Combination of Geographic Information System (GIS) and Radio Frequency (RF) Planning Software, to Assess the Market Potential of Wireless Broadband Internet to Unserved Rural Populations

Daniel Cossette*, M. Sawada*, Gérald Chouinard, G.Briggs***, Peter G. Johnson******
*Laboratory for Applied Geomatics and GIS Science (LAGISS), Department of Geography, University of Ottawa, 60 University St., Ottawa, ON K1N 6N9 geomatics.uottawa.ca
** Program Manager, Rural and Remote Broadband Access, Communications Research Centre (CRC) Canada.
***Industry Canada
****Chair, Canadian Polar Commission and Department of Geography, University of Ottawa

ABSTRACT

Millions of Canadians do not have broadband Internet access and the majority of these households reside within rural and remote communities of Canada. This situation has led to an urban/rural 'broadband divide'. Barriers exist in the deployment of wireline broadband for rural and remote regions because of the significant expense to install and maintain a wired infrastructure required to reach remote dwellings and businesses. In such situations the costs outweigh the benefits of wireline access. Spatial differences in Internet accessibility have led to an urban/rural 'broadband divide' in Canada.

Accessibility to terrestrial broadband wireless technology is a question based on spatial and regional topography and the capacity for different technological solutions to reach profitable population bases. Various standards organizations such as the IEEE (Wireless Metropolitan Networks WMAN 802.16, Wireless Regional Area Networks WRAN 802.22) are developing technologies that would permit wireless Internet access over much greater distances than current technologies. The benefits of such new technologies include rapid deployment, flexibility, scalability and the lack of a physical connections being required to connect a subscriber.

Our approach to determine potential market served by news broadband wireless technologies in Canada combines Radio Propagation software (Planet EV) and Geographical Information Systems (GIS). We demonstrate a method capable of identify areas where deployments would be profitable from a business viewpoint and areas where difficulty would arise either due to topography, vegetation or lack sufficient households . This method has yet to be fully realized however from preliminary results we found that a considerable amount of the unserved population could be provided with access. This study is of internet to service providers, telecommunication manufacturers and both policy and frequency regulators in Canada.

Key words: Broadband, Internet, Remote Communications, Broadband Divide, Geographic Divide, Wireless Telecommunications, GIS, Radio Propagation, Wireless Access, WiMAX

1. Introduction

The idea of an "Information Society was hinted at in the early 1960s" (Wellar, 1985) and presently, many households are taking part. Prior to taking part in the information society, households with broadband internet first had to have broadband services available (Figure 1). Having access to broadband (high-speed) internet enables households to take part in distance learning, e-government, e-commerce, banking, communication, cultural and other information services. Without broadband communications, households cannot enjoy the benefits of being part of the Information Society which creates a divide or an inequality households with and households without broadband access. Many households are unable to part-take in the information society due to the geographic divide because broadband services are simply not available in their particular geographic location. Hence, a geographic divide exists, because these households are located in an area where broadband is non-existent.

The reason why the majority of rural and remote areas lack broadband is there so few households to financially support the required infrastructure needed. Unlike rural areas, urban regions have more households per unit area resulting in fewer essential infrastructures per household because of the short distance between homes. This results in a polarized "society of two extreme groups: those with access to technology and those without access" (Fourie and Dowell, 2002), and in the case of broadband internet access, a so-called geographic divide leads to have and have-nots.

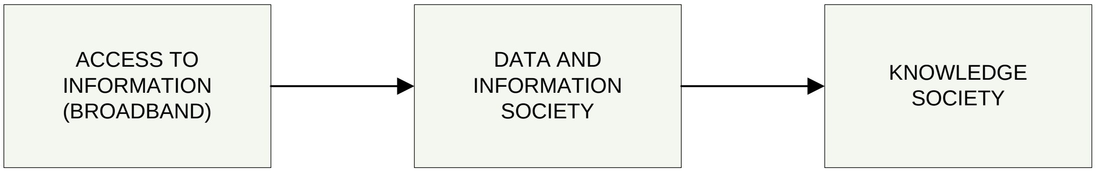

Figure 1. Schematic illustrating the steps from access to knowledge with regards to broadband wireless telecommunications.

