Wireless	Satellite	Rural/Remote	National
	Fixed Wireless	Rural/Urban	50 km

amounts of data over long distances without interference or signal degradation. However, fabrication and installation of optical fiber are very expensive, making this technology inappropriate for dwellings in rural areas (Frigo et al., 2003).

The most promising technologies for northern, isolated, rural, and remote areas, primarily because they do not require wireline infrastructure, are the two technologies in the wireless group, that is, satellite and fixed wireless access. In this paper, we limit our discussion to the fixed wireless access component.

Broadband wireless access (BWA) is the most flexible technology for serving dwellings which are not readily connected to a financially viable and time-efficient wired solution (Intel, 2003). Standards (IEEE 802.16–2004) set by the Institute of Electrical and Electronics Engineers (IEEE) are designed to provide for non-line-of-sight connections, low latency links (WiMAX Forum, 2004b), and coverage to a radius of up to 50 km (WiMAX Forum, 2004a; Alvarion, 2004) using both licensed and unlicensed frequency spectra (Wingfield, 2004). Further, in the near future mobility extensions will be introduced to the standards, namely IEEE 802.16e and IEEE 802.20 (WiMAX Forum, 2004b). With these extensions, the infrastructure deployed for fixed BWA will be re-used for mobile services such as cellular phones, resulting in major deployment cost reductions in remote regions.

Among the design features that make fixed BWA especially pertinent to this study is its ability to deal with connections on a link-by-link (or connection-by-connection) basis. Further, different modulation schemes are able to account for varying amounts of signal losses as well as the different data rate demands of various applications (Fujitsu Microelectronics America, 2004). Finally, BWA is purported to be appropriate for areas of low population density (WiMAX Forum, 2005), and capable of providing access for the millions of individuals who could not otherwise participate in the digital revolution (Alvarion, 2004). As a result of those design considerations, BWA is an appropriate “test bed” for assessing the contribution that GIS could make to closing Canada’s broadband divide.

3. Canada’s urban/rural broadband divide

Canada is one of the most highly urbanized countries in the world, with more than 80% of its 32 million residents living in urban areas. However, the urbanized population occupies only about 4% of the landmass. Further, almost two-thirds of the entire population is concentrated in twenty-seven major urban centers located within a few hundred kilometers of the US border (Statistics Canada, 2002; Natural Resources Canada, 2005). Or, to re-phrase for emphasis, less than 20% of the population is spread out over 96% of Canada’s vast expanse, with many of these dwellings located in the northern, remote, and isolated reaches of rural Canada (Wellar, 1989; McNiven and Puderer, 2000).

These numbers demonstrate that Canada’s urban/rural divide is significant in terms of the numbers of dwellings involved, as well as the spatial divide aspect, that is, urban concentration versus rural dispersal. As for the relationship between the population divide and the broadband divide, it is intimate and significant: approximately five million people (as of late 2004) of varying socioeconomic and demographic backgrounds live within northern, isolated, rural, and remote regions where no broadband Internet services currently exist other than satellite (Fig. 1) (Industry Canada, 2003).

The broadband access problem is acute in Canada's northern and/or isolated communities, especially those located in the Arctic, and an urgent need exists to solve the access problem in those locales (Industry Canada, 2001). As a result of broadband's superior ability to overcome physical or geographic distance with regard to communications, the argument can be made that broadband contributes to increased quality of life (Industry Canada, 2001). The basis of the argument, which is similar in structure to societal assessments of previous advances in information technology (Wellar, 1977, 1983b), is that individuals who can fully utilize bandwidth-intensive Web sites for data/information gathering and other communications-based services, are enabled to perform or function at higher individual and community levels (Industry Canada, 2001; Gómez-Barroso & Pérez-Martínez, 2005).

As a result, and again, in parallel with assessments of previous milestone developments in the field of computers/communications (Wellar, 1977, 1983a,b), broadband technologies are

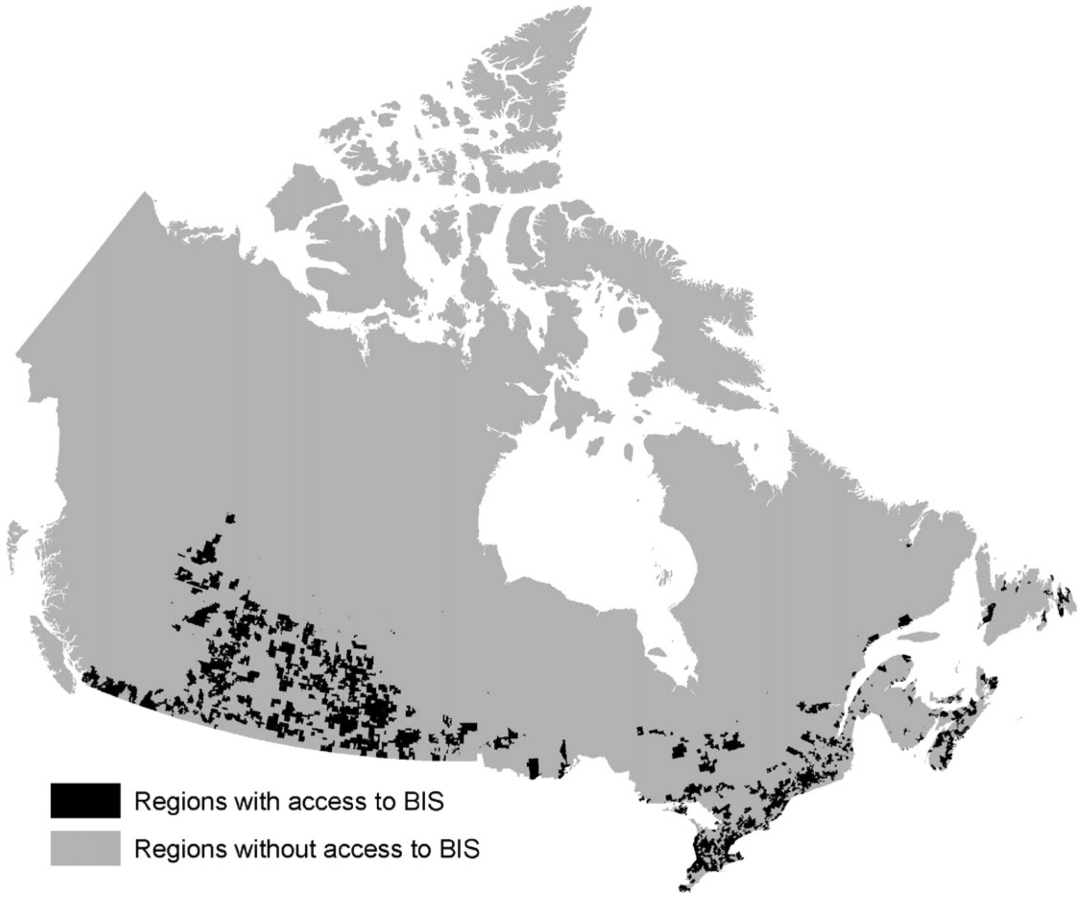

Fig. 1. Current availability of broadband Internet access in Canada is shown by the shaded areas.

now generally perceived to be part of the essential infrastructure that is necessary for the effective and efficient operation of enterprises and organizations in the Information Society. That is, broadband connectivity is deemed to be essential for the delivery of programs such as e-medicine, e-health, e-education, e-governance, and e-entertainment, all of which are available to urban residents (Industry Canada, 2004a). With that premise as our overall term of reference, the goal of our paper becomes mission-oriented: to provide guidance on how to achieve broadband connectivity as a means of e-program delivery to communities and dwellings in Canada's northern, rural, remote, and isolated areas.

