Broadband Coverage: Assessing the Digital Divide in Winona County, Minnesota

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Abstract

High-speed internet access is a becoming a greater necessity for people to participate in today's economy. However, even though broadband networks have been greatly expanded, there are still areas that do not have access. This study examines the extent to which Winona County, Minnesota is connected to the internet via broadband connection and the opportunities for expanding broadband penetration. The Network Analyst extension in ESRI's ArcGIS allowed for extensive analysis of which central switching offices (COs) would be the best candidates to upgrade to provide broadband service via the New Location-Allocation, also known as, "maximal coverage location problem."

Introduction

For any community to grow and prosper in the 21st century, it must have access to broadband -- defined by the Federal Communication Commission as supporting at least 200 Kbps connection speed to the internet, both downstream and upstream (Grubesic and Murray, 2002).

With broadband, businesses can communicate with, and receive feedback from, their customers as well as keep track of their markets. Private citizens can access information from around the world, trade stocks, and search for places of employment. There are other myriad advantages to broadband access including: public safety, education, and health care (Resz, 2010).

Large urban areas already benefit from broadband networks and have connection speeds of greater than 50 Mbps, but rural areas, on the other hand, are "lagging far behind" (Grubesic and Murray, 2002).

The Broadband Infrastructure

The infrastructure that supports the broadband network in the U.S. consists of a series of more than 22,000 central switching offices (COs) and wire centers (Grubesic and Murray, 2002). The wire center refers to the actual physical location where customers' lines terminate (Newton; 2000 as cited in Grubesic and Murray). The CO is the building that houses the "circuit switching equipment for all telephone lines serving a geographic area" (Grubesic and Murray).

This network of wires has been built over the past 60 years. Many of the wires are old phone lines (twisted pair copper wires). Grubesic and Murray (2002) point out that "high quality digital transmissions are reliant on quality media," and twisted pair copper wires do not constitute a quality media. Therefore, one of the key parts underpinning the broadband network is the fiber-optic cable, which delivers up to 100 Mbps capacity

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with a quality that surpasses twisted copper wire (Grubesic and Murray, 2002).

The main strategies used to expand the broadband infrastructure are: Fiber to the Home (FTTH) and Fiber to the neighborhood (FTTN) (Lee and O'Kelly, 2009). FTTH, as the name implies, has a fiber-optic connection all the way to a subscriber's home/business. FTTN, on the other hand, delivers broadband to a neighborhood via a fiber-optic cable but still utilizes the 60+-year-old network of twisted pair copper wires to deliver the signal to the home, thus restricting the area of coverage.

Study Area

The area studied was Winona County (Figure 1), which is situated along the Mississippi River in southeastern Minnesota. Winona County covers 626.21 square miles and had a population of 51,232 in 2013. The median household income between the years of 2008-2012 was $46,900, which was $12,226 below the state's median household income (US Census Bureau).

Figure 1. Map of the study area: Winona County, Minnesota covering nearly 626 square miles in size.

Winona County was chosen due to how its population is distributed with a mixture of urban and rural areas. The objective of this study was to examine the extent of the digital-divide in a region, hence using a largely urbanized county, like Ramsey County, Minnesota, would have been counterintuitive.

This research is important to regions of similar makeup as Winona County because as broadband providers continue to expand coverage, some areas will benefit while others will not due to geographical limitations on the network (Grubesic and Murray, 2002). Understanding how these limitations come into play when examining broadband coverage in a county like Winona is an important first step in ameliorating the connectedness of rural areas.

Limitations to Broadband Coverage: The Digital Divide

Spatial Limitations to Broadband Coverage

Lee and O'Kelly (2009) noted spatial limitations of broadband technologies due to the inverse relationship between a digital signal's strength as it passes through a physical medium and the distance to the transmitter. The Digital Subscriber Line (DSL), for example, is only available within 18,000 feet of a Central Office (Lee and O'Kelly). However, being able to provide DSL to locations 18,000 feet away is not always possible due to other factors such as: 1) the gauge of a copper wire being less than 24, 2) the copper wire not being insulated from electro-magnetic transmissions, and 3) too much contact with high groundwater content areas (Grubesic and Murray, 2002). Grubesic and Murray add that some providers will not offer service to customers unless they live within 12,000 feet from the CO.