Organizations such as the Institute of Electrical and Electronics Engineers (IEEE) are working on the development of wireless technologies that can cover greater distances than are currently possible (WiMAX). Benefits of such new technologies include rapid deployment, flexibility, affordability, scalability and the major benefit of not having to physically hook up to homes. Aside, simply connecting millions that would otherwise be left out of the knowledge society the benefit of wireless technology is that it has the ability to allow connections that are non-line-of-site (NLOS) and service radii of up to 50km[1]. However, to facilitate a financially sustainable broadband tower, a sufficient number of households capable of to a communication tower are required. In order to provide broadband, wireless technologies must overcome possible interferences to radio-waves.

Our approach combines Radio Propagation software (Planet EV) and Geographical Information Systems (GIS) in order to determine potential market served by new broadband wireless technologies in Canada. We demonstrate a method able to identify areas where deployments would be profitable from a business viewpoint and areas where difficulties would arise due to variable physical conditions affecting signals quality and strength. This method has yet to be fully realized however from preliminary results we found that a considerable amount of the unserved population could be provided with access.

2. Data

The importance of detailed data is vital in making accurate predictions. The idea is reflected in the acronym GIGO (Garbage-in Garbage-out). It is commonly known that higher resolution data yields better results (Thieken, 1999) because low resolution data could potentially cause misinterpretations when using RF software at a local scale. The data used in our project are listed in Table 1.

Table 1. Data required and land use along with the resolution/scale and source.

General Description	Type of Data	Resolution / Scale	Source
Digital Elevation Model (DEM)	Raster	30m	DMTI Spatial Inc
Clutter Data (Land Use and Type)	Raster	30m and 90 m	DMTI Spatial Inc
Provincial Boundaries	Polygon	1:50,000	DMTI Spatial Inc
Census Dwelling Count Dissemination Area	Polygon	1:50,000	Statistics Canada
Rivers and Lakes	Polygon	1:50,000	DMTI Spatial Inc
Communities with access and without access (served / unserved)	Table	n/a	Department of Industry
Block Population	Point	Variable	Statistics Canada

[1] Alvarion. Introducing WiMAX: The next broadband wireless revolution. 2004. (Date Accessed: 23 July 2004) http://www.alvarion.com/RunTime/Materials/pdffiles/Wimax_wp.pdf

Clutter data is utilized in the wireless telecommunication industry in order to determine optimal locations of towers. This data is specifically developed for Radio Frequency (RF) propagation in order to “refine signal loss prediction models according to the characteristics of the underlying terrain and ground cover” (DMTI Spatial, 2005). This data is important because surface features can affect wireless communication and this data “is classified as the man-made and natural features that may impair radio frequency propagation by reflection, diffraction, absorption, or scattering of the transmission waves” (DMTI Spatial, 2005). The Digital Elevation Model (DEM) is also used for determining the RF propagation as it used for signal loss.

DMTI Spatial Inc. of Markham, Ontario created the clutter data from the Government of Canada’s National Topographic Data Base (NTDB). They classified the data based on land use into both 30 and 90 metre raster datasets. The classification use was as follows: freshwater, ocean, coniferous forest, deciduous forest, open land, airports, industrial, urban, dense urban and wetland. One could create this data however it would be very time consuming if they would want to examine a large area.

The provincial boundaries are used to delineate an accurate outline of Canada, where the rivers and lakes are used to help eliminate the location where households can not exist. The communities with access and without access data are provided by the Department of Industry. The data helps indicate which communities have broadband access in that area and is spatial represented by being combined with the block population.