4. The digital divide and current Canadian broadband situation

As indicated by Fig. 1, the availability of broadband Internet in Canada is strikingly different between rural and urban areas. Over half of Canadian households have broadband services via Cable or DSL, but these households are mainly in urban areas (Veenhof et al., 2003). In addition to the availability of service question, however, it is necessary to briefly consider Internet adoption characteristics that led to a digital divide that temporally preceded and overlapped the widespread BIS offerings. Internet adoption characteristics offer lessons for the existing broadband digital divide and, as a result, affect the policy recommendations presented later in the paper.

In densely populated urban areas, and within areas where Internet service (IS) is available, not all dwellings immediately adopt IS offerings. As might be expected from the experience of previous computer/communications eras, differences in adoption practices can be traced to socioeconomic and demographic factors (Grubesic and Murray, 2002; Grubesic, 2003; Prieger, 2003). Income and education are the main drivers that positively encourage the adoption of IS. Also, the structure and age of the dwelling head can affect IS adoption (Sciadas, 2002). IS adoption, like any new technology, lags behind in lower income households. By way of illustration, in 1997, only 5% of lower income dwellings had obtained access to (adopted) an Internet service(s), whereas the rate increased to 26.7% in 2003 (Statistics Canada, 2003a). More recently, gender differences in IS uptake have been recognized in Canada (Melissa, 2004).

Key factors for Internet adoption are highlighted in Table 2 (Statistics Canada, 2003b). However, because studies examining the digital divide typically only compare use and demand

Table 2
Leaders and trailers in the adoption of Internet services

Group characteristic	Leader group	Trailing group
Age of dwelling head	Under 35 (80%)	65 and over (25%)
Structure of dwelling	A family with unmarried children (under 18) (84%)	One-person dwelling (40%)
Education	University degree (88%)	Less than high school (32%)
Income	Highest quartile ($70,000 and more) (90%)	Lowest quartile ($23,000 or less) (35%)

versus demographic factors, the divide may actually be influenced more by the geographic availability of a given IS or BIS than is generally recognized (Prieger, 2003).

As a result, and notwithstanding the factors that might affect a dwelling's ability or desire to adopt IS or BIS, it appears clear that the geographic distribution of BIS is the first issue to address when considering the matter of access in Canada. It is clear that access is the prerequisite for BIS adoption (Grubesic and Murray, 2002). That is, it is logical, and necessary in our view, to first deal with questions about how to overcome the geographic divide and to then contemplate questions, concerns, and public policy strategies about how to increase adoption rates.

It is appropriate to note in closing this section that the United Nations has recognized that the geographic divide is an important policy matter that needs to be addressed by member countries. At the last summit on the Information Society (December 12, 2003), a number of the proposals for improving global connectivity and access were explicitly tied to the idea of linking localities and spatially distributed groups to the Internet (United Nations, 2003) as a pre-condition for effectively dealing with issues underlying the digital divide.

5. Record of the Government of Canada in supporting broadband connectivity to communities

The first Canadian National Broadband Task Force (NBTF) in 2001 recommended that every Canadian community should be provided with BIS access by the end of 2004 (Industry Canada, 2001), and emphasized that aboriginal communities are to receive accelerated focus. The NBTF report resulted in Industry Canada's Broadband for Rural and Northern Development Pilot Program,[2] www.broadband.gc.ca. The goal of this portal is to help distribute broadband Internet to rural, northern, or remote communities where market forces alone have insufficient incentives for BIS development (Industry Canada, 2001, 2002; Hamilton, 2002). Industry Canada has developed two programs to help provide required infrastructure. In the Broadband for Rural and Northern Development Pilot Program, $79 million was invested in organizations representing 1380 communities (Industry Canada, 2004b). The second program, National Satellite Initiative, was established for communities where satellite is the only possible means of delivering broadband. Various partners contributed $155 million to help cover the high cost of satellite technologies and equipment. However, a "community connection" is expected to be available for only 10–15 years, which is the life span of the satellite (Industry Canada, 2004a).

5.1. Current regulatory issues affecting wireless services and policy formulation

Industry Canada (IC) has many responsibilities, including the important mandate of making "Canadians more productive and competitive in the knowledge-based economy, thus

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[2] In 2004, with the addition of the national satellite initiative, the Web site now reflects the broader goal of "High-capacity Internet for all Canadian communities."

improving the standard of living and quality of life in Canada." (Industry Canada, 2005). One means of achieving its mandate is by the promotion of telecommunications through the *Radiocommunication Act* and the *Telecommunications Act*.

The *Telecommunications Act* (Government of Canada, 1993) instructs IC to create policy objectives and regulatory controls, whereas the *Radiocommunication Act* (Government of Canada, 1985) instructs IC to plan the management, licensing, and allocation of spectrum for communication purposes. One of the key objectives of the *Telecommunications Act* is to "render reliable and affordable telecommunications services … to Canadians in both urban and rural areas in all of Canada." (Government of Canada, 1993).

Section 46.5 (1) of the *Telecommunications Act*, "Contribution to fund," contains provisions for subsidizing telecommunication costs in areas where operating costs are high, that is, in rural areas. While it may appear that Section 46.5 (1) is applicable to broadband deployment, it is not the case. The Section applies only to basic telecommunication services, and not to Internet Service Providers (ISPs). As stated in the legislation, collection of funds can only be conducted for essential telecommunications services (Government of Canada, 1993), and broadband is not contribution-eligible. Consequently, under the current language, and contrary to the case for telecommunications, funds cannot be collected from urban areas for re-distribution to support rural broadband communications.

When the Canadian Government stated, in the 1997 Throne Speech, that it wanted Canada to be at the forefront of the information revolution (Industry Canada, 2002; Governor General, 1997), Industry Canada was charged with achieving this goal. In the past few years, and in various phases, the agency has auctioned blocks of prime spectrum (2.3, 3.5, 24, and 38 GHz) that would allow various wireless technologies to be used (Industry Canada, 2004c,d). However, the fact is that broadband Internet access is still basically limited to the urbanized regions of the country (as illustrated by Fig. 1), which means that a number of public policy, regulatory, technical, and economic/financial matters remain to be addressed.