Cost Limitations to Broadband Coverage

Along with the previously noted geographic limitations, there are cost limitations. The two main aspects related to broadband coverage are: coverage/penetration of broadband and the quality of service (i.e. upload and download speeds). The problem, however, is that achieving both may not be economically feasible due to limited resources (Lee and Xiao, 2009). Expanding coverage of a broadband network increases the distance between facilities; thus, an expensive investment in copper wire or fiber optic cable to connect the facilities is required (Lee and Xiao). Also, Grubesic, Matisziw, and Murray (2010) posit costs of "upgrading a CO in order to provide xDSL can be substantial." A switch to handle 256 subscribers retails for around $7,000 (Grubesic, Matisziw, and Murray).

Quality of service, on the other hand, requires a broadband network to be well-connected. Lee and Xiao (2009) observed that a network with four connected COs will have better service than a network with only one CO because if the link between the user and one of the COs in the network gets congested, sent packets can be rerouted though the other COs in the network. However, with only one CO, sent packets have no other option than to use the congested link.

Suppliers are left with the choice of providing everyone in a given geographic area with broadband coverage, or providing most people in a given geographic area with high quality coverage through a network of well-connected central offices.

Demand Limitations to Broadband Coverage

In conjunction with the limitations of space and cost, there is a third factor that adversely affects broadband coverage: consumer demand.

Grubesic and Murray (2002) point out DSL service costs between $50 and $200 for the monthly service with a $300 installation fee. Not every house will be able to afford such costs, thus the providers will instead focus on areas where they know there will be high demand (Grubesic and Murray).

McGrath (2011) provides the example of Panoche Valley, which although it is situated only 100 miles to the south of Silicon Valley, residents do not have access to broadband service. Among the many possible causes for this gap in service is that even if broadband were available, few people in Panoche Valley could actually afford it (McGrath). In situations like Panoche Valley, providers would face the prospect of high costs and low demand if they were to expand coverage to that area.

Public vs. Private Provision of Broadband

Some cities have taken steps to diminish the digital divide by using public utilities to deliver high speed internet to their communities. Lafayette, LA is one such case in point. Lafayette Utilities System Fiber (LUS Fiber) has laid more than 800 miles of fiber-optic cable capable of up to 100 Mbps upload speeds (Jervis, 2012).

There is some controversy over whether or not government entities should interject themselves in the telecommunication market. Those in favor cite benefits broadband brings to communities in the form of commerce, banking, insurance, government, education, etc. (Bray, 2009). Furthermore, the profit incentive is not there for private companies to extend coverage to everyone. In the case of Lafayette, LA, when the city asked private companies to partner with them to increase coverage they refused because of a lack of a return on the investment (Jervis, 2012).

Opponents of city intervention in the telecommunication market argued the city should not get involved in the "costly and at times risky business of providing internet service" (Jervis, 2012). A second issue brought up by opponents is the inherent unfair advantage a publicly owned company would have. Cox Communications spokesman Todd Smith asserted that it is "an unfair advantage for your competitor to also be your regulator" (as cited in Jervis, 2012).

Using Geographic Information Systems to Determine Broadband Penetration

Geographic Information Systems have considerable ability to evaluate current broadband coverage and identify underserved communities (Grubesic and Murray, 2002). Grubesic and Murray suggest even a simple spatial analysis using a 12,000 foot buffer around every CO could provide valuable information by analyzing the demographics of the covered buffered area. Furthermore, they state cost could be incorporated to create more sophisticated models for better assessment of broadband coverage (Grubesic and Murray).

Methods

Data Preparation

Determining the extent of broadband coverage in Winona County required specific spatial and demographic data on a small enough scale to make analysis possible. For example, obtaining demographics at the county level would be useless, as there would be no way to differentiate one region of the county from another. Therefore, demographic data obtained from the US Census Bureau were at the census tract level thus fragmenting the county into smaller areas to be analyzed. A shapefile containing all thirty-eight census tracts and a demographics table were obtained and imported into ArcGIS.

