The Benefits of Wireless Broadband For Rural Deployments

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Current U.S. policy promotes broadband deployment and adoption, with an emphasis on meeting the needs of unserved and underserved communities.[1] An important component of this policy is providing broadband infrastructure to less populated, rural areas. Any public policy should meet its objectives at the lowest possible cost. To help policymakers in evaluating approaches to meeting the broadband needs of rural America, this paper examines the relative cost of providing wireless and wireline infrastructure to the least populated areas of this country—the areas most likely to lack broadband infrastructure today.

Wireless infrastructure can and should play an important role in providing broadband access to all Americans. Because wireless access has significant cost advantages over wired access in reaching homes in rural areas, it is often the most efficient way to provide broadband access. ***The analysis below examines the most rural counties—those covering about 6% of the population and half of the landmass of the U.S.—and finds that all of them can be more cost-effectively reached by wireless broadband access***. As shown in the figure below these results are robust. In the counties in blue on the map, the per-household-reached wireless cost advantage over wireline is less than $1,000 per household.[2] In contrast, in the counties in red, the wireless cost advantage exceeds $7,500. The cost advantage of wireless makes wireless broadband access a very attractive option for meeting the needs of rural America.

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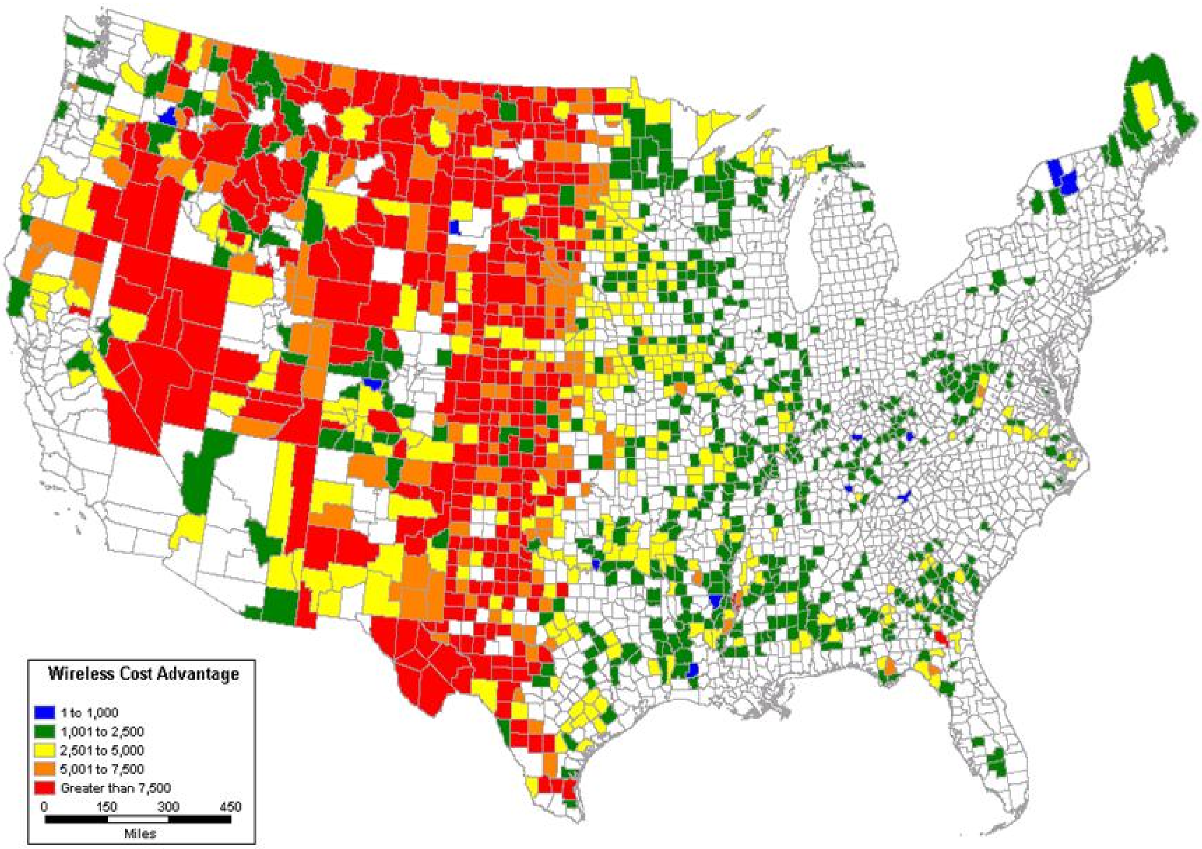
1 See, for example, the National Telecommunications and Information Agency's Broadband Technologies Opportunity Program (BTOP) and the Federal Communication Commissions' National Broadband Plan.

