Costs and Benefits of Universal Broadband Access in Wyoming

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Abstract: *Achieving broadband access to the Internet is as important today as was access to roads, railways and telephones in the last century. At the request of policy makers, the Wyoming Telecommunications Council (WTC) was tasked to identify those areas of the state in which there was no market provider of terrestrial broadband Internet access and to estimate the lowest cost technology to provide broadband access to these locations.*

To support these objectives, a GIS was developed to visualize broadband-served areas, existing equipment locations, and unserved households. Additionally, output from the GIS supports a bottoms-up engineering economic cost model. Together, the GIS data and cost information help policy makers and service providers visualize current broadband deployment, potential demand, and potential deployment costs so that informed decisions can be made to weigh the costs and benefits of providing broadband access to these areas of the state

Introduction

Broadband Internet access is as important to education, economic development and communities as roads, rails and canals were 100 years ago.

Realizing the significance of this information infrastructure, the Governor of the State of Wyoming asked the Wyoming Telecommunications Council ("WTC") to study areas in the State which did not have broadband Internet access.

In broad terms the Council study had two objectives. The first was to identify those areas of the state which were not accessible via terrestrial broadband services. The second was to estimate--for those areas not receiving broadband—the investment necessary to deploy terrestrial broadband compared to satellite broadband services.

The study drew heavily from the support of broadband service providers: cable, satellite, telecommunication, and wireless ISP (WISP) companies. Without their time, data and assistance, this study would not be possible.

Study Parameters

Broadband Internet access was defined as providing at least 1Mb/s downstream (to the customer) and 256 Kb/s upstream (to the network) deployed using technologies currently available to providers within the State of Wyoming.

Broadband services were further categorized in terms of being terrestrial or satellite based. Satellite services as deployed by Wild Blue™ are available in nearly all areas of the State through many telecommunication providers. Although Satellite broadband services are comparable in end-user price, speed and bandwidth to terrestrial broadband service, there are a number of issues related to signal latency that may diminish the utility of the offering to some consumers[1]. The Commission decided that satellite based broadband could be a viable alternative for the study, but it should be considered separately when comparing costs to broadband services that do not have latency related issues.

The terrestrial technologies studied (telco DSL, cable DOCSIS® 2.0 cable modem, and fixed wireless) are described below. As directed by the Council, it was assumed that equipment deployed would augment either existing narrowband networks or provide new service in unserved areas. In other words, broadband networks were being grown out to serve new territories using as much of the existing viable plant as possible.

The unit of service demand was housing units within eligible census blocks. The study measured the investment necessary to deploy each broadband technology to every housing unit in Wyoming. Housing unit and population data were derived from Census 2000.

At the request of the Council, census blocks covered by Yellowstone National Park, Grand Teton National Forest and John D. Rockefeller Memorial Parkway were removed from the study.

Study Methodology

The study was accomplished in four phases.

The first phase identified service providers and obtained information regarding their costs, network architecture and service boundaries.

The second phase developed and cataloged the geospatial information received in the prior phase. This involved integrating georeferenced data submitted, purchased or developed using non-georeferenced sources.

The third phase combined the data created in the second phase with baseline demographic and geospatial data. This phase allowed the development of maps which illustrated areas of the state that were Broadband Gap Areas (BGAs or gaps) and calculated population and housing unit count in the BGAs and Broadband Served Areas (BSAs).

The final phase distilled all of the information from the prior phases and combined this with CostProWY a cost model. CostProWY is a forward looking communications cost model which estimates the cost of deploying broadband in a geographic area. It is based upon well proven forward looking network engineering and plant placement algorithms.

Developing Geospatial Data

After receiving information from providers, the second phase of the project involved developing geospatial data which captured Broadband Gap Areas. Finding these gap areas required the completion of four subsidiary tasks: developing baseline geospatial data, determining service provider boundaries within a service territory, determining broadband service boundaries, and locating/placing fiber network plant.

Source of Geospatial Data

Census blocks were selected to be the basic unit of study geography and investment reporting. Census blocks (or CBs) were selected because they represent the smallest areas of geography for which non-sampled population and housing unit data are tabulated within the decennial census. Census block boundary information was obtained from TIGER® 2004[2]. Total population and housing count data are taken from Census 2000.

There are approximately 8,000,000 census blocks in the United States. Within Wyoming, there are approximately 80,000. As directed by the Council, after eliminating Yellowstone National Park, Grand Teton and John D. Rockefeller Memorial parkway from the study, 65,000 census blocks remain. The remaining census blocks are shown with green borders in the figure below.

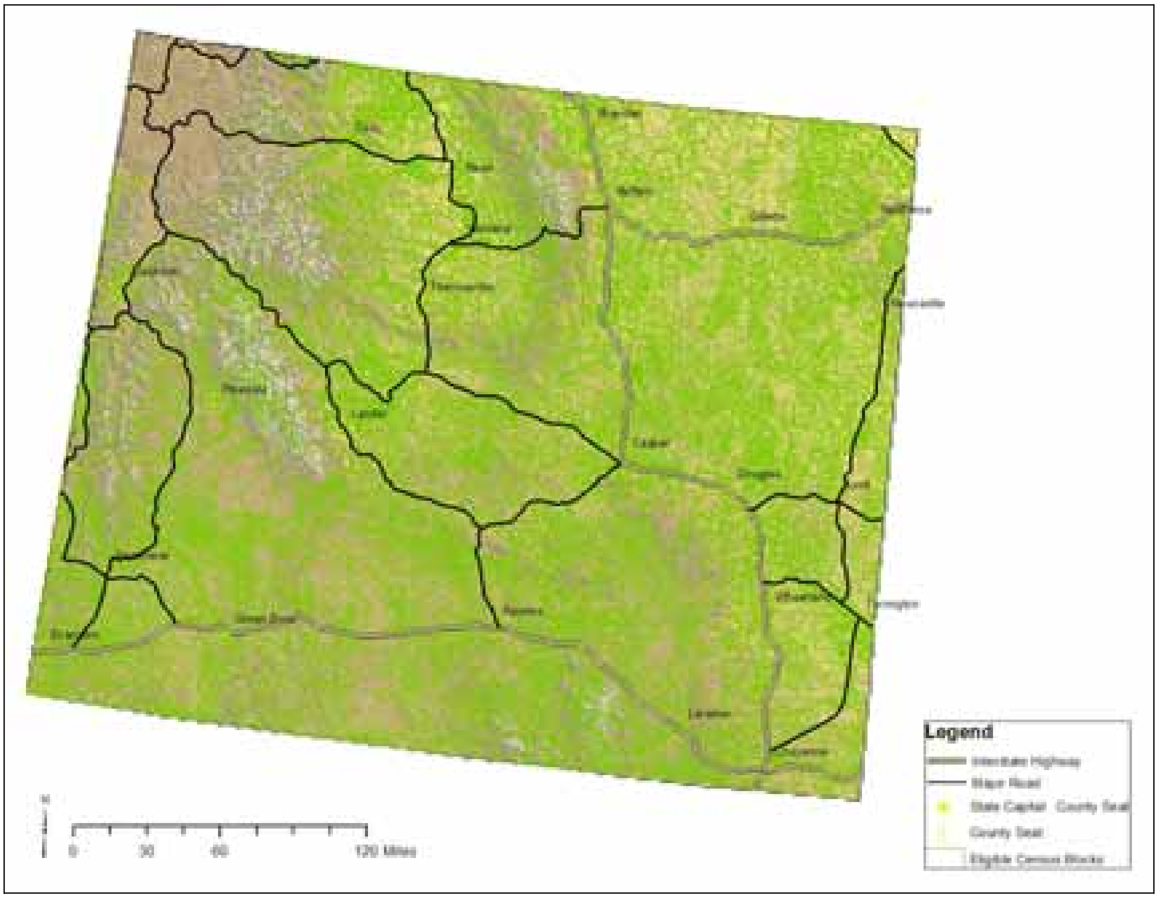

Figure 1-Census blocks in study area

The Census Bureau calculates population density at 5.1[3] persons per square mile. The national average is 79.6.[4] Wyoming has the second lowest population density in the United States.

Geologically, in Wyoming the Great Plains meet the Rocky Mountains. As a result, the state has the second highest mean elevation in the nation.

Clearly, the effects of low population density and extreme terrain will have significant cost implications upon the economics of terrestrial broadband deployment.

Baseline Service Demand Data

Within a communication network cost study the number of structures to deploy service to as well as the number of demand points within each structure are key investment drivers. In this study census housing units were used to represent locations where a potential broadband customer may live. A housing unit is defined as “a house, apartment, mobile home or trailer, a group of rooms or a single room occupied or intended to be occupied as separate living quarters.”[5]

Based upon housing unit in structure estimates by census block group and county, (from US Census, Summary File 3) housing units were accumulated to ‘structures’ within a block group and county until the density of housing units in structures fell into reported ranges.[6]

After completing the structure accumulation process, demand was described in terms of structures within census blocks to deploy broadband to. Although targeting structures to build to, the number of housing units in each structure was retained as this was necessary for the model.

To make a fair representation of demand, each of these service point locations (structures) were dispersed within a census block. To simulate the actual dispersion, structures were randomly distributed along roads (or portion of a road or road side) contained in a Census Block. The assignment process randomly selected a road segment and within that random assignment made a second random assignment to place that structure within the address range upon that road segment. Road data was extracted from US Census TIGER 2004 data.

From randomly assigned street segments and house numbers, address geocoding[7] was used to find an exact location for the demand point. Using an ESRI geocoding service, each structure was placed on the selected street segment and its location on that segment was interpolated based upon the address ranges available. Each structure’s location was rectified to be 100’ back from the centerline of the road.

At a state level, the above process resulted in an estimated structure dispersion as shown below.