With the pertinent data gathered, the next step was to make it useable to determine the maximal coverage of broadband-equipped COs based on a series of variables. The maximal coverage location problem determines which facilities should be upgraded to meet the greatest demand. Consequently, it was necessary to have both demand and facility points.

Centroids of each census tract were generated thereby creating a demand point for each tract. Next, a join relationship between it and the demographics table was established by entering a new field in the table to hold the corresponding SCTFIPS number, which would serve as the primary key. At this stage, the demand points were ready for analysis.

The next step was to generate a point feature class representing the COs. To accomplish this, the locations of all COs in the US were purchased from TelcoData.

The CO data were delivered in a tab delimited text file with the XY locations given in decimal degrees. After the table was imported into ArcGIS, it was used to create an XY point feature class representing the facilities (Figure 2).

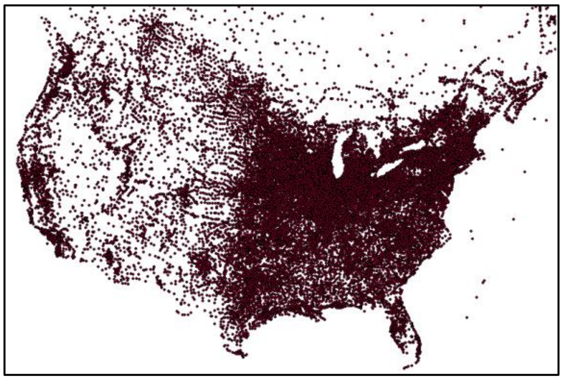

Figure 2. XY locations for all central switching offices in the US.

Building the Network Dataset

With both facility and demand points established, all that remained before analysis of the data could begin was to establish a medium by which the distance between the facility and demand points could be gauged.

Referring back to the maximal coverage location problem, determining how to best allocate facilities to meet the greatest demand requires an understanding of the nature of a broadband network. Not only does a signal's strength depreciate as it travels along a physical medium, but also the communication cables, rather than extending outwards from a CO like the radians of a circle, travel along roads. Consequently, using a simple buffer around the COs, while adequate for simple analyses, would not provide as accurate a result as using a road network (Figure 3) measuring distance as the impedance.

Therefore, a shapefile of Winona roads was acquired from the MnDNR Data Deli and used to create a network dataset. The connectivity policy used was 'Any Vertex,' as the intricacies of the road system have little bearing on the broadband network other than communication lines generally travel along roads.

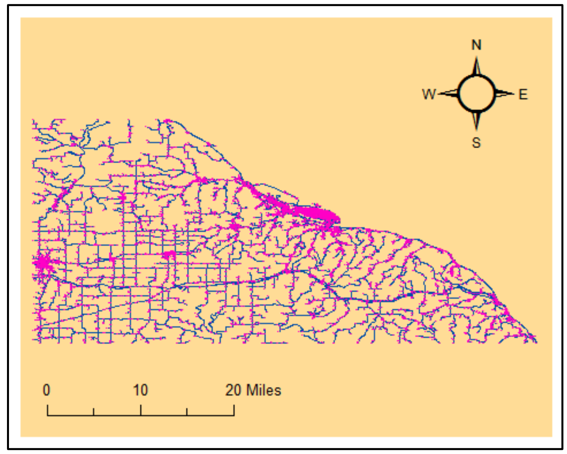

Figure 3. Network dataset of Winona County, MN roads created for use with the maximal coverage solver.

To solve the maximal coverage location problem of which COs to upgrade with broadband, the Location-Allocation solver in the Network Analyst toolset was used on the created network dataset. When using this solver, a new analysis layer was created within the active Data Frame with which the user could manipulate various parameters.

The Analysis Settings used in this study were: Impedance set to feet, Start Time was not a factor, Travel from Facility to Demand, U-Turns were allowed, Output Shape Type was Straight Line.

In Advanced Settings, the settings used consisted of the following items: Problem Type: Maximize Coverage; Facilities to Choose was treated as a dynamic variable; Impedance Cutoff: 18000 feet (the maximum distance a broadband signal can reach).