6. Geographic approaches in the study of broadband planning and deployment

Accessibility to terrestrial broadband wireless technology is a spatial issue, and the problem to be resolved can be expressed as a classic market or demand–supply task: that is, to ascertain the ability of different technologies to reach a base of consumers which is large enough to financially sustain the service.

Two kinds of specialized software for analyzing and planning of wireless technologies are pertinent to this paper with regard to the spatial connections between communications towers and dwellings—the potential BIS market. Radio propagation software can accurately estimate the signal reach of a communication tower. However, due to computational limitations, radio propagation software appears to be best suited for application in small regions. As a result, since the area involved in this study is the large land mass covered by Canada's rural, remote, and isolated regions, it is appropriate to utilize the software and procedures contained within GIS for first approximation purposes. The radio propagation software can then be used to site the individual towers.

6.1. Geographic information systems

GISs are a component of the science of geomatics, a multi-disciplinary field that encompasses such disciplines as geography, mathematics, and remote sensing, among others, and involves a range of computer/communications devices including global positioning systems (GPS). The most salient structural and functional features of GIS for this are "…computer software, hardware, and peripherals that transform geographically referenced spatial data into information on the locations, spatial interactions, and geographic relationships of the fixed and dynamic entities that occupy space in the natural and built environments" (Wellar, 1993, p. 7).[3] Although there are many variations on aspects of the above definition of GIS, there is general agreement as to its main features, namely, a database of map layers defined by spatial and attribute data, and software with capabilities to analyze and synthesize the relations between features distributed among different layers (Sawada, 2002).

In the United States, various ventures are using GIS to support the deployment of broadband. For example, the Oregon Economic and Community Development Department provides a map of Digital Subscriber Line (DSL) Access, and a map of Oregon cities where broadband is provided by cable companies (Oregon Economic). In a related vein, an Oregon consortium (Eastern Oregon Telecommunications Consortium) used GIS to map infrastructure and services, including the telecommunications component. Cai (2002) recently analyzed the ability of the Pennsylvania telecommunications infrastructure to supply particular bandwidth demands. Cai's research was undertaken in the context of a policy related to school multimedia accessibility, and illustrated that GIS analysis can contribute to policy formulation and investment decisions for non-connected regions.

The pertinence of GIS to this study is established by noting that spatial considerations are at the center of the wireless broadband service-dwelling relationship. That is, such tasks as delimiting market areas, locating towers, and calculating/estimating signal ranges involve the geographic concepts of distance, direction, location, accessibility, proximity, adjacency, containment, and spatial coincidence (overlay) among features on the earth's real and modeled surfaces. These kinds of tasks are, by definition, at the heart of GIS applications (Wellar, 1993). Further, the power of GIS means that *every* location on the landscape (natural or built) can be visited, and at each location, a broadband tower deployment can be simulated. For each simulated deployment, the number of dwellings provided access within a given service radius (a function of radio frequency, system hardware, customer premise equipment (CPE) and software among other factors) can be estimated and/or calculated.

7. GIS case study: WiMAX market potential in Alberta

Estimating the number of dwellings that can be serviced can be done under two scenarios: first, service via non-line-of-sight, or NLOS, technology and, second, service by line-of-sight,

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[3] Also quoted in Introduction to GIS, URISA 2000. Available: www.ci.bothell.wa.us/html/FAQ/GIS/WhatIs.htm.

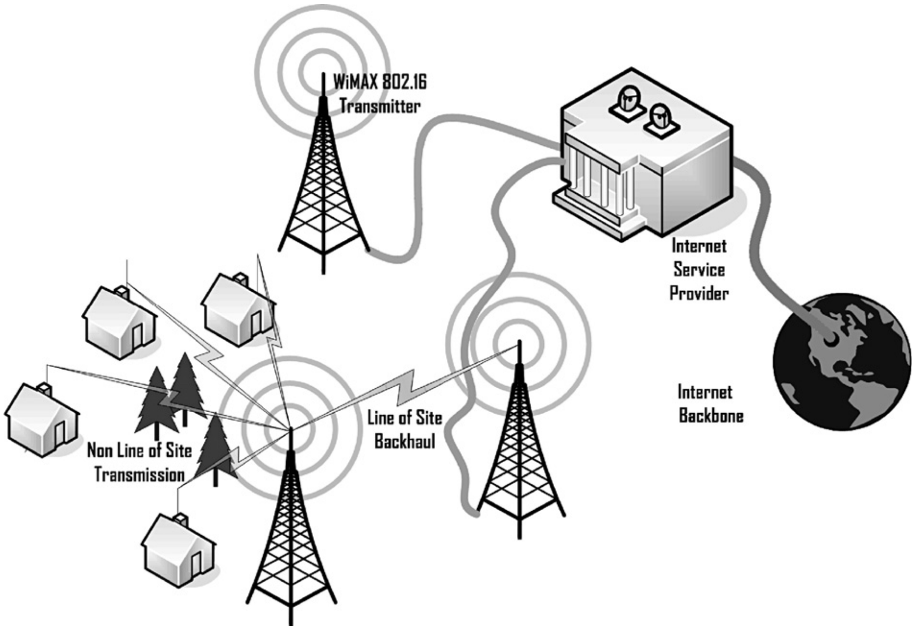

Fig. 2. Schematic of a WiMAX Communication Network (Grabianowski and Brain, 2004).

or LOS, technology. The upper and lower bounds of the potential market can be approximated by the two scenarios. In this study, we explore the contribution that GIS can make to deploying broadband Internet services by utilizing Worldwide Interoperability for Microwave Access (WiMAX) wireless technologies as the demonstration vehicle. The design of WiMAX (also called the IEEE 802.16-2004 standard) incorporates both NLOS and LOS services, and its performance features are sufficiently well specified at the conceptual level that we can use the features to illustrate how a GIS capability can contribute to the analysis, planning, and deployment of terrestrial wireless broadband services.

Fig. 2 (Grabianowski and Brain, 2004) provides a schematic representation of a WiMAX communication network. Some of the key characteristics of the 802.16a standard are that it has a NLOS range of 8 km; a LOS range of up to 50 km[4] (WiMAX Forum, 2004a); and a high spectrum utilization of 3.8 bit/Hz where each base station can transmit up to 280 Mbps securely, depending on the user's antenna distance from the base station (Alvarion, 2004). We now use those WiMAX design features to conduct the GIS case study illustrating how GIS can help to deliver WiMAX-type services to unserved dwellings in Canada's rural, remote and isolated regions.

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[4] These numbers require that the service provider and consumer use certain hardware. The reader is referred to detailed documents from the WiMAX forum cited herein.

Table 3
Data required and land use along with the resolution/scale and source

General description	Type of data	Resolution/ Scale	Source
Census dwelling count, dissemination area (DA)	Polygon	1:50,000	Statistics Canada
Rivers and lakes	Polygon	1:50,000	DMTI Spatial Inc.
Communities (Industry Canada, 2001) with access and without access (served/unserved)	Table	Variable	Industry Canada
Provincial boundaries	Polygon	1:50,000	DMTI Spatial Inc.
Digital elevation model (DEM)	Raster	300 m	Center for Topographic Mapping, Natural Resources Canada

7.1. Study area and data

The study area chosen to demonstrate the utility of a GIS approach is the Province of Alberta, which comprises a large part of the Canadian land mass with a large rural/remote population who lack broadband access (Fig. 1). The types of data required for the study (as well as the data sources) are noted by Sawada et al. (2005) and are briefly described as follows (Table 3).