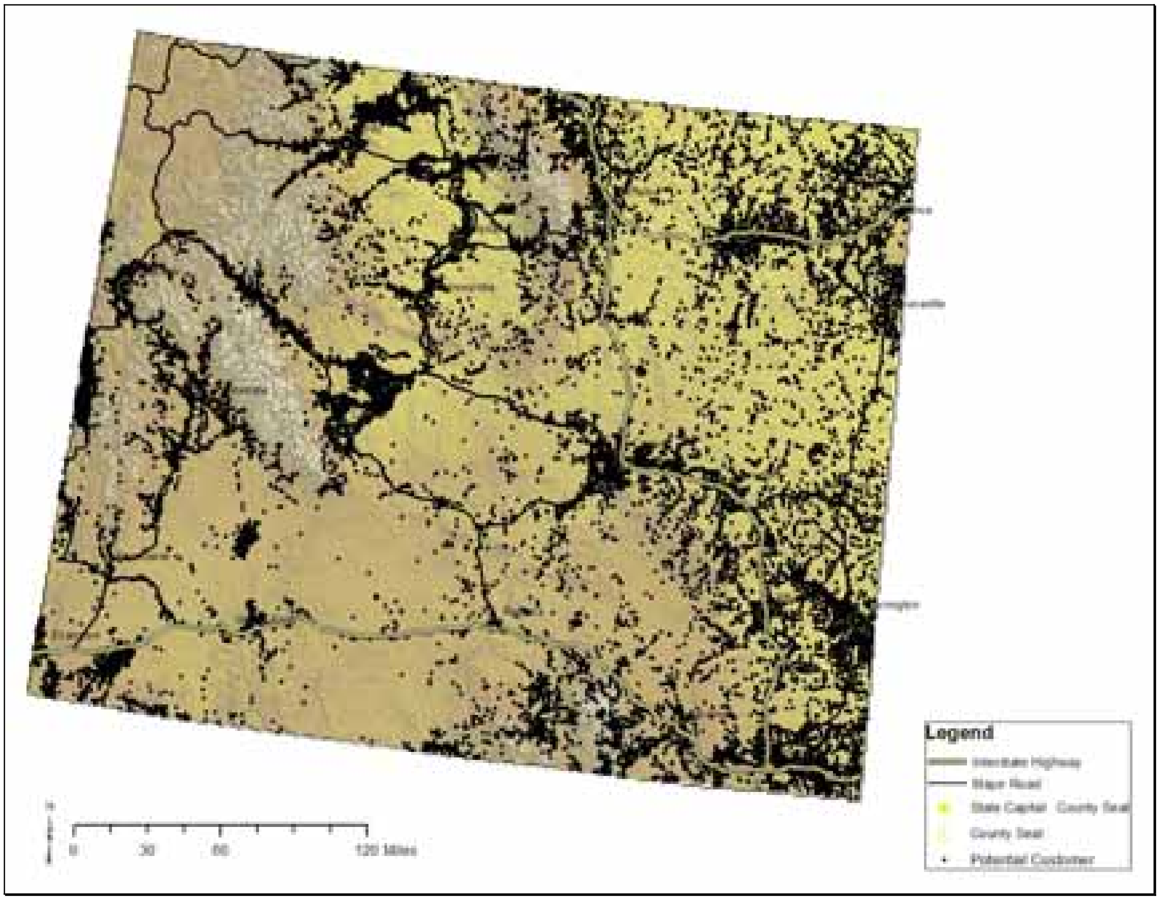

Figure 2-Structure dispersion in study area

Each black dot represents a structure which contains at least one housing unit. Recall that there may be multiple housing units in each structure.

If one were to “zoom” into this image, it would be possible to observe how demand points are distributed within a town or city along a road segment—as is the case with typical population patterns.

Determining Service Provider Boundaries

Service provider boundary information was derived from a variety of sources.

As part of the initial data request, service boundaries and broadband enabled areas were requested in a GIS compatible format. This data was to be used for two purposes. First, the general service boundary was used to demonstrate the extent of outside plant (poles, conduit, etc) available whether already broadband enabled or available for augmentation to provide broadband. Second, the broadband served area data was used to determine those areas in which broadband service was currently available. Unfortunately only one provider was able to provide the data in this format.

This meant a supporting process had to be developed to generate this crucial data in a GIS compatible format.

Determining Total Service Boundary

The Wyoming Public Service Commission supplied files to define telecommunication exchange boundaries.

Cable system boundaries were originally taken from Media Prints (May 2005)[8]. Upon review with various stakeholders, it became apparent that in many cases these boundaries seemed to overstate coverage area[9]. As a result, the Warren Media boundaries were not used in the final analysis. Instead, cable system boundaries were based upon buffered areas around fiber node locations. If the system operator couldn't provide fiber node location, the census place boundary for an area identified as served was used.

To create potential fixed wireless boundaries that could be served with existing facilities, distance buffers were created around existing towers within the state. These fixed wireless boundaries essentially represented groups of towers that formed a common backhaul network.

Tower locations were obtained from three sources. The FCC's Antenna Structure Registration System[10] was queried to find objects within the state boundary. The second source was obtained from a commercial vendor--Spectrasite[11] (now American Tower). The final tower source was the State of Wyoming. Various agencies contributed broadcast towers (Wyoming Public TV) and public safety towers (WyoLink). Because of the likelihood that a tower could be represented in each of the 3 data sources, when a group of towers were closer than 50'to one another all but one tower was eliminated.

The final selected towers within the state are shown in the figure below.

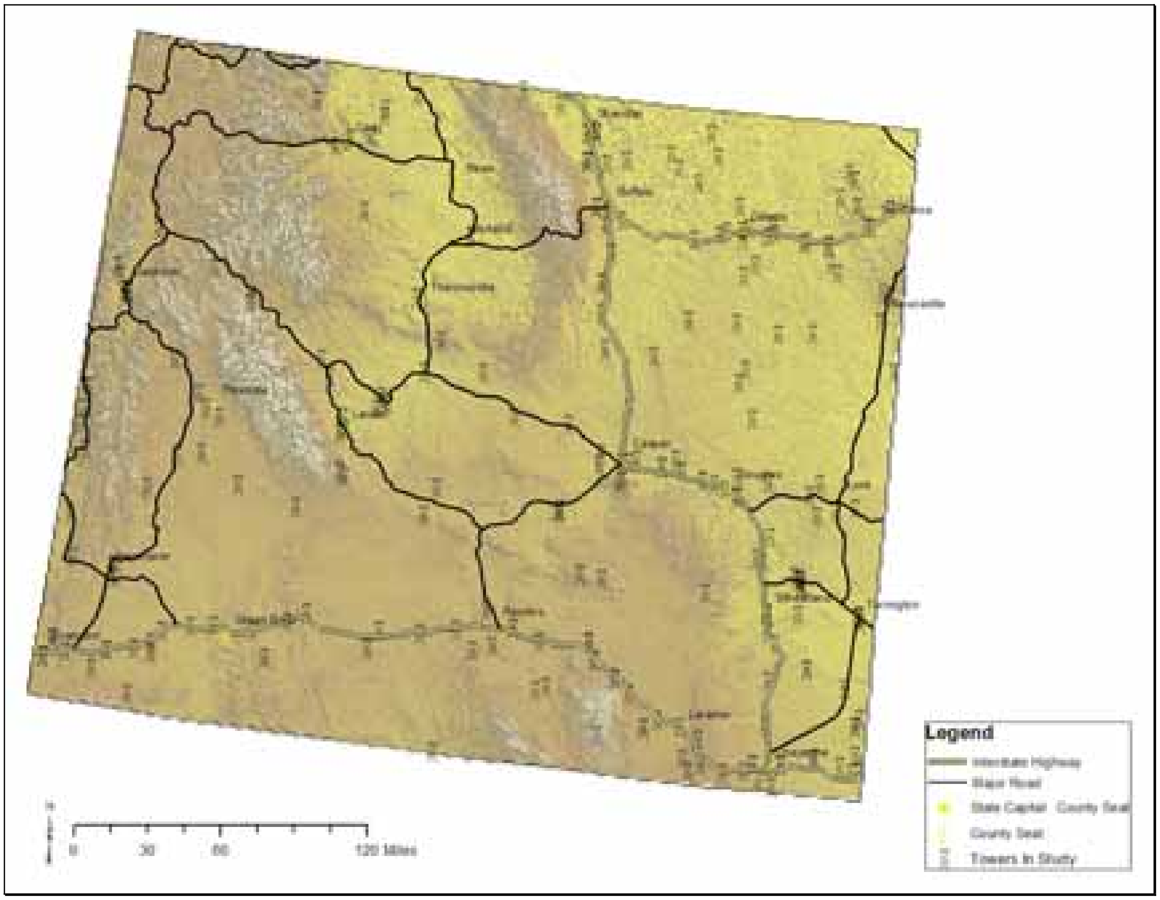

Figure 3-Towers used in study

At the completion of this stage, a service area boundary map for each terrestrial technology was available. Boundaries of wireline telecom wirecenters are shown below.