3. Methodology

As aforementioned, the general method for the examining the successfulness of the providing wireless broadband to unserved households is to combine a Geographic Information Systems (GIS) approach with Radio Propagation Analysis (RPA). Combining the two methods allows for factors that are known to cause signal degradation to be considered at the regional level while conducting an examination at the national scale. An illustrated diagram of the procedure is outline in Figure 2.

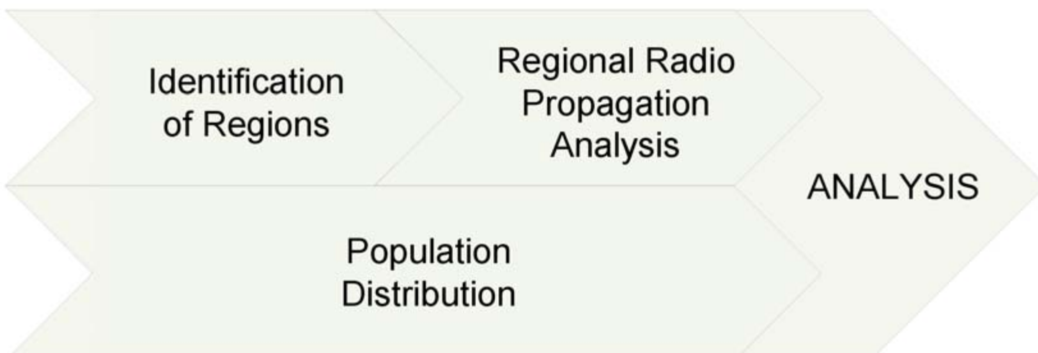

Figure 2. Steps for the examination of broadband to households without broadband access.

3.1 Identification of Regions

The first step of the analysis is to identify various vegetated and topographic regions of Canada in order to conduct RPA in these regions. This step identifies the various regions such as flat open land (Southern Saskatchewan) verses hilly vegetated (Northern Ontario) areas. This step is required in order to determine if broadband is capable of being delivered in different regions of varying clutter and elevation.

The data provided by DMTI Spatial is provided by map sheet and therefore requires lengthy manipulation in order to have the data in one map sheet prior to identifying general regions. Additionally, because of the prediction model being used in the RPA, data was reclassified in three categories: open land, vegetated and urban area.

3.2 Radio Propagation Analysis

After having outlined various geographic regions, a RPA analysis is conducted in each of these regions based on criteria provided by the WiMAX Forum. WiMAX was selected over parallel technologies because the IEEE has a number of publications available for conducting a proper radio propagation analysis. For this analysis both DEM and clutter data are in the Radio Propagation software called Planet EV, developed Marconi. Some of the variables used in the software include an examination at a distance of 50 kilometres (km), tower heights of 30 metres, a receiver height of 5 metres, frequency of 2500 MHz, and customized propagation models for urban, suburban and quasi-urban. The propagation models are based on research by Hata. (Hata 1980)

3.3 Population Distribution

In the third step the dwellings counts are the primary inputs into the analysis. We assume that each dwelling is a possible subscription unit to a wireless broadband service. Given that the spatial data for the census boundaries are general maps, the accuracy of the maps was increased by removing (cutting-out) water bodies and other areas where people and households cannot physically reside (Figure 3). While in reality households will 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 distributed equally across the census unit. As such, we distributed the households within and across units into a more organized and systematic grid.