2 The wireless cost advantage is defined as the costs of reaching a given household with wireline technology, less the cost of reaching the same household with wireless technology.

Map of County Price Differentials



USEFULNESS OF WIRELESS FOR RURAL BROADBAND

All broadband networks require significant upfront investments before the first customer can be served. These investments can be characterized as of two types. First, non-customer-specific network investments must be made. These would include switching and routing hardware, network operations centers, and administrative systems. They would also include, in the case of a possible wired network, laying fiber optic cables along a street or, in the case of a possible wireless network, mounting antennas on a base station tower and providing backhaul connectivity to the tower. Second, customer-specific investments must be made. These investments could include dropping a line from the street to a customer's house or installing antennas or other customer premises equipment.[3] Both types of investments are often referred to

[3] The fixed infrastructure investment of broadband networks can be divided into two broad categories. The first is coverage—the investment needed to provide the option of service throughout a region. The second is capacity—the investment needed to carry the increased traffic generated as subscribership grows. This

as fixed investments because they do not typically vary significantly with a customer's usage of the network.

Broadband networks also generate operating costs. These costs include such items as network maintenance, electricity, and help desk services. Some of these operating costs are relatively fixed in nature and do not vary significantly with customer usage. Such costs would include the maintenance of the central part of a network—for example, a trunk fiber optic cable for a wired system or a radio tower for a wireless system. Other operating costs vary with customer usage, such as help desks or interconnection costs.

The capacity of a given fiber optic system or radio tower is not infinite, so at some level of usage, additional customers (or, possibly, additional usage by the same customers) create the need for more infrastructure. This is clearly seen in the design of cellular networks. As a cell within a cellular network reaches capacity, it is replaced with several smaller cells that increase capacity by allowing additional reuse of radio spectrum, but at the added cost of additional cell sites. (Alternatively, more radio spectrum could be added to the network, but again only at added cost for spectrum and for equipment to exploit the additional spectrum.)

In the provision of broadband services, a key driver of costs per user—both fixed and operating—is the physical density of the population served. The more customers along a street or within range of a radio tower, the more the fixed costs are spread out over customers. Similarly, maintenance costs of a more heavily used radio tower are spread out over more customers.

DEFINITION OF RURAL

Three primary definitions of what constitutes a rural area are provided by the Bureau of the Census, U.S. Office of Management and Budget (OMB), and Economic Research Service of the U.S. Department of Agriculture (ERS).[4]

- Under the Bureau of the Census definition, an urbanized area (UA) has a population of 50,000 or more, includes a central city, has a population density greater than 1,000 per

second category of investment, although not specific to any one customer, is only incurred as subscribership grows.

4 http://www.nal.usda.gov/ric/ricpubs/what_is_rural.shtml.

square mile, and also includes areas outside UA's with a population greater than 2,500.[5] All other areas are considered rural. As a result of this definition, the Bureau of Census does not demarcate areas along county lines.