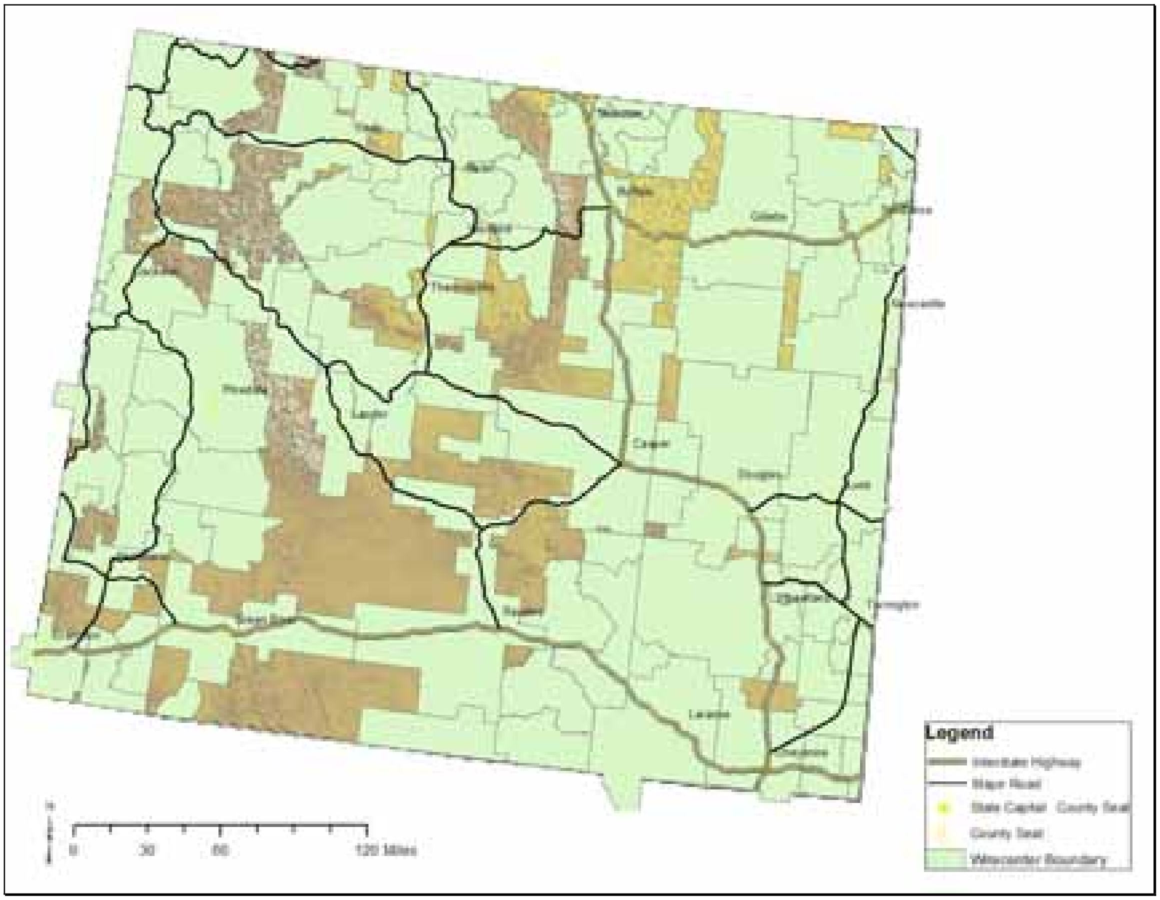

Figure 4-Telco certificated areas

Cable system boundaries are shown below. Cable systems are relatively small in geographic scope and tend to be deployed within cities and towns. This is most likely due to economics of providing service and the franchising agreements being handled at a municipal level. For clarity, these boundaries are highlighted in gold.

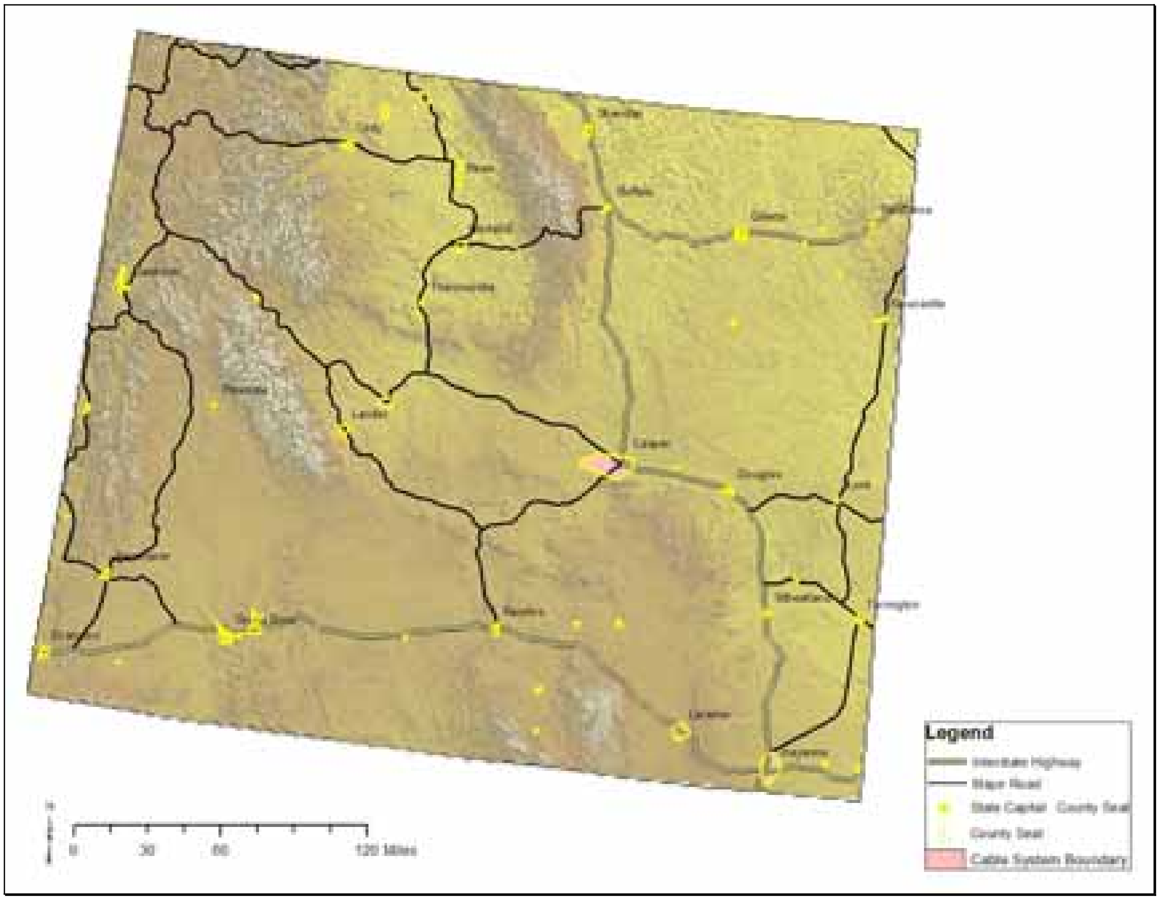

Figure 5-Cable service territory

Finally, the last figure shows the areas served by existing Wireless Internet Service Providers (WISP).

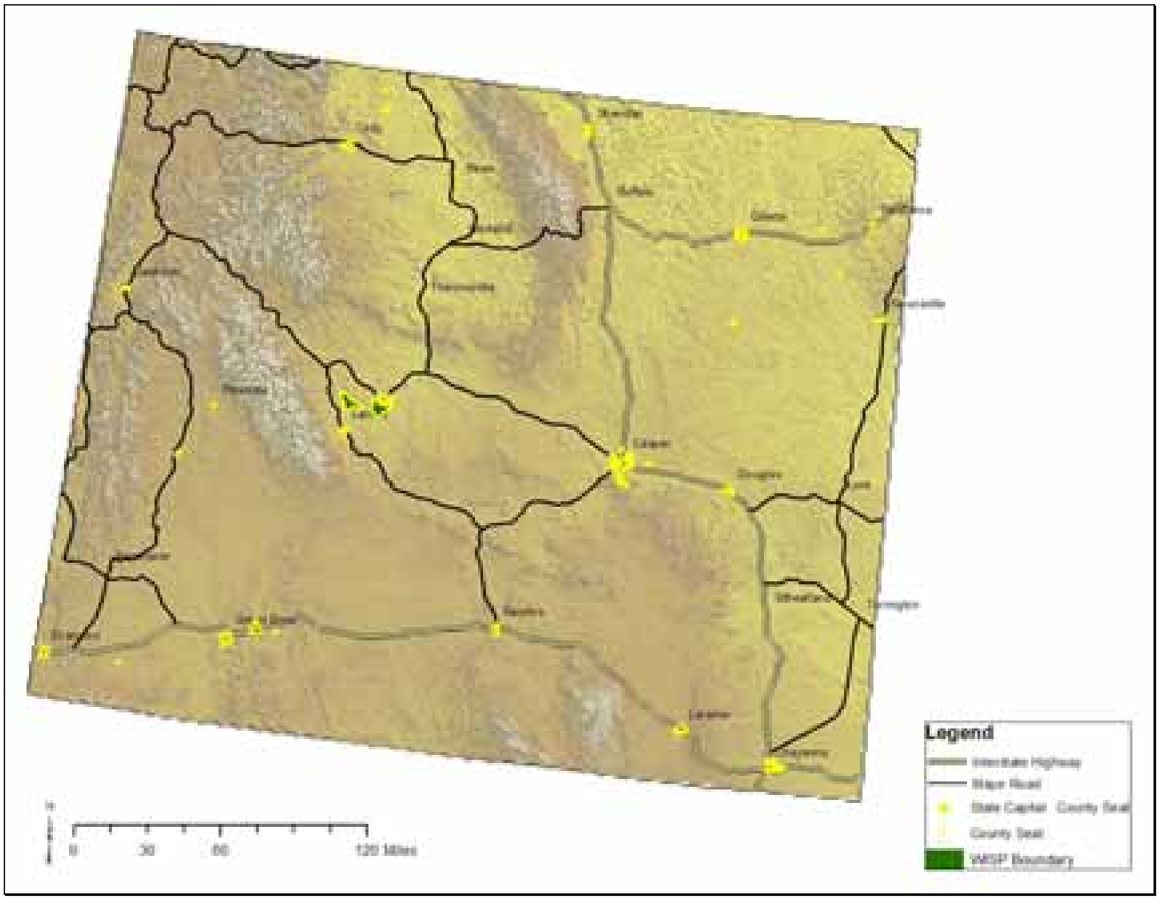

Figure 6-WISP service areas

From a cursory review of these data, it is apparent that there are many regions which have neither a certificated telecom provider nor cable/fixed wireless operator. Excluding non-studies portions of the state, areas in which there is no provider are illustrated on the figures above where terrain shows through. The implication of this is that in these non-served areas, a new terrestrial network must be deployed (there is no existing network to augment). This will be a significant cost driver for these potential customers.

Determining Broadband Service Boundary

Once the service boundaries were obtained, the next step was to identify the currently enabled broadband areas. As noted, we requested information from carriers in GIS format. However, only one provider was able to provide this information in the requested format.

For some providers CostQuest was able to obtain, from publicly available sources, GIS files containing Distribution Area (DA)[12] boundaries served by broadband equipment. From these files, broadband boundaries were developed for this carrier.