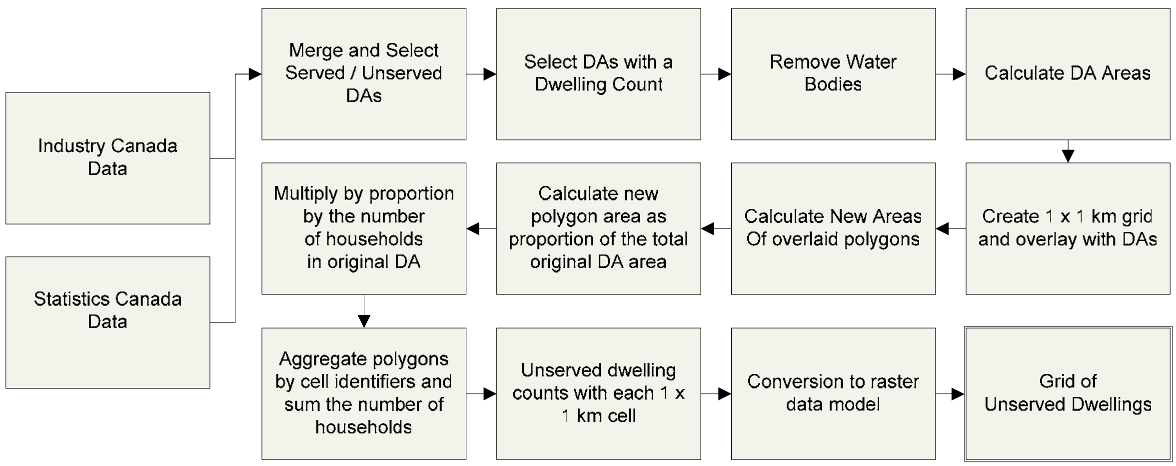

Figure 2. Cartographic model representing the method used for preparing the population data.

The irregular shapes of the dissemination area's (DA) dwelling data from Statistics Canada were converted into discrete non-overlapping 1 x 1 km grid cells (Figure 3). The 1 km resolution produced more that 20 million grid polygons and pushed the limits of the processing power for the eight computers used in analysis[2]. The procedure of preparing the population is depicted in Figure 3 as a flowchart that outlines the logic of the analysis process. The method used in distributing households from irregular DAs into regular grid cells is as follows:

1. Join of Dissemination Area's with data provided by the Department of Industry to determine DAs currently without broadband access, here called *DA Population*;
2. Removal of the DAs without dwelling counts;
3. Removal of areas where broadband is available;
4. Removal of lakes and river areas of each DA;
5. Calculation of the area of each DA, here called *Area of the DA*;
6. Creation of a 1 *x* 1 km grid with a unique identifier (id number) for each cell spanning all of Canada.
7. The grid created in step six is unioned with the layer representing unserved DAs, step 5 and 6. This results in the creation of numerous polygons where more than one DA intersects a cell. Each new polygon contains the cell identification number and DA dwelling count.
8. The areas of all new polygons are calculated, here called *Area of Split Polygon*;
9. The population of each new polygon is calculated as:

[2] Dell Precision 650 Workstations each with two Xeon 3.2 GHz processors and 4 GB of RAM.

$$New\ Population\ =\ \left(\frac{Area\ of\ \ the\ Split\ Polygon}{Area\ of\ \ the\ DA}\right)\times DA\ \ Population\ ;$$

10. Using the unique identifier, the New Population is the summed for each cell identifier and dissolved into 1 x 1 km cells for subsequent analysis.
11. Total dwelling counts from step ten are compared to the unserved dwelling counts in step 1 for Canada to ensure process validity. Therefore, the number of dwellings at the beginning needs to be the same as comes out.