- The OMB defines a metropolitan statistical area (MSA) as including either (1) a city with a population with at least 50,000 inhabitants or (2) a UA as defined by the Census Bureau (50,000 inhabitants) and a total MSA population of at least 100,000.[6] Any county not within an MSA is considered nonmetro.
- Using the metro/nonmetro classification, ERS classifies each county on a scale of 1-9 depending on population density.[7] This analysis uses the ERS definition, classifying counties ranked 1-3 as metro and those ranked 4-9 as nonmetro, as further detailed in Table 1.

The rural-urban definition from the three sources in addition to the Census Bureau's list of incorporated and unincorporated places[8] allows for a total of nine useful definitions that yield varying allocations of population and area into rural and urban areas.[9] The current analysis starts with the metro/nonmetro classification along county lines.

Table 1
2003 Rural-Urban Continuum Codes

Code	Description
Metro counties:	
1	Counties including all or parts of metro areas of 1 million population or more.
2	Counties including all or parts of metro 250,000 to 1 million population.
3	Counties including all or parts of metro areas fewer than 250,000 population.
Nonmetro counties:	
4	Urban population of 20,000 or more, adjacent to a metro area.
5	Urban population of 20,000 or more, not adjacent to a metro area.
6	Urban population of 2,500 to 19,999, adjacent to a metro area.
7	Urban population of 2,500 to 19,999, not adjacent to a metro area.
8	Completely rural or less than 2,500 urban population, adjacent to a metro area.
9	Completely rural or less than 2,500 urban population, not adjacent to a metro area.

Source and Notes: http://www.ers.usda.gov/briefing/rurality/RuralUrbCon/

5 http://www.census.gov/population/censusdata/urdef.txt.

6 http://www.census.gov/population/www/metroareas/metrodef.html, New England requires an MSA population of 75,000.

7 http://www.ers.usda.gov/briefing/rurality/RuralUrbCon/. The term *county* refers to counties, parishes, boroughs and other county-like geographic political subdivisions of states.

8 Legally defined boundaries by a State are referred to as *incorporated places*. Population concentrations identifiable by name and recognized by local experts are referred to as *census-designated places*, or *unincorporated places*.

9 http://www.ers.usda.gov/data/ruraldefinitions/documentation.htm.

The key difference between providing broadband services to urban versus rural areas is the population density of customers. The summary statistics for the definition of rural areas that we are using are provided in Table 2.[10] The differences in population density are striking. Whereas the overall population density of the United States is about 78 people per square mile, that density rises to 255 people per square mile in urban areas and falls to only about 18 people per square mile in rural areas. Note that the ERS classification is imperfect. For example, Owyhee County, Idaho (population 11,000, land area 7,800 square miles) is classified as a metro county because many residents live in the northern end of the county and work in the adjacent Boise metro area. Despite such imperfections, the classification is generally accurate and appropriate for the analysis offered here.[11]

Table 2
Population Density—Metro, Nonmetro, Total

		Population *[A]*	Area (Sq. Miles) *[B]*	Pops/Sq.Mile *[C]*
Metro	*[1]*	232,579,940	913,851	255
Nonmetro	*[2]*	48,841,966	2,676,438	18
Total	*[3]*	281,421,906	3,590,289	78
Metro	*[4]*	83%	25%	325%
Nonmetro	*[5]*	17%	75%	23%

Source and Notes:
[1], [2]: Metro, nonmetro definitions based on 2003 Rural-Urban Continuum Codes, http://www.ers.usda.gov/Data/RuralUrbanContinuumCodes/
[1] [C] = [1] [A] / [1] [B].
[2] [C] = [2] [A] / [2] [B].
[3] [A] = [1] [A] + [2] [A].
[3] [B] = [1] [B] + [2] [B].
[3] [C] = [3] [A] / [3] [B].
[4] = [1] / [3].
[5] = [2] / [3].

10 Note that all numbers are based on the 2000 census.

11 To the extent the county based classification used understates rural areas the benefits noted below understate the true benefits of wireless deployments for rural America.