Some providers provided paper maps. If the paper maps were referenced in terms of the Public Land Survey System (Township, Range and Section -- T-R-S), the maps were georeferenced using best efforts. The uncertainty in georeferencing could lead to an error of at least 1 mile if a T-R-S was misidentified.

Some providers supplied non-georeferenced paper street maps with broadband served areas circled or otherwise indicated. In this case, the maps were translated into the GIS through manual digitizing against TIGER 2004 roads. Again, best judgment was used to accurately translate the map into georeferenced data. In this case, error could be introduced but is difficult to quantify as no specific georeferencing existed in the source document.

In the case of some Cable and Wireless ISPs, providers indicated that an entire city or town was covered by broadband service. In these circumstances, census place boundaries were used to define broadband coverage. At this stage of the study we assumed that coverage within these areas was uniform—but it is likely that within each of these coverage areas there may exist areas of non-coverage due to plant deficiencies or local topography. These non-covered areas are referred to as 'urban holes'.

Under a protective agreement, some providers supplied fiber node locations. If possible, the plant locations were geocoded. If the plant object could not be geocoded with adequate precision, but the object's location was supplied in a mapped format, the object was brought into the GIS through manual digitizing. The fiber node locations were buffered 15kft for telco providers and 6 kft for cable providers. These distances served to approximate broadband capable serving areas. In the circumstance where an entire serving area's fiber nodes were obtained, a broadband service area boundary was formed by forming a convex hull[13] of each of the buffered nodes.

From the information collected the terrestrial broadband served areas by technology were developed and loaded into the GIS. Only census blocks with their center in a broadband served area are considered falling within a BSA.

The first below demonstrates the telecom broadband served areas.

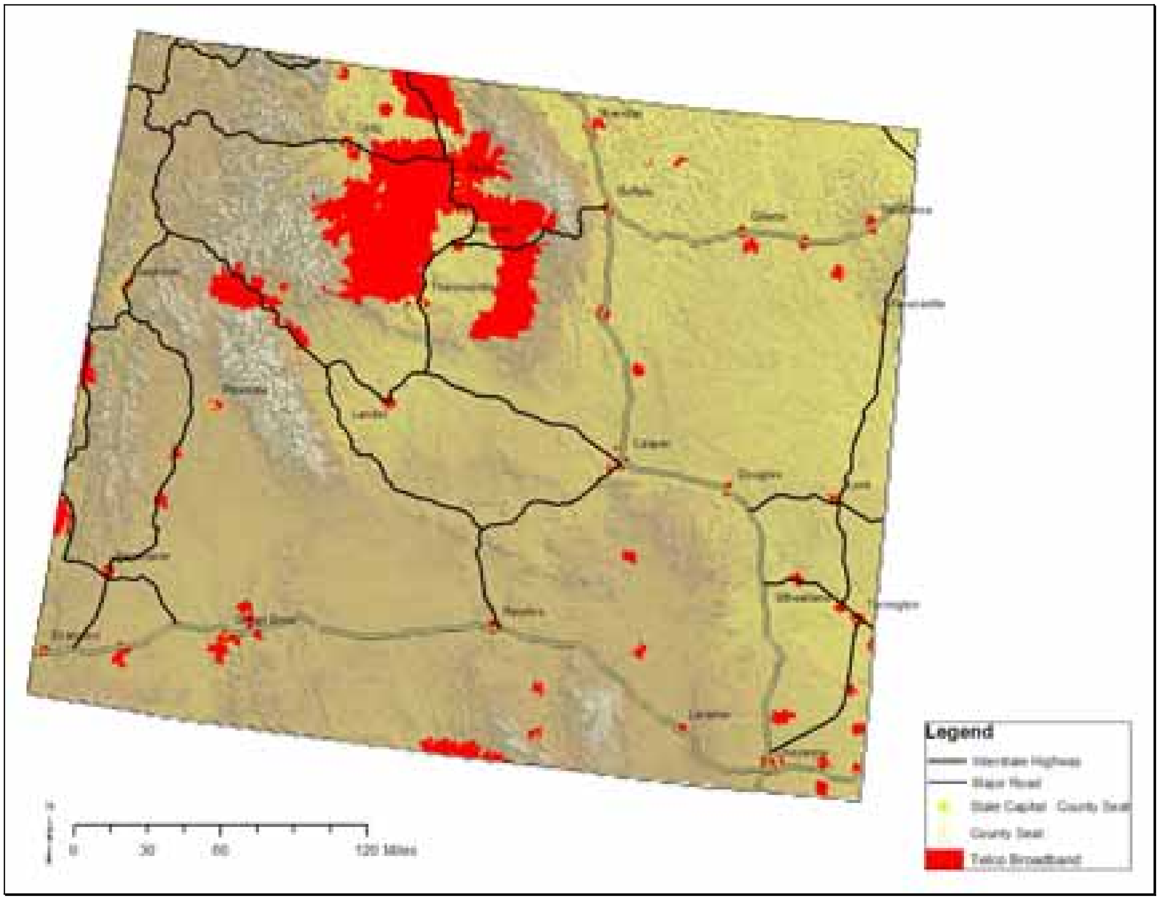

Figure 7-Telco broadband areas

The next figure demonstrates the current cable broadband served areas.

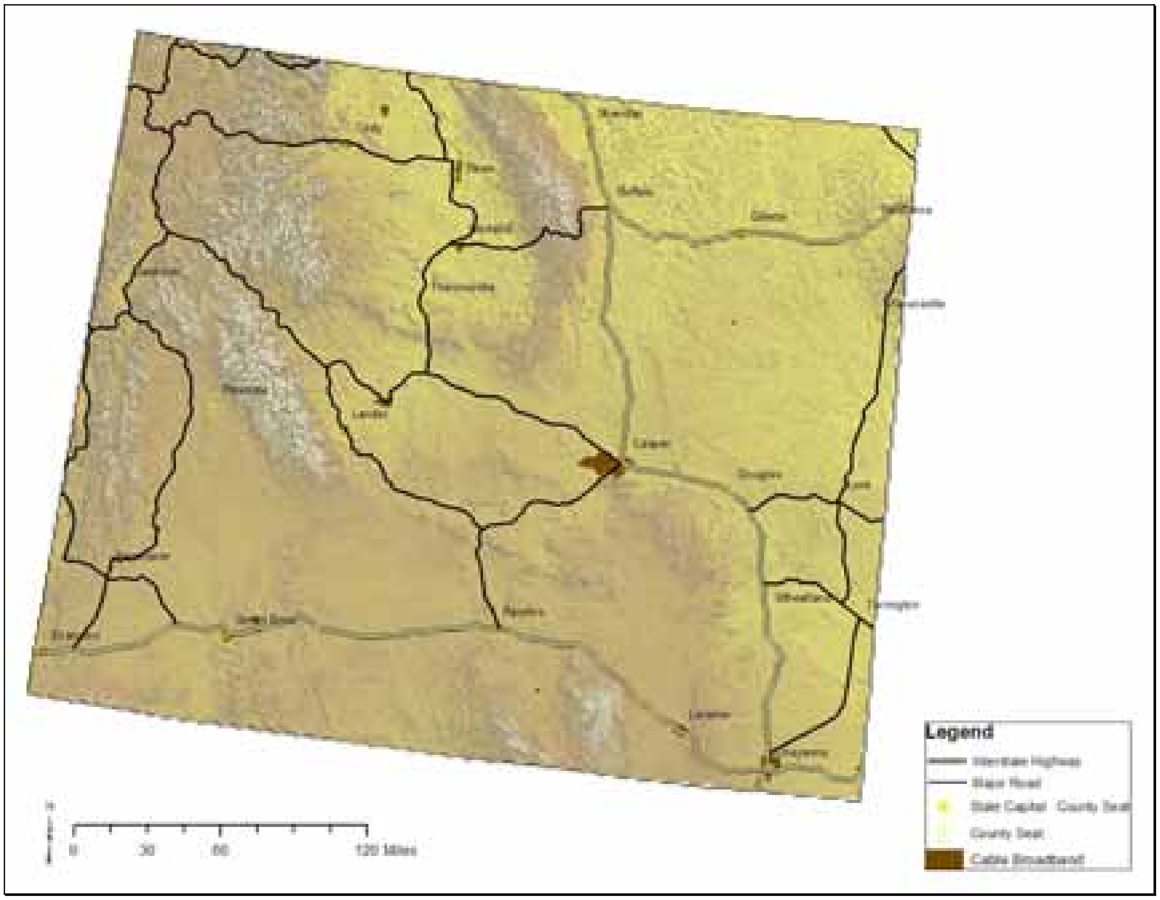

Figure 8-Cable broadband areas

The next figure demonstrates the fixed wireless broadband served areas.