Once the parameters had been set, demand and facility points were placed on the network, via the Network Analyst window, as close to their corresponding centroid or CO as possible. After all the points had been placed, copies of the *Maximum Coverage* layer were created so individual weights could be assigned to the demand points and analyzed separately.

Gauging Demand

With data prepped for analysis, the next analytic phase was to assign weights to the demand points. Gauging demand for any product is not simply a matter of how large the population in the service area is since many variables determine whether or not people will purchase a good. Weighting demand points allows the maximal coverage solver to account for key variables affecting demand, thereby returning more accurate results.

While it would not be possible to account for every factor influencing demand, elucidating a few, broad variables would be. To that end, the following variables were chosen to use as weights for the demand points: Median Age, Median Income, and Population.

Median Age was chosen as it is more likely that areas with a high median age would demand less broadband service than areas with a lower median age due generational differences.

Income levels are an important measure of demand, as broadband service could be considered a luxury good thus as incomes fall so would the demand for broadband service.

The last variable accounted for in the study was population. Weighting each demand point by population will show which COs should be upgraded based on which one would serve the most people.

Summary of the Methods Used

The workflow diagram presented in Figure 4 provides a higher view of the process used in this research. The central switching offices and demand points with their various attributes were input into the Location-Allocation Solver. The Network Dataset is shown in its role as a property of the solver.

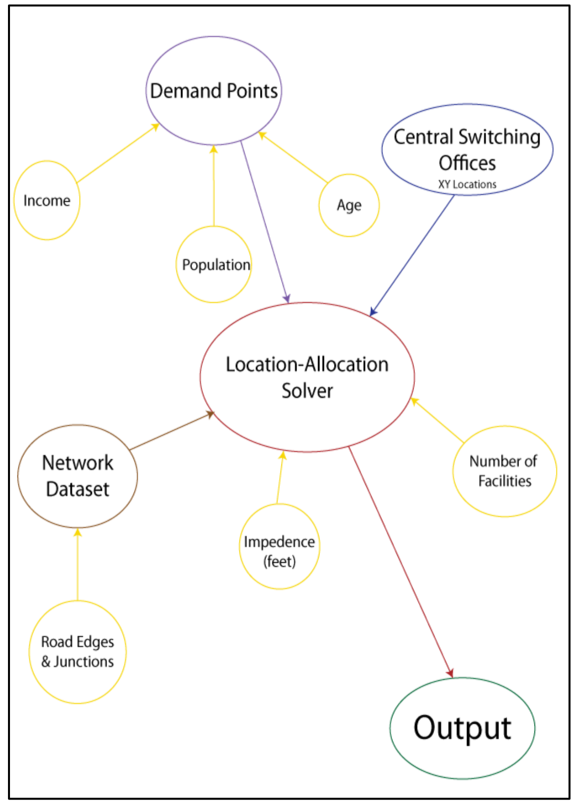

Figure 4. Workflow Diagram: The demand points, census tract centroids, and facilities, COs, are input into the solver; the network dataset selected; parameters set; and the output generated.

The two parameters to be manipulated in the study, feet and facilities, are depicted as attributes of the Location-Allocation Solver.

Finally, the output from the Solver is displayed in the lower right hand corner of the diagram. This feature represents the several solution sets generated by the solver which contain the COs that should be upgraded to provide broadband service based on the specified parameters.

Results

Maximizing Coverage

Several iterations of the maximal coverage problem were run to determine what, if any, differences there were between income, age, and population as demand and to see which COs should be the first to be upgraded with broadband capabilities.

The first iteration was run with the facility limit parameter set to one and the impedance cutoff set to 18,000 feet. Additionally, the demand points were weighted based on population. This was done to find out which CO was providing the greatest amount of coverage to the most people thereby establishing a baseline with which subsequent results could be compared. When the solver was run, the first CO to be upgraded was in the City of Winona (Figure 5). The number of demand points served was 22 of 39, and the total population within broadband coverage was 22,480 people, or 43% of Winona County.