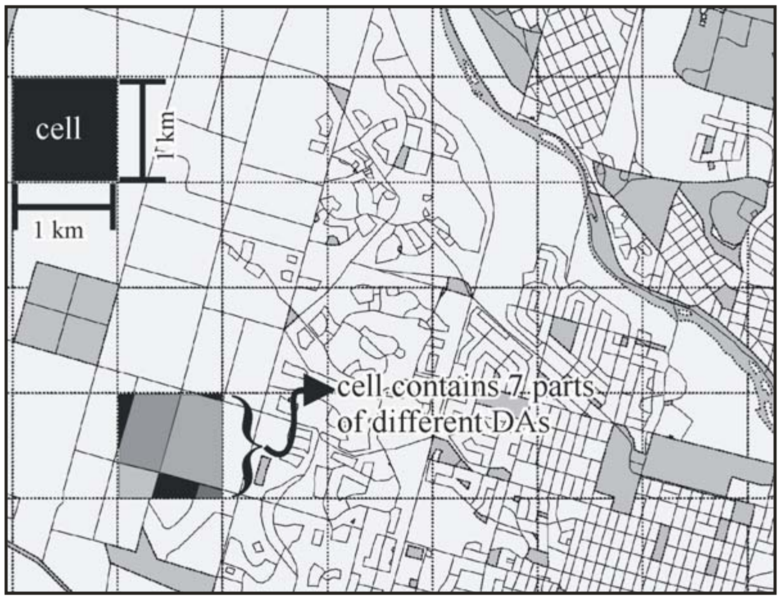

Figure 3. Example of regular grid overlaid on dissemination areas (DAs); light grey areas are the DAs, darker grey areas are water bodies or DAs without populations that were removed from analysis; dotted lines represent the 1 km cells (one is highlighted in black with dimensions); one example is given of how one cell intersects seven different DAs and as such, the number of households assigned to the cell is equal to the sum of households taken from the proportional population assigned to each piece of the 7 DAs intersected by the cell.

3.4 Minimum Sustainable Size

With the households distributed within the 1 km^2 grid cells, our next step was to estimate the minimum number of dwelling-based subscriptions required for a telecommunications tower to be profitable if it were to be constructed in one cell. The key input is the minimum number of dwellings that can financially sustain the construction of a telecommunications tower through paid subscriptions for wireless broadband services.

We assume that 200 dwellings at minimum could support the construction of a broadband tower if after five years at least thirty percent of the dwellings with access have subscribed to the technology. Moreover, after 4 years, there would be a total take rate of 25% and the tower would be paid for after six years. The reason for such a high cost of the tower is largely due to questions of accessibility within rural and remote regions. (Sawada et al, 2005)

3.5 Analysis

Once the irregular shaped EA were converted into regular equal area cells then the raster (grid or cell) calculator can be used which allows for efficient calculations. At the point the region outlines, dwellings counts, elevation and distance decay functions are used. We then visit each cell in order to count the number of dwellings that could be provided with broadband where only dwellings capable of being provided by broadband are counted. There are two steps to before being able to provide a final raster layer with just dwelling counts. The first step examines a cells ability to establish line-of-site (LOS) communication to each cell. Figure 4 is a 3d model of the LOS process. If a cell does have LOS with the currently visited cell (in Figure 4 it is the very centre cell) than it is assumed that communication is possible. Therefore LOS cells are summed together and excluded from being examined in the next step, (Figure 6).

The remaining cells within the 50 km radii are examined using a distance decay function developed from the RPA. The distance decay functions' used is the one specifically for created for the location of where the cell being examined is located. Each cell will have the total number of households that could be provide with broadband. Figure 4b illustrates the final value that would be represented in a cell and this step is repeated two mentioned steps are repeated for every single cell.