STYLIZED COST MODELS

Population density affects the fixed costs of providing service differently for wireline and wireless networks. This section illustrates how population density affects costs for these two different types of networks. It is not the intent here to develop detailed cost models but rather to develop reasonable stylized models that allow an apples-to-apples comparison of cost drivers.

Several caveats are in order. Most obviously, the actual cost of providing service to any given rural area depends on many factors not captured in the models presented here. There are many different technologies—both wireline and wireless—that a provider could choose, each creating different levels of costs and with different impacts from various levels of population density. Topography and terrain may also have significant effects on costs of different technologies.

The analysis below focuses on the per household costs of the fixed part of the distribution network. This would be the cost of running the distribution wires (typically along telephone and utility poles) for a wireline network and the cost of towers, radios, and antennas for a wireless network.

Upstream of the distribution network, costs would be expected to be similar between a wired and wireless network—the required switches, routers, interconnections, etc., are not significantly affected by the choice of wireless versus wireline distribution networks. Downstream of the distribution networks (*i.e.*, at the customer's home or business), the cost of connecting the customer to the distribution network varies significantly but not consistently by the choice of wireline or wireless networks. For example, a wireless network could have relatively expensive customer premise equipment (CPE) such as an exterior antenna or relatively inexpensive CPE such as a lap-top card. Similarly, a wired network could have a relatively inexpensive cable modem or relatively more expensive fiber network interface device. The wired network's connection to the residence could be a low-cost above-ground drop or a more expensive buried connection. Because these costs are driven by very specific technology choices—a level of detail that is beyond the scope of this paper—and the costs associated with those technology choices are not correlated to the choice of wireline versus wireless networks, the analysis below ignores differences in costs downstream of the distribution network.

Operating costs are a significant component of the total costs of any broadband network. Nevertheless, with one exception for backhaul in the wireless network, the current cost modeling exercise ignores them. Doing so introduces bias into the analysis only to the extent that operating costs systematically differ between wireline and wireless networks, and the level of bias is only the *difference* in those operating costs. Only a fuller analysis that incorporates operating costs can evaluate the total costs of serving rural customers by wireless and wireline networks.

Wireline

This analysis uses a cable broadband network as an example of a typical wireline broadband network. This may be more expensive than a DSL network (but with further reach—important in rural areas) but less expensive than a fiber-to-the-home (FTTH) network. FTTH networks likely command higher subscriber payments, presumably offsetting their higher price.

The figure of $12,500 per mile for a cable distribution network is used.[12] This cost per mile is applied to the number of miles of road network in a county to estimate the total cost of the wireline distribution network within a county.[13] Total costs in a county are divided by the number of households in the county to get the cost per household of a wireline distribution network.

An example for Richie County, WV, is provided below in Table 3. Richie County, WV is used to illustrate the differences between wireline and wireless costs because it is typical of the rural counties in our sample. With a population density of about 23 people per square mile, 549 road

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12 I believe that this number is reasonable and appropriate, even conservative, for the purposes of this study. It is based on personal experience with cost models and discussions with knowledgeable engineers. It is in line with the distribution network costs for a FTTH network. For example, Corning reports the cost to pass a household in a number of rural markets at between about $1,750 and $3,500. In the rural counties analyzed, rural households average about 5 per mile, implying $12,500 per mile if the per household cost is about $2,500. Using the top end of the costs reported by Corning, the cost per mile would be $17,500—about 40% higher. See, John Igel, "Innovations in FTTH reduced cost and improved scalability of deployments," Corning Inc.

13 Road miles in a county are calculated by The Brattle Group from GIS analysis of Nationwide Streets and Highways data from Caliper Corporation. Limited access roads, access ramps, roads accessible only by 4WD vehicles, alleys, and pedestrian only roads were omitted.

miles per cell, and an average of 5 households per mile of road, it is near the average value of various statistics for the set of counties used in the comparisons presented here.