Data on the spatial location of dwellings in the unserved (study) area were obtained from the Canadian census. Dwelling counts were derived from the 2001 geographic census-reporting unit known as the Dissemination Area (DA). Typically, a DA provides demographic data for 400 to 700 dwellings.

There are more than 52,000 DAs in Canada (the US equivalent of a Canadian DA is the Block Group). In reality, dwellings tend to be clustered in particular parts of a census unit; the necessary assumption made here is that the values measured within a census unit are uniformly distributed across the polygon. Provincial boundaries are used to delineate an outline of Canada, and the rivers and lakes are used to eliminate locations where dwellings do not normally exist. As such, the spatial accuracy of the dwelling data was increased by using GIS operations to remove (cookie-cut) water bodies and other areas where people and dwellings do not physically reside.

With those basic operating rules, we distributed the dwellings within and across the DAs into a systematic grid of 1 km^2 resolution (Fig. 3). The redistribution of dwellings within a GIS is described in Sawada et al. (2005) and for Alberta resulted in over 320,000 cells containing just over 152,000 dwellings. Cai (2002) discusses in detail the issues and approaches to spatial data integration and transformations in the context of telecommunications analyses in GIS.

The data on communities[5] with access to BIS, and without access to BIS, were provided by Industry Canada (IC) and were current as of November 2004. Spatially within the GIS, through

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[5] The term “community” is loosely defined as a locality with “…a name, a distinct physical location and territory, and a population … for purposes of defining infrastructure gaps.” Industry Canada (2001).

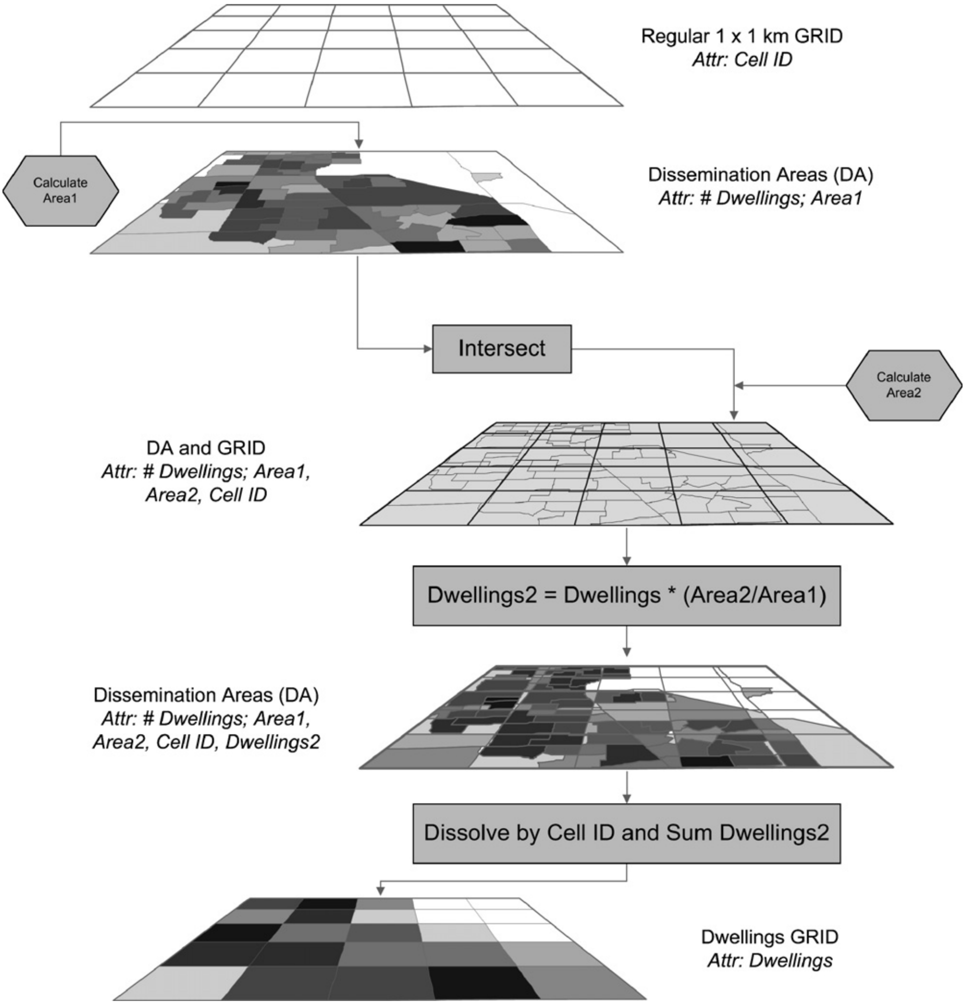

Fig. 3. Process of deriving the regular 1 × 1 km grid of dwelling counts from irregularly shaped dissemination areas (DAs). This process begins once all waterbodies and rivers have been cut-out of the DA layer. If the number of dwellings input equals the number in the output then the process is validated.

a process similar to that depicted in Fig. 3, we derived a layer of served and unserved dwellings for the 1 × 1 km grid.

Finally, a digital elevation model (DEM) was used to conduct the line-of-sight (LOS) examination[6]. Within GIS, LOS analyses are conducted using specialized functions that compute viewsheds surrounding a given observation point (Burrough, 1986; Franklin, 2002). A viewshed is defined as the terrain surrounding an observation tower that is directly visible

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[6] Also known as “intervisibility analysis.”

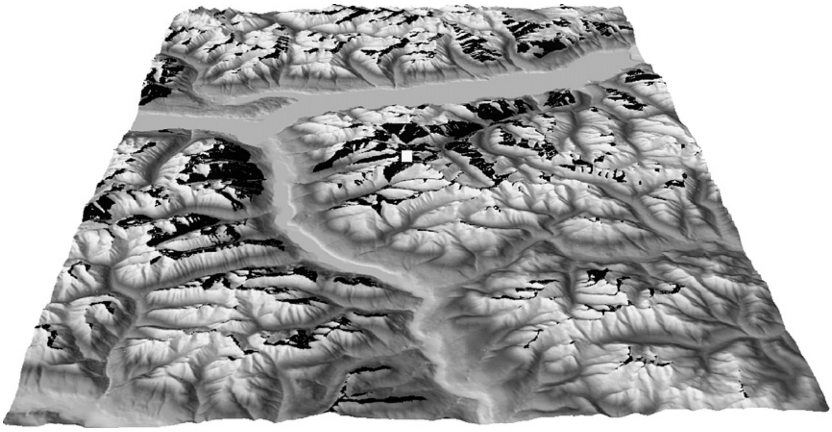

Fig. 4. Example of LOS examination for a proposed tower location within the Nelson, British Columbia region. Black patches represent areas visible from the communication tower (White Square).