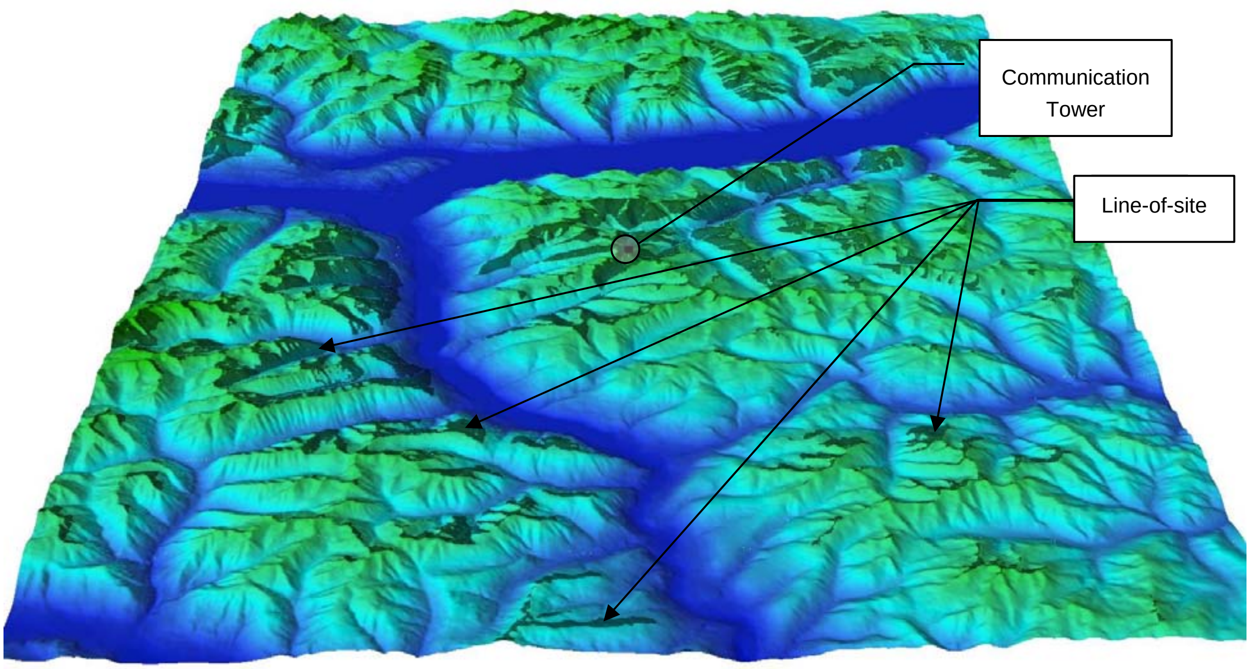

Figure 4. 3D Visualization of the LOS Examination for a sample map sheet for the Nelson, BC area. Dark patches represent area's visible from a communication tower of 50m.

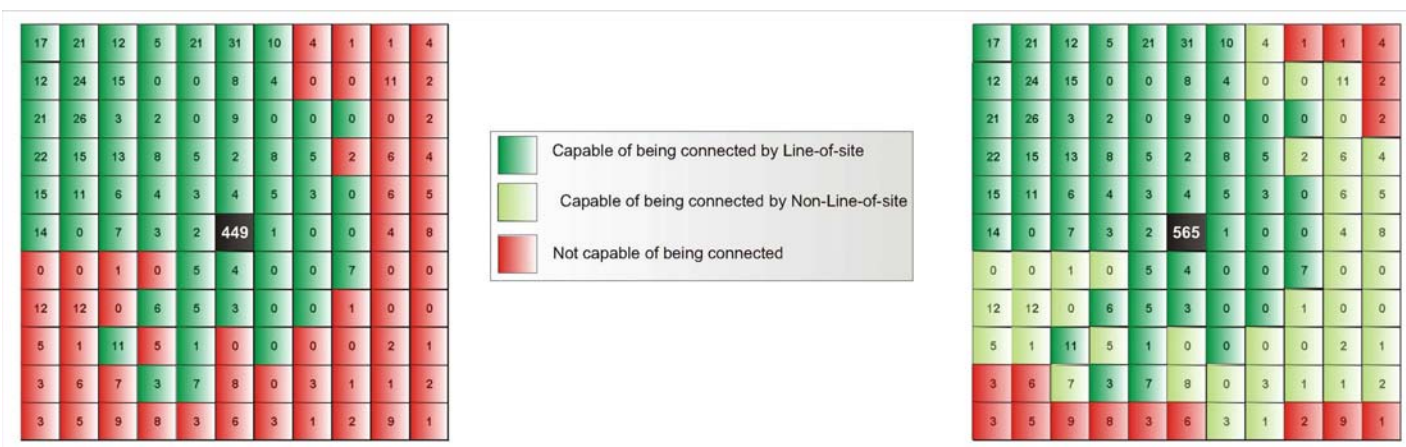

Figure 5. Diagrams (a - left) Illustration of the cells that could be covered through the examination of LOS from the centre cell where a dwelling count of the LOS cells are totalled. (b - right) Illustration of the cells that could be covered through the examination of LOS and a distance decay function from the centre cell where a dwelling count of the LOS cells are totalled.