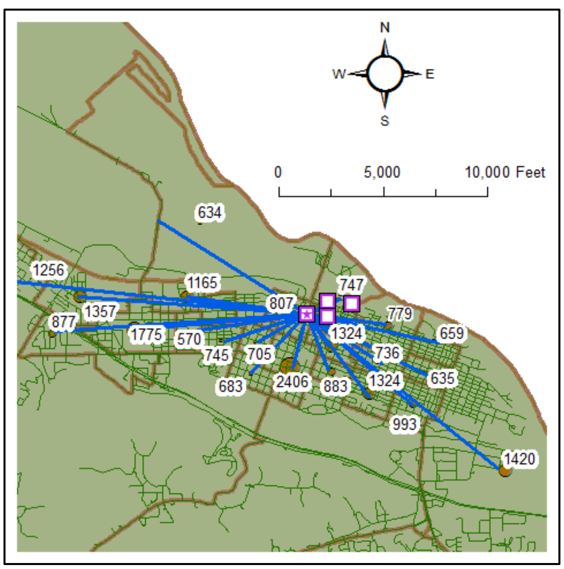

Figure 5. The starred square represents the first CO to be upgraded with broadband equipment within the City of Winona, MN. Blue lines indicate which demand points are covered.

The second iteration increased the facility limit parameter to 2, with the impedance cutoff remaining at 18,000 feet. Running the solver a second time with the new parameters resulted in the facility in St. Charles, MN being upgraded. This CO only provided coverage to one additional demand point thereby increasing the number of demand points served to 23 of 39, and expanding the number of people served to 25,506, or 49% of the county.

Increasing the facility limit to three brought in the CO in Lewiston, MN. This upgrade increased the number of demand points served to 24 of 39. This level of coverage put the number of people served to 27,357, or 52% of the county.

When the facility limit was increased to four, a second CO in the City of Winona was chosen (Figure 6). This expanded the coverage to a new demand point bringing the total population served to 29,178, or 56% of the county.

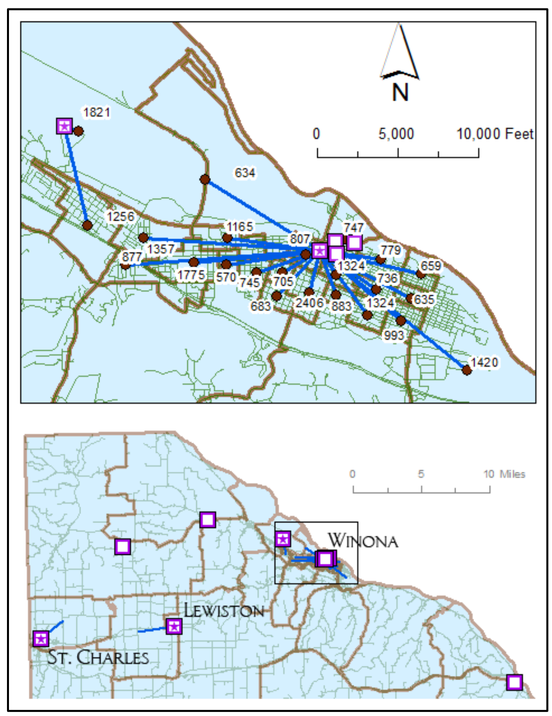

Figure 6. COs that should be upgraded based on population served in the City of Winona, MN. Blue lines indicate which demand points are served by each CO. The labels by each demand point show its population.

At this point, increasing the amount a facilities resulted in no further increase in broadband coverage, rather additional COs in the City of Winona were upgraded, thereby increasing the quality of service in that area.

A simple trend analysis of the results showed a steady increase in the percent of population served until after the fourth CO, at which point all the demand points that could be serviced, were identified (Figure 7).