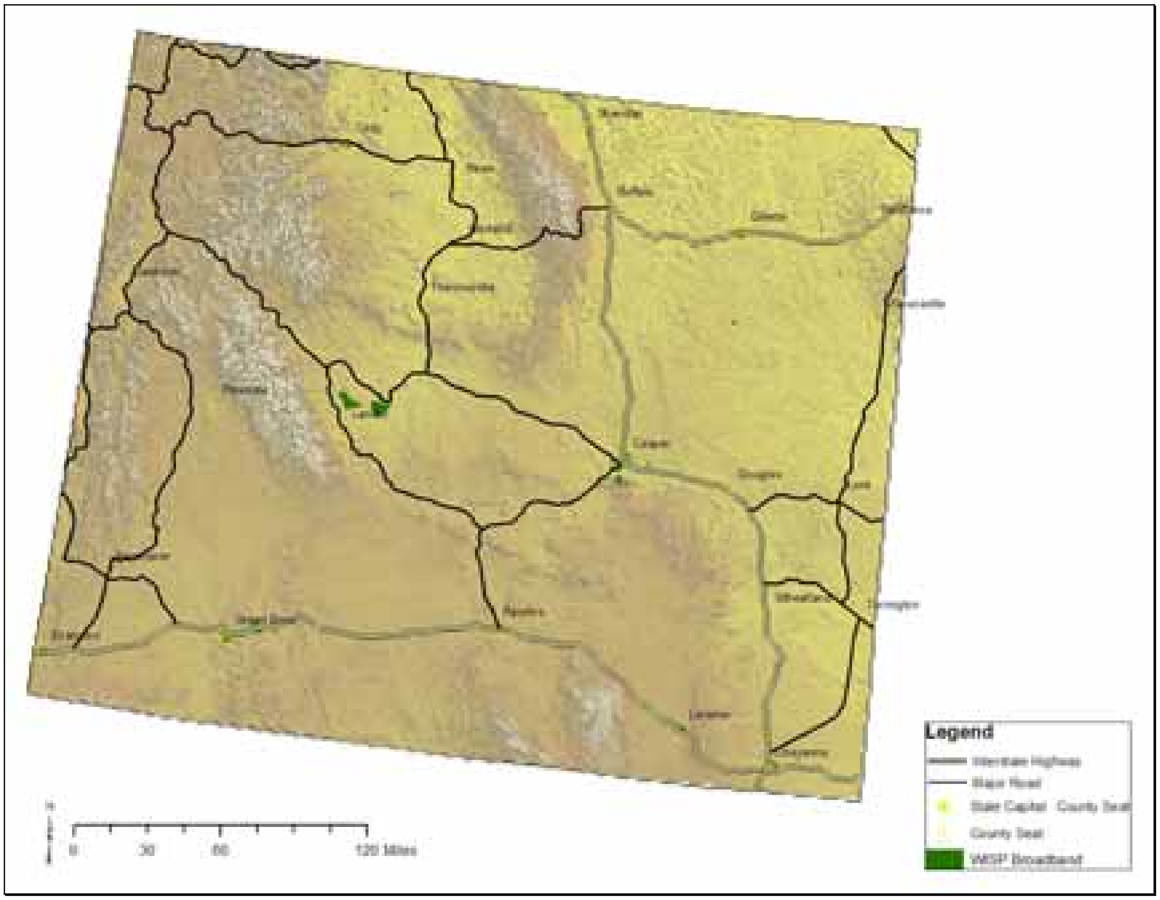

Figure 9-WISP broadband areas

Combining these data it is possible to generate a map of areas that have no access to terrestrial broadband technologies (shown in yellow) contrasted to areas that have at least one terrestrial broadband provider (shown in magenta).

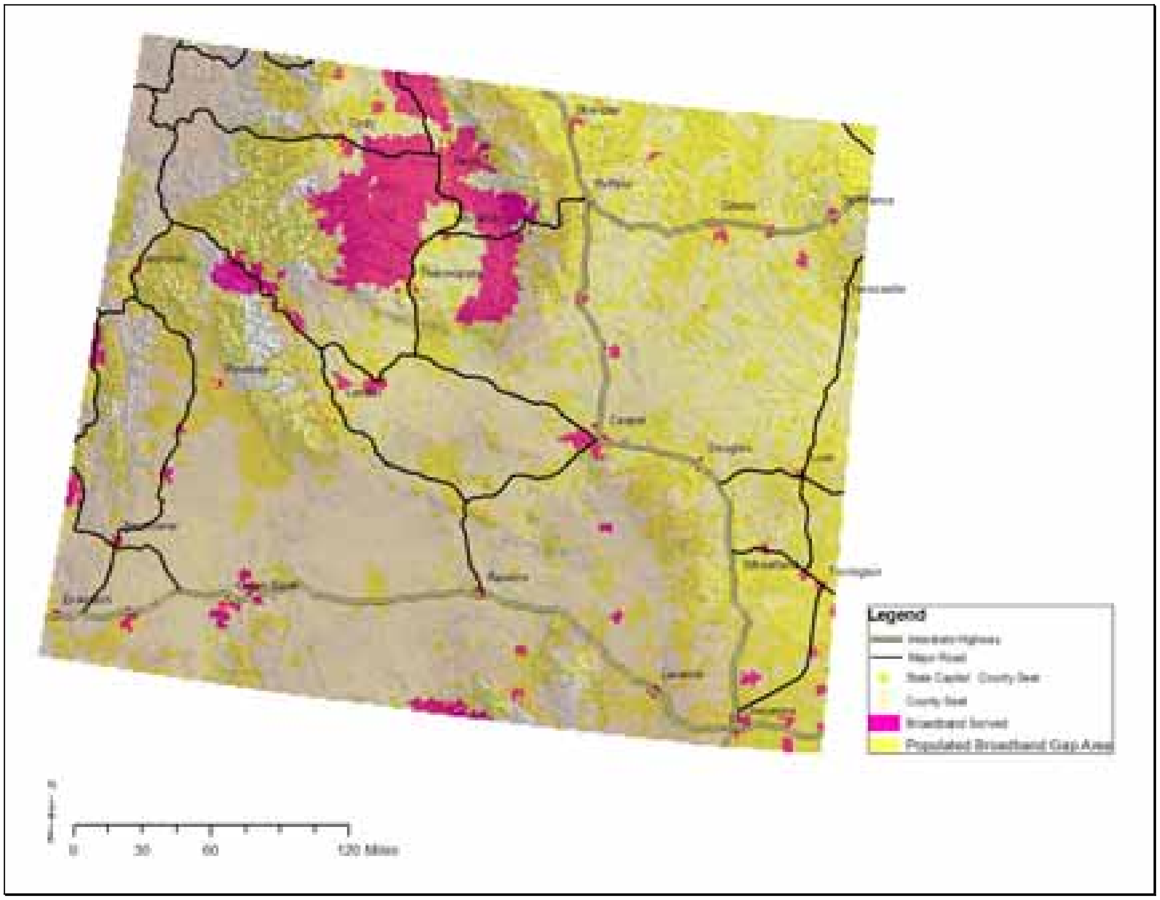

Figure 10-Broadband coverage throughout study area

When viewing these figures, it is important to note that within the eligible Broadband Gap Areas, there is a significant amount of land area not served by any provider—telco, cable or wireless. The majority of this unserved area has extremely low population density. Because of this in Figure 10, populated Broadband Gap Areas were shaded in yellow, while unpopulated/unstudied area has no shading—terrain is apparent. It is for this populated Broadband Gap Area that cost estimates will be developed.

CostProWY Cost Model

The CostProWY Cost Model has, as its foundation, a series of proprietary algorithms that have been used and widely accepted for forward looking economic-engineering studies. These algorithms were borne from a need to develop accurate cost estimates for UNE, Universal Service and interconnection studies. They form the basis of the CostProLoop[14] Cost Model. CostProLoop is in use by 4 telecom carriers with operations in over 30 states. The model has been accepted by every state regulatory commission it has come before.

Over the past several years the model has been extended to business planning, network rebuild and valuation studies domestically and internationally.

For wireline technologies (telco and cable), the model takes great care to run plant along roads and obeys road network pathing to connect points of demand. This is accomplished through a minimum spanning road tree routine ("MSRT") that optimizes the network pathing over roads.

For fixed wireless deployment, a clustering algorithm was employed to efficiently serve areas around existing towers.

Once the engineering areas are created and the network pathing determined, CostProWY developed the cost of augmenting the existing network or building new networks in areas where existing facilities do not exist.

As a final step, the augmentation costs are attributed to housing units to arrive at a cost per "customer". These costs are developed for Cable, Telco, Fixed Wireless, and Satellite technologies and can be rolled up at various geographic levels.

Engineering and Cost Assumptions

CostProWY designed engineering areas to ensure that fiber and copper cable, structure and electronics were efficiently deployed. In the case of fixed wireless, the cost model carefully selected towers and placed antennas to provide optimal coverage to users while minimizing the number of towers used and the antennas placed on each tower. The cost model also selected between antenna frequencies to maximize the number of participating customers while minimizing the cost of hardware.

For cable providers, unserved areas outside of existing two-way broadband areas were engineered using a Hybrid Fiber Coax architecture, DOCSIS® 2.0 compliant. If a provider's existing network was not yet serving any broadband, the entire network was overbuilt to be DOCSIS® 2.0 compliant. Under both cases, cost estimates were developed for the new plant required to provide service. A typical network is shown in the figure below.

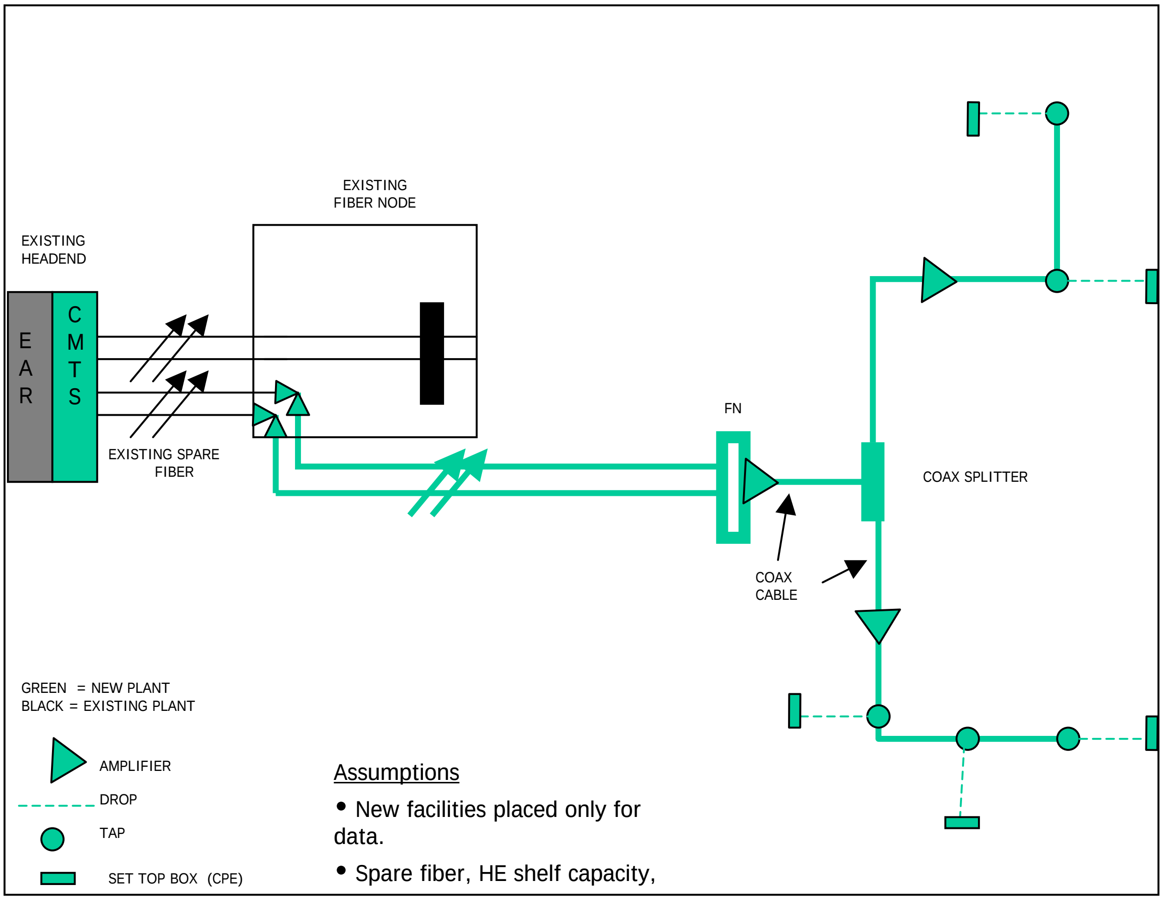

Figure 11-Cable broadband network deployment

The green portions of the figure capture the typical plant requirements for which costs estimates were calculated. No cost of video head end or customer premise video equipment was captured in this study.