4. Preliminary Results

Without accounting for radio propagation, nearly 85% of Canadian households could be provided with a WiMAX type wireless connection capable of providing broadband. This study was conducted at varying radii, 5, 10 15, 25, 35 and 45 km (Sawada et al. 2005) in order to understand the requirements that will be needed by new wireless technologies. The results are presented in Table 2 and Figure 7.

Table 2. Number of dwellings reached with broadband wireless technology at various radii from potential communication towers.

Province/Territory	5 km	15 km	25 km	35 km	45 km	Unserved > 45 km
Nunavut	4,261	1,945	245	0	0	1,726
Northwest Territories	39,585	939	0	0	0	1,466
Yukon	818	216	0	207	0	1,023
Quebec	527,200	17,088	3,152	2,134	687	4,375
Newfoundland and Labrador	84,073	9,081	3,436	1,517	495	1,535
Saskatchewan	26,752	39,519	7,808	2,485	0	2,393
British Columbia	123,940	17,180	6,916	4,286	1237	5,326
Alberta	93,463	48,069	5,651	1,931	609	2,775
Manitoba	73,561	25,866	1,441	761	0	3,439
Ontario	505,479	29,112	2,915	2,470	3312	4,056
New Brunswick	139,482	6,177	1,644	339	0	6,25
Nova Scotia	92,848	12,033	1,118	294	0	5,81
Prince Edward Island	22,958	0	523	0	0	37
CANADA	**1,734,420**	**207,224**	**34,850**	**16,424**	**6,340**	**29,356**