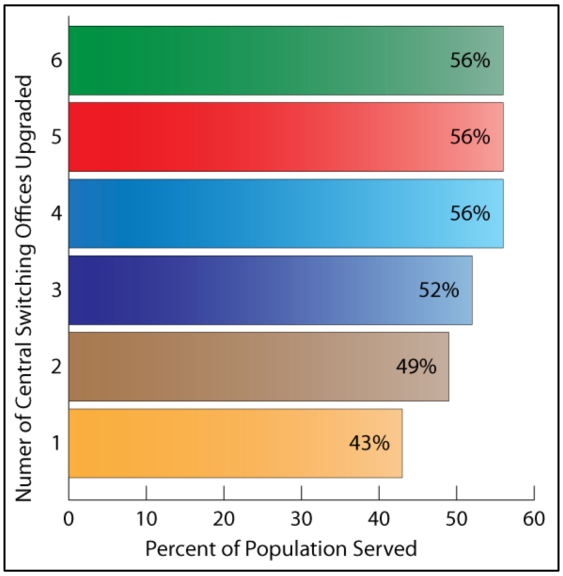

Figure 7. Bar chart depicting the increase in the percent of the population served as the number broadband equipped COs grows.

Maximizing Quality of Service

Another important factor that service providers consider is the quality of service provided to the customers. To reflect a higher quality of service in the solver, the impedance was changed from 18,000 to 7,000 feet, which could be translated as faster connection speeds. The solution set generated for this group of parameters differed from the previous ones in that all of the COs to be upgraded were located in the City of Winona (Figure 8).

Overall broadband penetration was markedly lower than that of the previous iterations. The first upgrade only extended coverage to 22% of Winona County.

Furthermore, with all possible COs upgraded, only 35% of the county was covered.

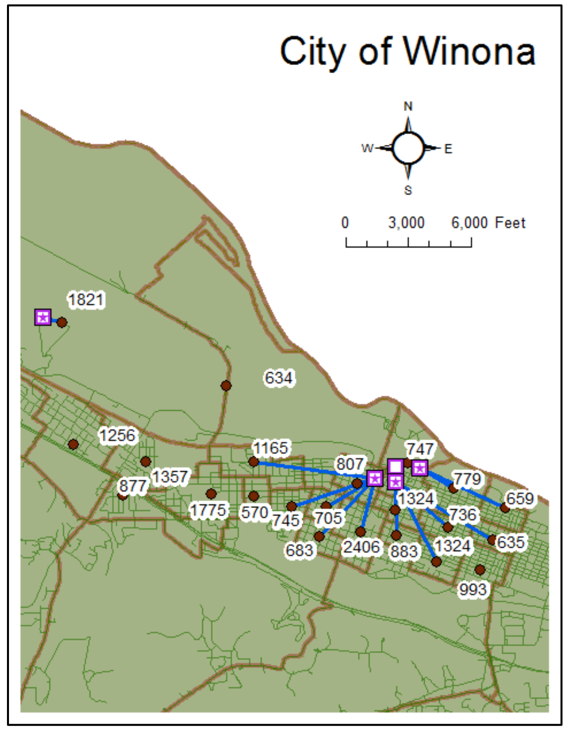

Figure 8. COs to be upgraded when a higher quality of service is prioritized. The blue lines indicate the demand points served.

Demographics

When comparing the affects age, income, and population had on which CO should be upgraded, two of the variables, age and population, yielded the same results. The solution set for income, however, was slightly different in that the order in which the facilities were prioritized changed.

When weighting the demand points by age and population, COs in the City of Winona and St. Charles were selected due to the demand points representing census tracts with greater populations and a more ideal median age than the other areas.

However, when the other variables were held constant and income was measured, COs in the City of Winona and Lewiston were selected. These results indicate while other demand points may contain more possible customers, the demand points around the two cities selected contain a set of customers that are more likely to purchase high speed broadband service due to their higher income levels.

However, when comparing the median incomes of the Lewiston and St. Charles, $52,067 and $50,984 respectively, the difference is so narrow that it is hard to conclude that it would have an appreciable effect on a household's ability or desire to purchase broadband services.