Moreover, it is important to note that most cable systems in Wyoming are already two-way, broadband capable. However, their service footprint does not cover major areas of the state. As such, the cost of broadband augmentation for cable providers captures almost 100% new build, rather than augmentation of existing networks.

For telco providers a Fiber/Copper DSLAM architecture was selected. This architecture, based upon Carrier Serving Area design, is similar to what is currently deployed by a number of carriers nationally. In rough terms, it mirrors a Fiber to the Node (FTTN) architecture. However, the cost captured and the network constructed does not address any of the voice requirements of the network. It was assumed that voice would flow along the existing network.

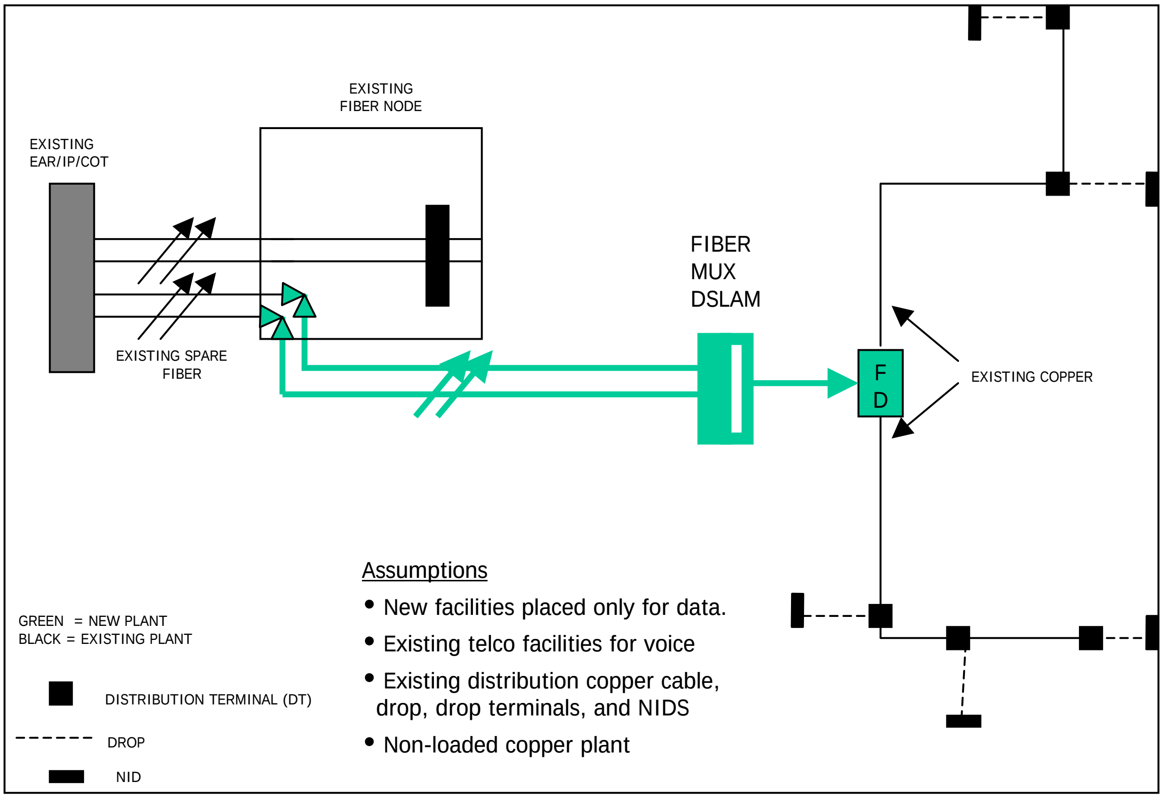

Figure 12-Telco broadband network deployment

A typical FTTN design is shown above. As with the cable figure, the green parts of the figure capture augmentation requirements for which costs were calculated.

Since most residents of Wyoming have telephone service[15], the cost of broadband deployment for a telco provider captures, for the most part, an augmentation of existing networks. That is, new fiber cable is run out to DSLAM within 15,000 feet of the customer location. From the DSLAM to the customer, the existing copper distribution network is employed to provide the broadband connection to the customer's location.

For fixed wireless broadband access, the Motorola Canopy™[16] architecture was selected. As of the study date, the Canopy system had been deployed in parts of the state with good results[17]. A typical Canopy system is shown below.

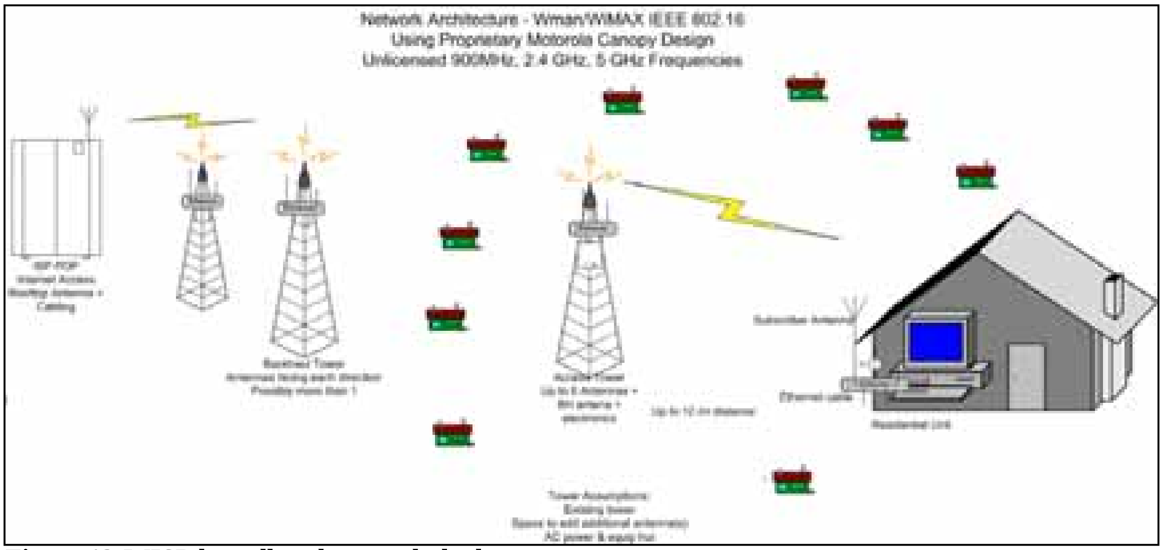

Figure 13-WISP broadband network deployment

The assumption with fixed wireless is that in unserved areas, the deployment would be all new build because there was no existing Canopy equipment to augment. A key aspect of the fixed wireless engineering was that only existing towers were utilized. The selection of what towers to use was further prioritized by the tower owner (e.g., State of Wyoming owned towers were always preferred over privately held towers).

Satellite broadband services were assumed to be available in nearly all areas of the state. Satellite Broadband capabilities and prices were modeled based upon Wild Blue™ service marketed through multiple local exchange providers. The end-user cost of satellite equipment, installation and monthly access were used as direct cost comparisons. As mentioned earlier, while there are some issues surrounding the suitability of service for all applications, satellite broadband services may provide a cost effective alternative in those areas of the state where terrestrial based services would be significantly more expensive.

Model Inputs

The cost study relied upon three principle sources of inputs. The first were investment inputs such as material and labor costs. The second were engineering planning rules such as the crossover distance between 24 and 26 gauge cable or the number of amplifiers allowed after a fiber node within HFC distribution or, the typical (design) backhaul distance from a wireless antenna of given frequency. The third set of inputs was the geospatial data mentioned in prior sections. The geospatial data described the location of network facilities, potential customers, service boundaries or broadband served areas.

In order to fulfill these data needs, a data request was circulated to telco, cable and WISP providers throughout the state.

Because much of the information requested was proprietary and confidential, data specific to costs and network engineering were blended to develop a melded, non-provider specific set of cost inputs for each technology.

The MSRT

At the root of CostProWY landline network deployment is the use of the MSRT. Using the MSRT, it's possible to show how points of demand are interconnected along roads.

The example below shows how distribution and feeder routing are accomplished by the MSRT. The results of the Wyoming study utilize the MSRT guided by the engineering and cost assumptions noted earlier in this document.