(Fig. 4). Viewsheds have been used extensively for LOS analyses in the planning and deployment of radio communication towers (Franklin and Guth, 2005; Dodd, 2001; Rose, 2001). However, viewsheds can differ among GIS systems, given the various algorithms that exist (Dean, 1997).

8. Methodology

GIS software has the ability to provide a count of the number of dwellings within a distance radius of each potential communications tower location by either line-of-sight (LOS) and/or non-line-of-sight (NLOS). Two BWA scenarios were run for this analysis within the GIS:

1. Upper limit scenario (ULS): The market potential procedure uses dwelling distribution analysis (DDA) for each 1 km^2 cell in Alberta. This approach calculates the number of dwellings that could potentially be reached by NLOS technologies operating at 5 km and 50 km. The resulting estimate represents the upper limit of the potential market for the existing design specifications of WiMAX technology at 5 km. The 50 km NLOS scenario is used here for comparative purposes. NLOS technology within 50 km from a communication tower does not currently exist within the WiMAX specification.
2. Lower limit scenario (LLS): For Alberta, at the same radii, the dwellings that could be serviced using only LOS technology are identified. This analysis yields an estimate of the lower limit of the potential market for BWA for existing WiMAX specifications.

It is appropriate to emphasize that we could also have included a likely limit scenario (LLS). However, discussion of differences among the three limits or cases would have taken us away from our primary interest of demonstrating how GIS can contribute to BIS analysis, planning, and deployment. That said, we are confident that our methodology is sound since the WiMAX technologies and extensions proposed by the IEEE would, upon becoming operationalized and implemented, effectively have the potential to serve a market that is somewhere between the upper and lower limit scenarios.

As for using the province of Alberta for the LOS analysis, that was not the result of a sampling process. Rather, Alberta was selected as the test bed for this project because it has topographic characteristics that are replicated across much of the Canadian landmass, it contains only two major urban centers (Calgary and Edmonton), and it has a significant rural population. In our experience, those reasons are more than sufficient to justify choosing Alberta as the locale for the GIS case study demonstration.

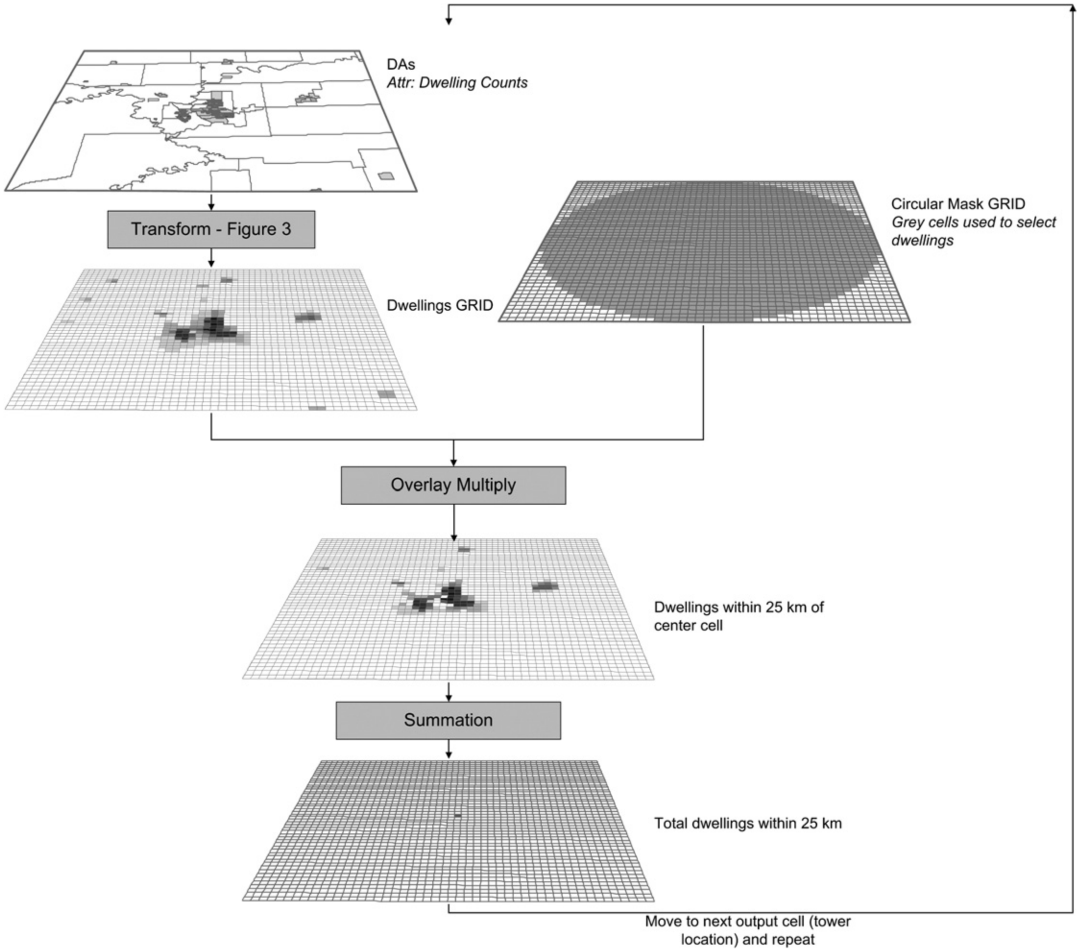

Fig. 5. Process of deriving the upper limit scenario (ULS) for the non-line-of-sight (NLOS) case. This example is for a 25 km radius surrounding the potential tower location at the center of the study region.

8.1. Upper limit scenario (ULS): NLOS dwelling distribution analysis

We assume that each dwelling is a possible subscription unit to a wireless broadband service. Again, we emphasize that we are concerned with geographic accessibility of BIS rather than the digital divide. For this non-line-of-sight (NLOS) analysis, the terrain is assumed to be completely flat. Under such circumstances, and with the exception of the earth's curvature, all cells would have a clear line-of-sight with a potential communication tower. Each cell within the unserved dwellings region is visited, and the number of dwellings is summed within a 5 km radius and a 50 km radius (Fig. 5).