Discussion

Results clearly showcased some obstacles standing in the way of expanded broadband coverage. For example, when coverage was maximized, only two COs outside of the City of Winona were upgraded, as the remaining ones were farther than 18,000 feet from the nearest centroid. Even if all COs in Winona County were upgraded, there would still be a large portion of the county left outside the coverage area. Even though some demand points were closer than 18,000 feet when measuring straight line distance, the structure of the road system pushed them out of the service area. Furthermore, the 18,000 foot coverage area is based on ideal circumstances, quality of the media, insulation from electromagnetic transmissions, etc., which are not always present (Grubesic and Murray, 2002). Therefore, many providers will not provide broadband service to customers beyond 12,000 feet, thereby reducing the coverage area even more.

When quality of service was prioritized, results were markedly different. All facilities selected were within the City of Winona. While this result may be related to the limitations of using census tracts as geographic representations of demand, it stands to reason that large population centers would benefit the most from a higher quality of service. This scenario showcased the competing choices between maximizing coverage and maximizing quality of service. The choices are oppositional in that businesses can either expand their broadband penetration or improve the service to their existing customers thereby retaining them as customers and possibly attracting new ones (Lee and Xiao, 2008). Therefore, while residents of the City of Winona would experience excellent service, other communities would not have any service.

As is evidenced by results, broadband providers are channelized into upgrading COs that are close to high population areas. Even when maximizing for coverage, only the COs near cities were upgraded because the other demand points were too far away.

Limitations of Data

Determining the maximum coverage of broadband-equipped COs required a feature class of demand points that held all the pertinent variables used for analysis and represented a geographical area in Winona County. To satisfy these requirements, demographic and spatial data were obtained from the US Census Bureau at the census tract level.

Using census tracts proved to have some significant drawbacks. First, the difference in size between each census tract was so great that the range was 107 square miles. Second, some census tracts were comprised of both urban and rural areas. Consequently, when the centroids were generated, many were placed more than 18,000 feet away from the nearest CO when, in reality, a large portion of the population was well within coverage. For example, one census tract, which contained a large portion of the City of Lewiston, encompassed 108 square miles. Consequently, when the centroid for that tract was created, the point representing it was placed over 24,000 feet from the CO in Lewiston (Figure 9). This no doubt skewed the results returned by the maximal coverage solver.

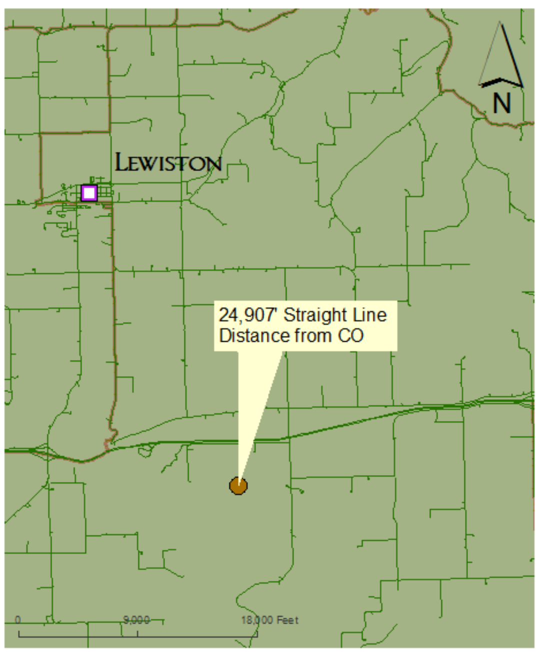

Figure 9. Depicts the discrepancy between centroid placement and population for large census tracts. The purple square and brown circle represent the CO and centroid respectively.

These limitations occurred in almost every area. The very design of census tracts was at odds with the overall design of the research because they effectually split up the population of the cities to spread their populations over a wider geographical area. Lewiston and St. Charles were both split between two tracts, however, in both cases one of the demand points was beyond coverage. Additionally, the southwestern portion of the City of Winona had the same issue with three large tracts encompassing sections of the city and large portions of rural land.

The effect this limitation had on the results was to distort the amount of the population served. In some cases more people would be served and fewer in others.

Ideally, demand points would be derived from areas of a more uniform size and shape, thus enabling the maximal coverage solver to more accurately account for variables such as population and income levels. In highly urbanized counties, like Ramsey County, MN, census tracts may be of a more uniform size, thereby rendering better results.

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