Table 3
Example of Wireline Cost

Cost per Mile ($/ Mile): $12,500 *[A]*

County *[1]*	Pops *[2]*	HH *[3]*	Area *[4]* *Sq. Miles*	Rural Road *[5]* *Miles*	Cost / HH *[6]* *$ /HH*
Ritchie County, WV	10,343	5,652	453	1,097	$2,426

Source and Notes:
[A]: Assumed.
[1], [2], [3], [4]: www.census.gov
[5]: The Brattle Group GIS output.
[6]: ([A] x [5]) / [3].

Wireless

The focus of a cost model for rural wireless deployments is simply the cost to cover a populated area. This is driven by the number of cell sites required to serve a given county. For counties with a population density of at least 75 households per cell site, the number of cell sites is estimated to be the area of the county divided by the area of a cell site. There were about 19 counties with a household density of fewer than 75 households per cell site, 6 of them in the 49 states excluding Alaska.[14] They undoubtedly have significant unpopulated areas. For those

14 An important assumption of the model is that providing wireless coverage along the roads within a county will provide wireless access for essentially all residences within the county because residences are close to roads. This assumption is reasonable for all states but Alaska. There are many communities in Alaska that are not connected to the road network—sometimes referred to as bush communities or "the bush." These communities can be reached by water, by air, or by snow machine. Consequently, this analysis excludes Alaska. Elsewhere, there may be a few exceptions—for example Vendovi Island in Washington State has one residence but no roads—but generally speaking, residences, even quite rural residences, are connected to the road network.

counties, the number of cells was estimated based on manually covering the roads of the county with cells.

In the model, covered households in each cell are assumed to be equal to the number of households in a county divided by the number of cells in the county. Each cell is provisioned with enough capacity to serve 33% of the households it is assumed to cover. The number of MHz required and the capital cost per cell depend on number of subscribers provisioned per cell according to Table 4.[15]

Table 4[16]
Subscriber Households and Incremental MHz and Cost Per Cell Site

Subcribers HH			MHz		Cost	
Increase	*Start*	*End*	*Increase*	*MHz*	*Increase*	*Cost*
	1	150		10		$260,000
150	151	300	10	20	$60,000	$320,000
150	301	450	10	30	$60,000	$380,000
150	451	600	10	40	$60,000	$440,000
150	601	750	10	50	$60,000	$500,000
150	751	900	10	60	$60,000	$560,000
150	901	1,050	10	70	$60,000	$620,000
150	1,051	1,200	10	80	$60,000	$680,000
150	1,201	1,350	10	90	$60,000	$740,000
150	1,351	1,500	10	100	$60,000	$800,000

15 The equipment costs reported in Table 4 are illustrative. They are not based on specific existing equipment, but rather are reasonable estimates of cost. Of course, using different costs can change the analysis presented here, but the alternative costs would have to be significantly different from the ones reported here to materially effect the conclusions of this analysis. To change the conclusions about the relative cost of wireless versus wireline in more than a few counties, the costs noted in this section would have to be off by a factor of 4 or more.

16 The costs of wireless base stations vary widely. A major factor in the variation is the cost of any towers needed to support the antennas. Another significant cost is real estate. This model assumes that, on average, the base station will be able to mount antennas on pre-existing structures at reasonable cost. It also includes an allowance for base station electronics. The model here consists of the following elements: Cell site electronics ($40,000), first transceiver for each sector (3 x $20,000), and structure and civil engineering costs ($160,000).

The model assumes the radius of a cell is about 10 miles and covers an area of 314 square miles.[17] It also assumes that 10 MHz of spectrum is needed per 50 households served by a sector, up to a limit of 100 MHz—roughly the amount of the FCC's spectrum screen.[18] The model assumes frequency-division duplexing and an average downlink spectral efficiency of 2 bps/Hz.[19] This would allow an aggregate downlink capacity of 10 Mbps, or an average of 200 kbps per household. (Under reasonable levels of use, the performance seen by subscribers will be better defined by the 10 Mbps peak level than the 200 kbps average.) No assumption is made about the incremental costs beyond 1,500 subscribers per cell (4,500 households per cell or density of about 14.3 households per square mile) and counties with those densities are dropped from the current analysis.[20] Backhaul and cell site rent are each assumed to be $50,000 per cell on a capitalized basis.