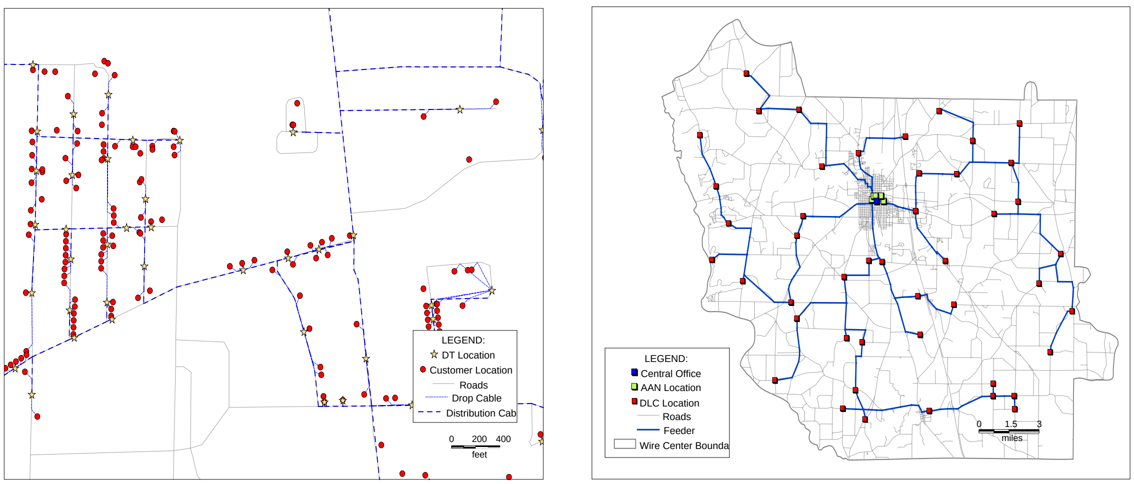

Figure 14-Network node deployment

Finally, based upon this MSRT a wireline network path as shown below could be constructed.

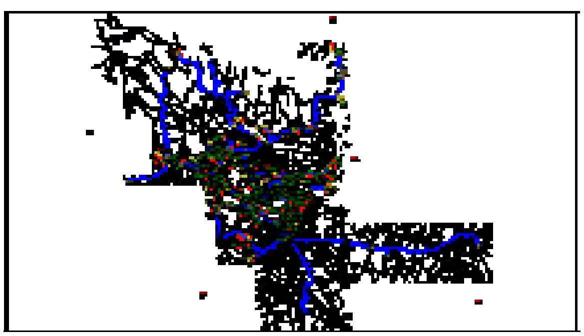

Figure 15-Full MSRT network path

Wireless Clustering Optimization

The goal with wireless broadband deployment was to serve as many customers as efficiently as possible using existing towers or attachment points. As this was a fixed wireless deployment, the cost model placed antennas on homes, terminated on a modem at the customer premise.

This arrangement meant that some potential customers—who were not close enough to an existing tower or attachment point—could not be served via fixed wireless broadband.

Based upon regional terrain, the state was divided into wireless serving areas. Each of the wireless serving areas shared common backhaul facilities. Data was transmitted from tower to tower via microwave link and then aggregated at a centrally located point of presence (either a telco Central Office or cable Head End).

Customers were 'collected' onto towers through an agglomerative clustering process. The goal of the clustering was to have as many potential customers on one tower, while placing no more antennas on a tower than was necessary. The diagram below shows the collection of customers (by color) collected onto the corresponding colored tower.

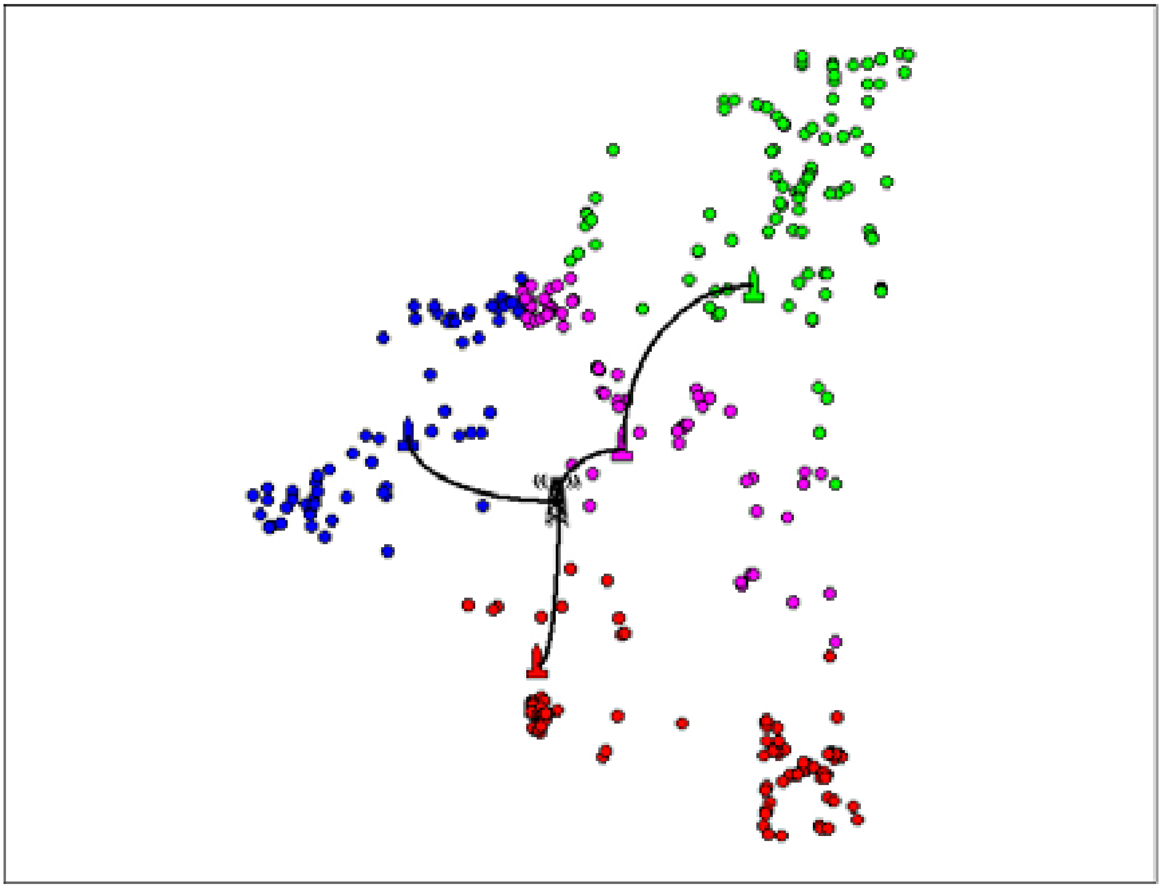

Figure 16-Antenna clustering and backhaul

Each tower within the tower serving areas shares backhaul to a common point, typically a telephone Central Office or cable Fiber Node.

Key Engineering Inputs

Each terrestrial technology modeled required a series of different engineering assumptions.

The assumptions for telco engineering are described in the table below. These assumptions were developed in terms of closely following CSA Guidelines.

15,000ft	Copper design distance around CO
15,000ft	Copper design distance around RT
1800	Max line count for a CSA
22/24	Copper gauge mix
DSLAM	Equipment used to provision broadband
Fiber	Media used to connect DSLAM
Modem	Placed at each house
EAR/IP	Availability assumed
Yes	Use of contracted labor

Table 1-Telco Engineering Inputs

The assumptions for cable engineering are described in the table below. These assumptions were reviewed by providers in the state and found to be reasonable.

6,000ft	Max Coax from Fiber Node (FN)
18,000ft	Spacing between Amps
475	Max line count for a FN
4	Houses per tap – design limit
Fiber Node	Equipment used to provision Broadband
Coax	Media from customer to FN
Fiber	Media used to connect FN to Head End
Modem	Placed at each house
EAR/IP	Availability assumed
Yes	Use of contracted labor

Table 2-Cable Engineering

The assumptions for wireless engineering are described in the table below. These assumptions were reviewed by providers in the state and found to be reasonable.

10miles	Design distance for access
20miles	Max distance for access (can be increased to 40 with placement of “repeater” antenna

	within 20 miles)
20miles	Design distance for Backhaul hops
70miles	Max distance for Backhaul hops
5.7GHz, 2.4GHz, 900mhz	Access frequencies used (distance dependent)
5.7GHz	Frequency used for Backhaul
Antenna	Placed at each house – provides Ethernet connection
EAR/IP	Availability assumed
200	Max subscriber count on an antenna
60º	Coverage arc of antennas
20%	Discount over vendor list price
Tower Priority	State owned towers given highest priority in Customer assignment – Cellular lowest

Table 3-Fixed Wireless Engineering

Cost Results

The intent of the study was to identify and then determine the cost of broadband augmentation for the broadband gap areas. From these results, policymakers can gain an understanding of the economics to serve broadband gap areas.

Policy can then be developed to determine the best approach to use in each area to encourage deployment. In some areas, it may simply be the identification of the demand and potential costs (the economics of the area may not necessitate any extra incentive for development). In other areas, loans, grants, or other economic incentives may prove useful to move the area over an economic hurdle for private investment.

The figure below shows a thematic map of the results on a relative investment per customer basis for wireless broadband deployment. Pink areas are those areas already broadband enabled. Orange cross-hatch indicates areas where WISP services could not be deployed. The gray to green areas are the broadband gap areas. The gradation of color indicates relative investment. Light gray represents a small percent of average investment. Dark green represents areas many times average investment.