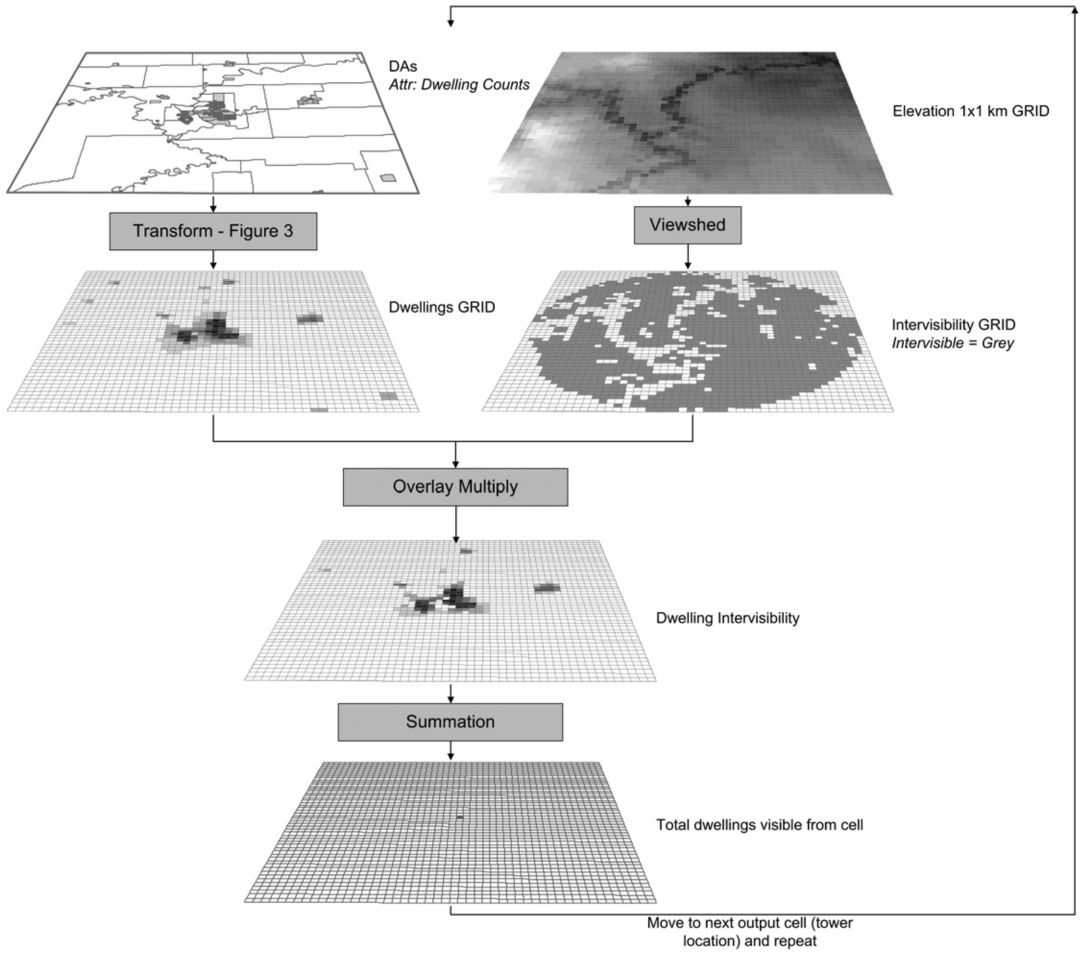

Fig. 6. Process of deriving the number of dwellings potentially served by WiMAX using LOS and viewshed analyses. This example is for a 25 km intervisibility analysis with the potential tower location at the center of the study region.

8.2. Lower limit scenario (LLS): line-of-sight dwelling distribution analysis

The same dwelling data set was utilized in this scenario and, in addition, a 1 km^2 digital elevation model (DEM) was also employed to identify the dwellings visible from each tower by direct line-of-sight.

By way of brief explanation, in order to count the number of dwellings, we visit each cell that could be provided with broadband Internet service (BIS) based on the establishment of line-of-sight (LOS) communication with other cells within a fixed radius of 5 and 50 km. Each observation point is a 1 km^2 cell with a tower of 30 m height above the terrain elevation, and includes a 3 m offset for the dwelling antenna. If a cell does have LOS communication capability with the currently visited cell (observer point), then it is assumed that provision of wireless BIS is possible, and the dwelling counts for the visible cell are added to the tower's total of dwellings served (Fig. 6).

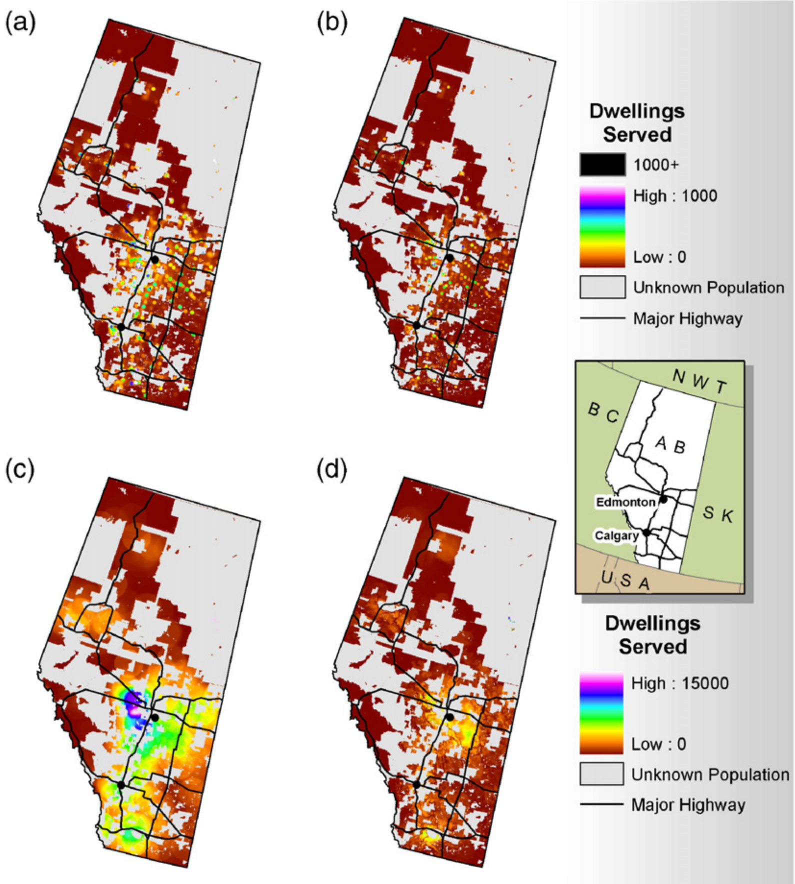

Fig. 7. Distributions of potentially servable dwellings under different scenarios: (a) ULS 5 km; (b) LLS 5 km; (c) ULS 50 km; (d) LLS 50 km. Note the differences in the legend magnitude between the 5 km radius criterion used in panels a and b and the 50 km criterion used in panels c and d.

For all cells that are visible within the fixed radius, the dwelling counts are summed and assigned to the cell being examined. The resultant maps illustrate the number of dwellings that could be served if a tower was placed at each cell. Alternatively, to re-phrase the comment, the maps represent a prediction of the potential market for wireless BIS in Alberta.

From a public policy perspective, decisions regarding subsidization may be considered for remote areas where wireless BIS markets are unlikely to be profitable in the short term. In order to provide a potential guide as to where such subsidizations may be warranted or not warranted in the short term, we consider the proportion of households potentially served in our study region based on a minimum sustainable business case scenario. Specifically, we assume that a wireless BIS deployment will need a minimum of 300 households, a number loosely based on a realistic WiMAX business plan for deployment in urban and rural areas (WiMAX Forum, 2005).