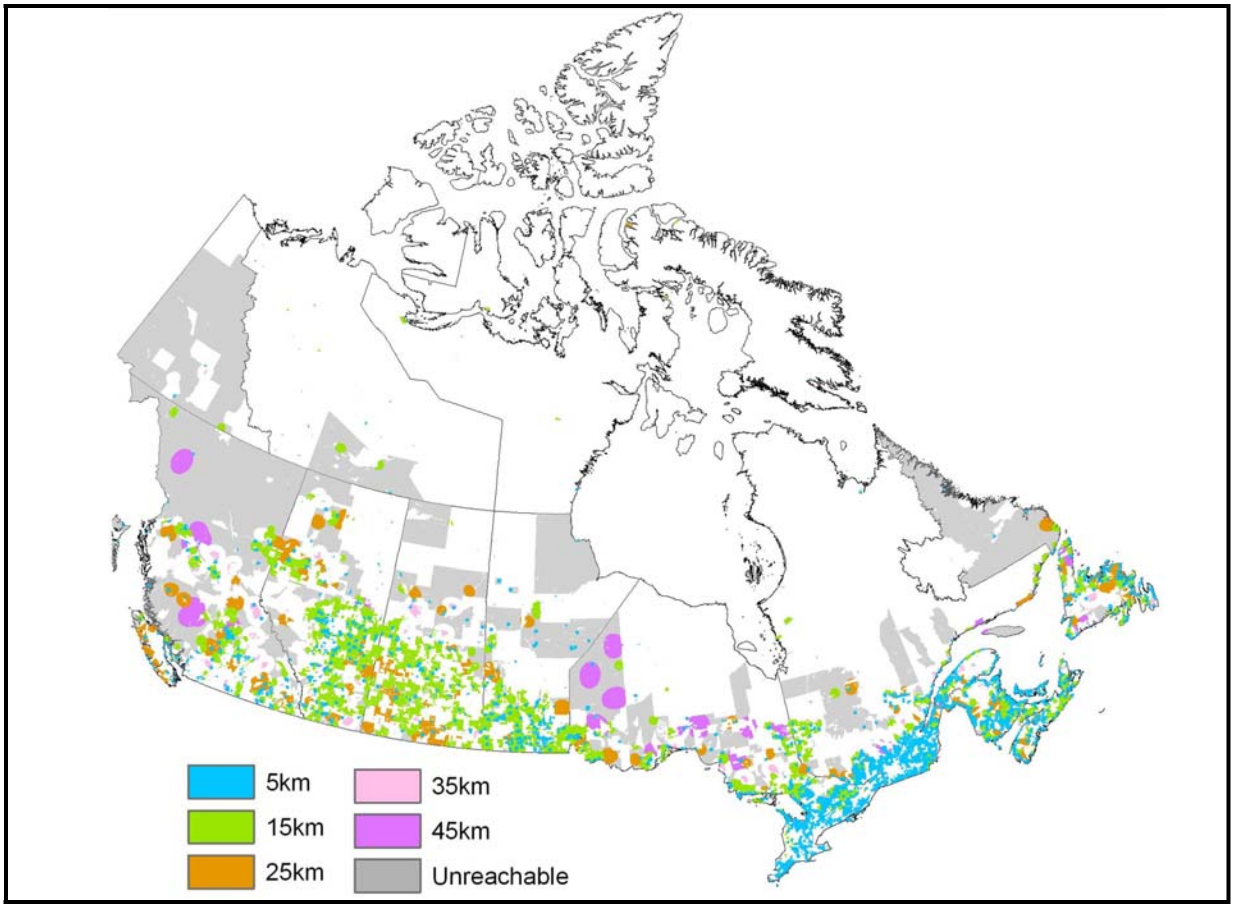

Figure 7. Unserved dwellings that potentially could be provided with fixed wireless broadband internet using various technogies with varying ranges in reach. Does not incorperate a radio propagation analysis.

5. References

DMTI Spatial Inc. Clutter Data. Markham, Ontario. http://www.dmtispatial.com/clutter.htm (Date Accessed: 04 May 2005)

Fourie, Denise K. and David R. Dowell. Libraries in the Information Age: An Introduction and Career Exploration. Greenwood, CO: Libraries Unlimited, 2002.

M. Hata. Empirical Formula for Propagation Loss in Land Mobile Radio Services. IEEE Trans. on Vehicular Tech., August 1980, pp. 317-325. [Hata model]

Sawada, M., Cossette, D., Chouinard, Gérald., Briggs, Gerry., Johnson, P.G. (submitted). A GIS Approach for Assessing Broadband Wireless Market Potential For Rural And Remote Canadian Communities. International Journal of Knowledge, Science and Society.

Thieken, A. Scaling input data by GIS for hydrological modelling. Hydrol. Process. 13, 611-630 (1999).

Wellar, B. (1985). "The Significance of Automated Cartography to an Information Society." Cartographica 22(4): 38-50.

WiMAX. IEEE 802.16A Standard and WiMAX Igniting Broadband Wireless Access. 2004. http://www.wimaxforum.org/news/downloads/WiMAX-The_Business_Case-Rev3.pdf (Date Accessed: 20 July 2004)

6. Acronyms

Broadband –	High Speed Internet
DA –	Dissemination Area
DEM –	Digital Elevation Model
DOI –	Department of Industry
GIS –	Geographical Information Systems
IEEE -	Institute of Electrical and Electronics Engineers
LOS -	Line-of-site
Mbps –	Transmission of 1,000,000 bits (megabits) per second
NTDB -	National Topographic Data Base
NTS -	National Topographic System
NLOS -	Non-Line-of-Site
RF –	Radio Frequencies
RPA –	Radio Propagation Analysis
WiMAX –	Worldwide Interoperability for Microwave Access (IEEE 802.16)
MHz -	A unit of frequency equal to 1,000,000 hertz