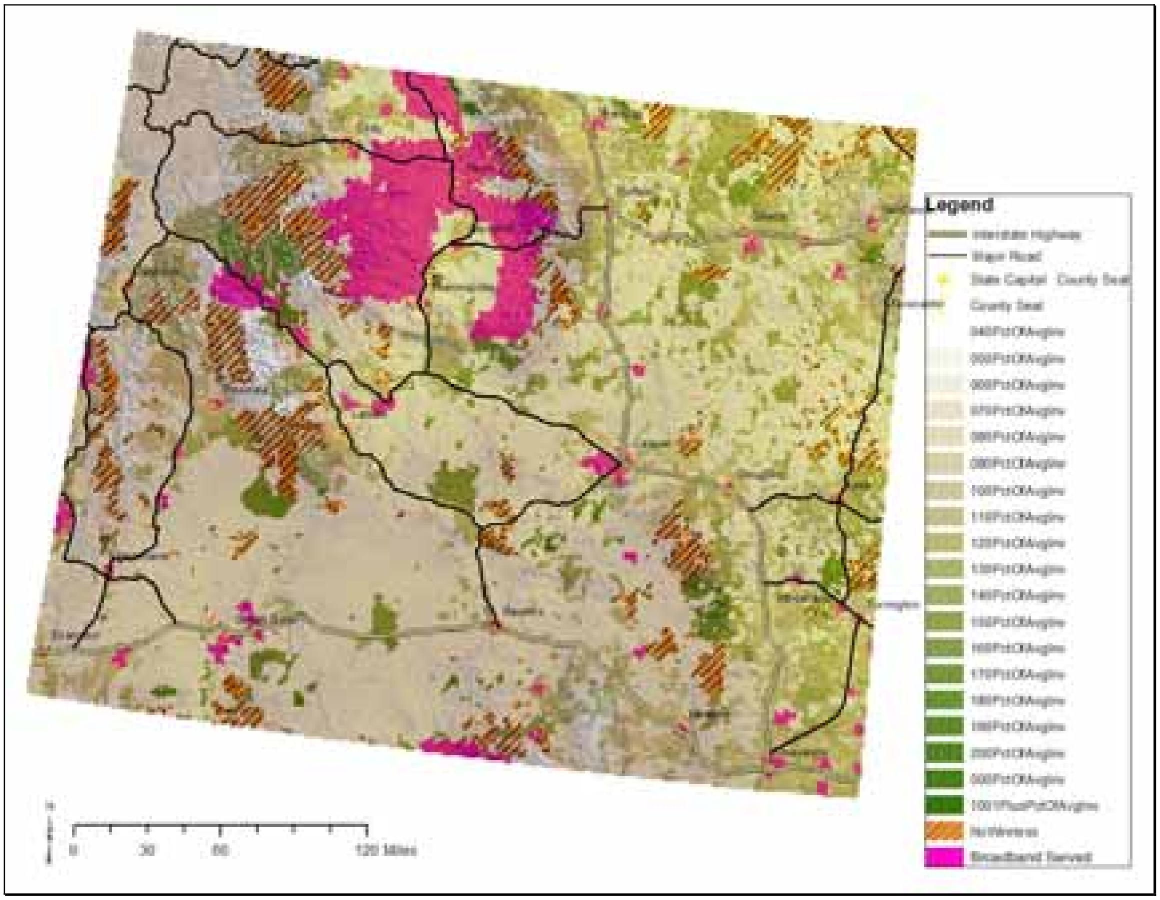

Figure 17-Wireless deployment investment estimate

The final figure shows a close-up of a portion of the state. The same color theme is used. In addition schools, recently permitted wells, towers, and other useful public domain geospatial data are presented. The combined view of this information should be useful to help understand the economics of deployment in an area.

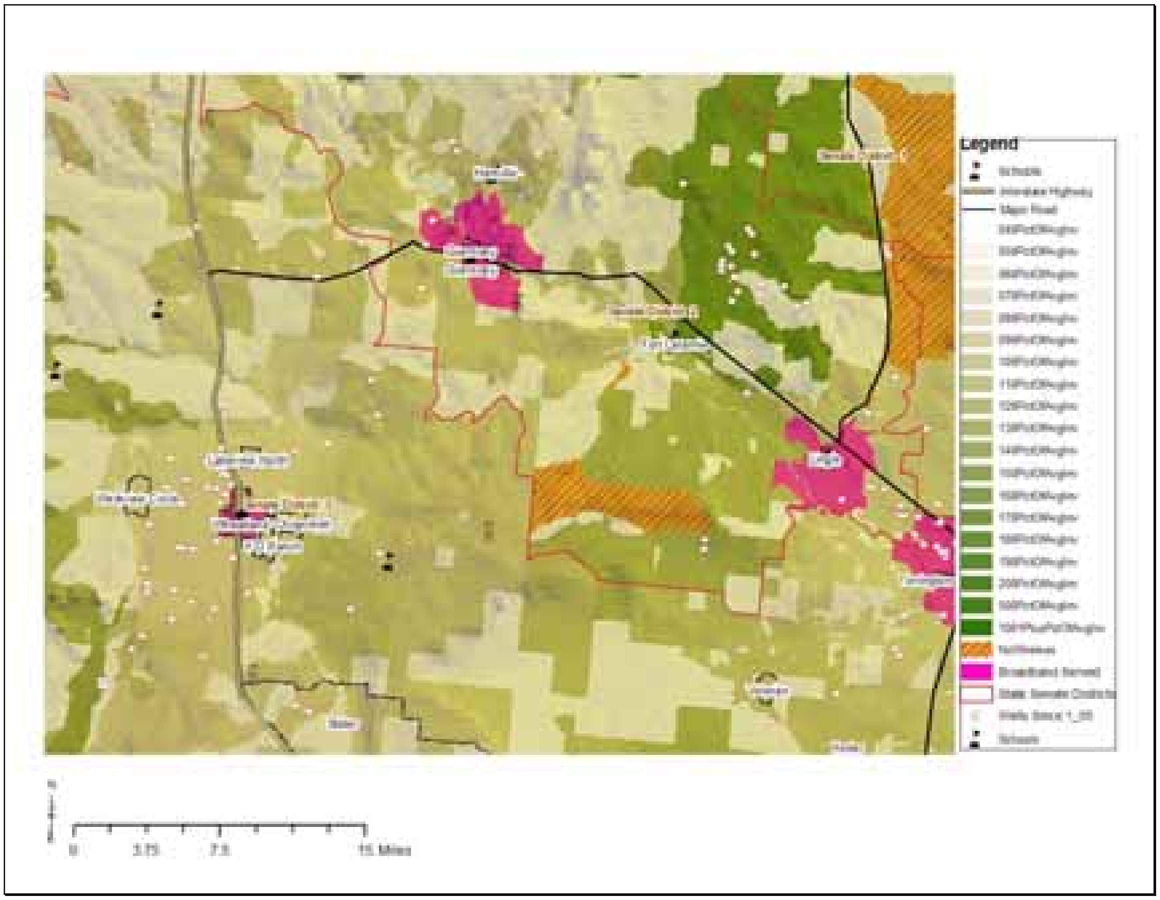

Figure 18-Investment map with related data

Acknowledgements

This study could not have been accomplished without the support of the telecommunication, cable, WISP, and satellite provider community in Wyoming. We appreciate their time, information and comments.

This document references trademarked products and services. All trademarks remain the property of their owners. Use in this paper does not constitute an endorsement by CostQuest Associates or the State of Wyoming.

Finally, this study could not have been completed without the direction and leadership of the members of the Wyoming Telecommunications Council. The assistance was invaluable.

This paper represents the opinion of the author and his firm. It does not necessarily represent the opinions of the WTC or the State of Wyoming.

End Notes

[1] The approximate ½ second signal latency impacts the use of services like VoIP, interactive gaming and some types of VPNs. A good discussion of these potential issues can be found at WildBlue's website, FAQ – Questions 31-33. Accessed 6/26/2006 <http://www.wildblue.com/aboutWildblue/qaa.jsp#1_5>

[2] US Census Bureau. Revised 9/13/2005. Accessed 6/26/2006. <http://www.census.gov/geo/www/tiger/tiger2004fe/tgr2004fe.html>

[3] US Census Bureau. Accessed 1/20/2006 <http://quickfacts.census.gov/qfd/states/56000.html>

[4] US Census Bureau-American Factfinder . Accessed 1/10/2006. <http://factfinder.census.gov/servlet/GCTTable?_bm=n&_lang=en&mt_name=DEC_2000_SF1_U_GCTPH1R_US9S&format=US-9S&_box_head_nbr=GCT-PH1-R&ds_name=DEC_2000_SF1_U&geo_id=01000US>

[5] STATS Indiana-Data Definitions. Accessed 6/26/2006. <www.stats.indiana.edu/web/definitions/data_definitions.htm>

[6] This description is a simplified discussion of the actual process. There were two complicating factors: first in sampled data (SF3) housing units in a structure are reported within a range. Because of the lower densities of housing in Wyoming, we used the bottom of the reported range as our allocation target. Second, because the SF3 data is sampled, the reported data at a Census Block Group level in SF3 may disagree with the sum of all SF1 Housing Unit counts. In this case a true up was performed at the county level.

[7] Address geocoding is a process that interpolates the longitude and latitude of a structure based upon the structure's address relative to the address range of the street segment upon which that structure lies. Additional information on address geocoding can be found at http://en.wikipedia.org/wiki/Geocoding

[8] More information on this product is available at <http://www.mediaprints.com/>

[9] Although the boundaries were not used, the data did provide useful information on the system operator and system status-if the cable system was two way and supported broadband.

[10] A list of structures registered by the FCC is available at http://wireless.fcc.gov/antenna/ . The data in this study was extracted on 8/4/05.

[11] A list of available locations can be obtained from http://www.americantower.com/OASISPublic/SitePublicPage/sitelist.asp?intQueryType=3&lngCountryID=&lngStateID=&lngCountyID=&strCountyName=&strZipCode=&lngMTAID=&strMTAName=&lngBTAID=&strBTAName=&dblLatitude=42.99858&dblLongitude=-107.55193&dblZoom=750. The towers used in this study were obtained on 8/4/05

[12] Distribution Areas (DA) are telecom engineering areas. A DA is a region typically served from a common Feeder Distribution Interface or Serving Area Interface (FDI or SAI). DAs are combined to create Carrier Serving Areas (CSAs). A Carrier Serving Area is the area that is served from a Carrier device like a Remote Terminal.

[13] The Convex Hull was generated with XToolsPro 3.0 (Build 208) for ArcGIS desktop. A formal definition of a convex hull can be found at <http://en.wikipedia.org/wiki/Convex_hull>.

[14] More information on the CostProLoop model can be found at <http://www.costquest.com/costquest/costpro.aspx>

[15] Household telephone subscribership in Wyoming is reported by the FCC to be 94.6% (Table 16.2) as of 6/21/2005.
<http://www.fcc.gov/Bureaus/Common_Carrier/Reports/FCC-State_Link/IAD/trend605.pdf>

[16] More information on the Canopy system can be found at <http://motorola.canopywireless.com/>

[17] Future studies could use a WIMAX type architecture as WIMAX becomes proven in rural environments.

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