We utilized ArcGIS 9.0 (Build 580) and ArcObjects RasterSurfaceOp coclass, ISurfaceOp2 “visibility” method to automate the analysis of the millions of individual locations whose viewsheds required determination. A custom application was written in Visual Basic for this purpose.

9. Results

Spatially, the highest concentrations of potential servable dwellings are concentrated around the Edmonton region of the province and in the municipalities along major roadways (Fig. 7).

To illustrate the target market, we assume that 300 dwelling subscriptions are the minimum required to support a WiMAX tower base station. Given this assumption, we can consider adoption rates within the service radius ranging from 100% to 10%. In the LLS at 50 km,

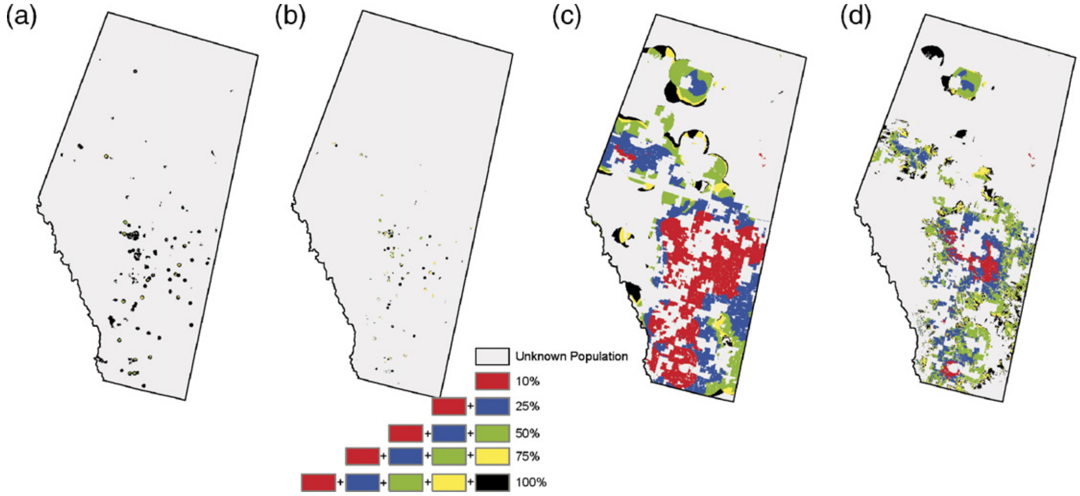

Fig. 8. Business case scenarios based on 300 household subscriptions at different market penetrations or take-rates; (a) ULS 5 km; (b) LLS 5 km; (c) ULS 50 km; (d) LLS 50 km.

Table 4
Summary of results for Alberta under ULS and LLS assumptions

Scenario	km	% of 152,493 households	
		Served	Unserved
ULS	5	41	59
LLS		37	63
ULS	50	99	1
LLS		86	14

adoption rates as low as 10% (indicated in red on Fig. 8d) illustrate large areas within the unserved populations of Alberta that could be profitable. Spatially, these tend to be adjacent to the already-served regions surrounding Edmonton and Calgary (see inlay on Fig. 7 for reference). Observations at the 5 km intervals (Figs. 8a and b) suggest that adoption rates tend towards 50%–75% for marketability. Fig. 8c represents the ULS at 50 km, which is unrealistic given today's technology, but serves as a means of comparison only. The required NLOS technology operating at a 50 km radius is unlikely to emerge.

Turning now to the overall numbers as a means of summarization, at the lower bounded estimate, given by the LOS analysis in the lower limit scenario (LLS), and as shown in Table 4 (last row), three-quarters of the (unserved) Alberta dwellings could be reached by WiMAX technology if the existing design features were implemented and operationalized. Further, and again on the premise of a fully functional WiMAX technology, even a 5 km radius provides broadband Internet access for 37% of the unserved population (Table 4, top row).

We might now consider a viable WiMAX scenario where NLOS is operational at 5 km (8 km is NLOS in the specification; WiMAX Forum, 2004a) and LOS is operational to 50 km.[7] In this case, as much as 90% of the unserved households could benefit from WiMAX technologies operating at specification. While this percentage is promising, it should be considered a first approximation because of other confounding variables that have not been considered.

10. Discussion

Our results illustrate where BWA tower deployments could potentially be placed and have sufficient market support. However, there are several caveats that need to be explicitly noted with regard to the data used, the spatial resolution of the study, and the assumptions underlying the analysis. From the research design and operational perspectives, the caveats are a guide to the informed use of the maps within the decision-making and planning processes and are intended to contribute to further model refinement. In addition, however, the caveats also serve

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[7] Because the analyses at 50 km in both the ULS and LLS include the household data at the 5 km analysis, we can subtract the 5 km LLS from the 50 km LLS and add the result to the 5 km ULS to produce a number that conforms to WiMAX specifications for NLOS and LOS services.

as warning signals, or advisories, to public policy researchers and decision-makers, and others who are evaluating or deliberating WiMAX deployment plans or proposals from industry or other interest groups.

To begin with, we have assumed that a tower, when placed, will be able to establish a link with the fiber optic-based backbone. Where tower deployments are concerned, the necessity of a backhaul/backlink point-to-point transmission system via microwave from each potential hub (tower) is not addressed in this research. We leave this assumption as an item for explicit inclusion in future model refinement, or for particular business case scenarios.

Moreover, we have assumed that a tower could be placed anywhere within the unserved regions except in water bodies, and we have analyzed each potential location or cell independently of the previous iteration. Any overlap between the serviced areas of each cell means that the locations of potential towers have not been spatially optimized. However, the maps in Fig. 7 do illustrate the hot-spots for potential WiMAX deployments that would capitalize on the number of dwellings serviced.

The point being emphasized is that this paper does not deal with the minimum number of towers required to service a region. Rather, we are concerned, at this stage, with accessibility to wireless BIS in Canada's northern, rural, remote, and isolated regions, and the matter of network layout optimization is a different task. Additionally, we have not addressed the possibility of alternate configurations for wireless networks such as mesh layouts (Industry Canada Broadband Technical Team, 2003) or build-outs from the urban/suburban periphery. Finally, we do not address the issue of different bandwidth requirements for different markets (Cai, 2002) (business, government, residential, etc.) since our present focus is on BIS access for residential dwellings.

It is also important to establish that, at the local scale (1–2 km^2), our results do not provide the accuracy needed for tower siting. To undertake that task, the identified regions could be analyzed utilizing higher resolution data with the same methodology. As noted above, our data sets were aggregated to 1 km^2 of spatial resolution for reasons of consistency and computational efficiency within GIS. One square-kilometer is far too coarse to determine a definitive placement for a radio communications tower. However, our maps illustrate where the unserved population could benefit from BWA deployment and higher resolution analyses.

Further, using wireless technologies to provide broadband service requires consideration of factors other than topography and LOS that affect the strength and quality of transmission signals. The following comments indicate how some of these factors can affect BWA access speed and carrying capacity:

1) Antenna height—Affects an antenna's range and effectiveness. Increasing the height allows for further range (Louis, 2002). However, increasing the height will also increase the interference, which is critical for cellular systems. Typical heights range from approximately 50 to 150 meters (Tamir, 1967).
2) Atmospheric scattering—Significant amounts of water vapor, humidity, or rainfall can decrease signal strength and increase signal scattering and absorption. Precipitation in the form of fog, hail, and snow can cause serious reduction in signal strength (NAVEDTRA,

2002) as it can "collect on the leaves of trees and produce attenuation until it evaporates" (InPath, 2004).

3) Frequency—The higher a frequency the less likely a connection can be NLOS. Also, with higher frequencies come smaller geographical ranges, as there is an inverse relationship between frequency and service range (e.g., 20 GHz–23 GHz–2 km; 800 MHz–6 GHz–45 km) (Louis, 2002).
4) Foliage (Vegetation Factor)—The presence of vegetation or forest cover causes a decrease in radio frequency (RF) energy (Tamir, 1967). Different types of trees have varying influences. For example, coniferous trees affect RF signal more than deciduous trees (InPath, 2004).
5) Topography (mountains, hills, earth's curvature)—Mountains and varying types of terrain, or even the curvature of the earth, can cause signals to be reflected, which, in turn, can cause signal echoes and path fading (Driessen, 2000).
6) Obstacles—Man-made obstacles and reflective surfaces (buildings, roadways) can affect both the range and path of a transmission signal (Louis, 2002).
7) Path—Depending on the environment, various paths from the transmitter to receiver may be possible. When combined at the receiver, these paths may create interference, reducing the signal quality.

These factors need to be considered individually and collectively in order to devise a plan that maximizes the number of dwellings potentially capable of using wireless technologies. While it is possible to integrate the above factors within a GIS, there are limitations to the use of GIS packages in conducting large-scale radio propagation analysis (RPA). Specifically, while GIS packages contain functions for visibility analysis, the capabilities to integrate such factors as the determination of radio signal strength are absent. However, integration of radio propagation can be done by means of custom application development or by combining geographic information systems (GIS) and radio propagation analysis (RPA) software.

Combining GIS and RPA allows for factors known to cause signal degradation to be considered at the regional/local level, while the role of GIS is found in conducting examinations of potential market locations at the national scale. Based on that methodology, our results should be considered a first-approximation that identifies candidate locations/regions for subsequent specialized RPA software analyses, or GIS analysis with higher resolution data.

11. Policy implications

The activities of several national governments have moved to the forefront in terms of making major investments in broadband infrastructure. South Korea and the United Kingdom surface on the leading edge, and we briefly note elements of their BIS policies that make them "countries to watch and learn from."

South Korea is presently the leading country in terms of the rate of broadband uptake and now ranks as the most connected country in the world. In 1998, only 14,000 dwellings had broadband; whereas in 2005, the number has risen to over 12 million out of 15 million dwellings (eMarketer, 2005). South Korean BIS growth can be linked to a number of factors, but the primary factor is that the national government aggressively promoted and launched various infrastructure initiatives. It began laying a framework for information promotion in 1995, with the objective of making BIS affordable and accessible to all South Koreans.

In the United Kingdom (UK), the UK government is working towards providing broadband to all those who desire the service. Already the UK has 99% coverage for mobile phones and 96% coverage for broadband (Ofcom, 2005).

We draw on those initiatives to suggest that our study provides a rationale and a route for the Government of Canada to follow when formulating and implementing policies and programs designed to enable Canadians residing in northern, rural, remote, and isolated areas to actively and equitably participate as full members of the Information Society (Governor General, 1999, 2001).

12. Policy message for Canada

While the goal of providing all Canadians broadband Internet access (BIS) by the end of 2004 (Governor General, 1999) has not been reached, the uniqueness of the Canadian situation in the context of connecting citizens to the Information Society needs to be recognized. On the one hand, Canada has the second largest northern, isolated, rural, and remote area among countries, and its expanses of unpopulated land and low-population densities are unlike those in the US, the UK, or South Korea. On the other hand, however, and despite the difficulty of providing BIS access to all Canadians, it needs to be borne in mind that Canada is a world leader in the field of telecommunications and, since 1999, federal policies have provided the majority of Canadians – those living in urban areas – with BIS access.

In this study, we demonstrate how geographic information systems (GIS) can assist the Government of Canada, as well as provincial and territorial governments and the broadband industry, to narrow, and then eliminate, Canada's urban–rural broadband divide (National Selection Committee, 2004). That is, by means of a case study, we show how GIS can contribute to the analysis, planning, and deployment tasks involved in providing broadband Internet services in Canada's northern, remote, and isolated regions. It is our belief that the research underlying the case study has due and appropriate regard for the social, technological, economic, and geographic aspects of the broadband divide and that, as a result, it could serve as a basis for launching public policy initiatives to ensure that all Canadians, including those located in the rural, northern, remote, and/or isolated regions have equal access to broadband Internet service.

13. Conclusion

We began this paper by establishing the importance of broadband connectivity to residents, businesses, institutions, and other entities in Canada's northern, isolated, rural, and remote communities. That part of the presentation includes a commentary on the role of the Government of Canada in providing broadband connectivity to residents of these rural communities, and outline of the current regulatory issues that govern wireless services and shape the policy formation and program implementation processes.

In the second part of the paper, we discuss why and how to use a geographic information system (GIS) approach in studies involving broadband Internet service analysis, planning, and deployment. Our GIS-based analysis permits rapid assessment of terrestrial broadband wireless markets in northern, isolated, rural, and remote regions with minimal data requirements.

Initial results indicate that a large proportion of Canada's rural communities located beyond the urban zone could potentially be served by wireless systems operating with current WIMAX specifications. We believe that these results are of direct political, social, and economic consequence to millions of Canadians in northern, remote, and isolated regions of the country who at present do not have access to broadband Internet service. In addition, and very importantly, we believe that the results and the research underlying their derivation provide evidence and direction for the Government of Canada to consider in its deliberations over how it can best proceed in order to achieve the national objective of all Canadians having full and equitable access to broadband Internet service.

Acknowledgments

This work was supported by an operating grant from the Natural Sciences and Engineering Research Council of Canada and infrastructure grants from the Canadian Foundation for Innovation and the Ontario Innovation Trust to M. Sawada. The authors wish to thank the three anonymous reviewers for their perceptive comments and instructive suggestions. The authors also wish to thank Mr. Gérald Chouinard and Mr. Gerry Briggs for their assistance in developing the database for the study. Finally, we are indebted to DMTI Spatial Inc. of Markham Ontario, the Industry Canada, Statistics Canada, and the Geographic, Statistical, and Government Information Centre at the University of Ottawa for data support.

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