A cost unique to wireless systems is the cost of access to licensed radio spectrum. This cost can vary significantly from one area to another and depending on the band of radio spectrum. Licensed radio spectrum is significantly less expensive in rural areas than in urban areas—population density is one of the drivers of value of radio spectrum, even when that value is expressed on a per person basis. For example, in the AWS auction, the average price of a spectrum license was $0.39/MHz-pop, but in urban areas (defined as MSA) the A Block was $0.48/MHz-pop and in rural areas (defined as the RSAs in the A block) it was only $0.11/MHz-

17 Area = $\pi * r^2$. This slightly overstates the area of a cell in a tightly packed grid, where it would be more appropriately estimated as the area of a hexagon or approximately $2.6 * r^2$. In the irregular configuration of a rural county, where inevitably there are some spaces with no homes, the approximation of a circle is reasonable. Even if a strict hexagonal approximation was more appropriate, the difference would effect about one-half of the counties analyzed, but the effect is never more than 7.5% of the cost difference.

18 This assumes use of all commercial spectrum bands. The results of the analysis are not qualitatively changed if the rural broadband is provided by 4 or 5 carriers instead of the 3 modeled here.

19 Although this level of efficiency is a little higher (perhaps by one-third) than the typical mobile broadband systems, given the fixed environment modeled here, such levels of throughput should be readily achievable in many situations. Even if one assumed significantly lower spectrum efficiency, say 1 bps/Hz, the system described here would provide true broadband service. The change in spectrum efficiency would have the same effect as increasing the oversubscription ratio.

20 There are about 723 nonmetro counties that would have subscriber densities above 1,500 per cell given the current model. Although they are classified as nonmetro, these counties seem to have sufficient population density (ranging from 17 people per square mile to 1,400 people per square mile) to be considered urban, or at least suburban, and are therefore excluded from the current analysis. 12 counties classified as nonmetro that are smaller than 100 square miles were also excluded because such compact political subdivisions distort the meaning of rural. Three of these areas—two very small cities in Virginia and Kalawao County in Hawaii—would have had small wireline cost advantages if included in the analysis.

pop.[21] This implies a ratio of rural to average value of 0.27.[22] If spectrum is worth $1.29 MHz-pop on average (the price of 700 MHz spectrum at auction), then the rural spectrum cost per person covered is $0.35/MHz-pop.[23] The spectrum costs for a cell are then the number of MHz the cell uses (up to 100 MHz maximum) times $/MHz-Pop cost of $0.35 times the number of households in the cell times the number of people per household for the county in question.

The total cost per cell is then the sum of the capital cost plus the spectrum cost plus the cell site rent plus the backhaul cost, all on a capitalized basis. Finally, the total cost per cell is divided by the households covered by the cell to get the cost of covering a household in a given county with a wireless distribution network.

An example for Richie County, WV is provided below in Table 5.

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21 AWS A Block (Auction 66) results available at: http://wireless.fcc.gov/auctions. Total A Block PWB was $2,247 million. MSA areas sold for $2,106 million with population of 220 million covered; and RSA areas sold for $141 million with a population of 66 million covered.

22 Due to rounding, the ratio is 0.27, not 0.28.

23 Not including the D Block, the average price of spectrum in the 700 MHz auction was $1.29/MHz-Pop (rounded).

Table 5
Example of Wireless Cost

Capital Cost ($/ Cell):	$620,000	*[A]*
Backhaul ($/cell):	$50,000	*[B]*
Rent Cost ($/cell):	$50,000	*[C]*
Cell Radius (Miles):	10	*[D]*
Subscribers (%):	33%	*[E]*
MHz (700 MHz):	70	*[F]*
700 MHz cost ($/MHz-Pop):	$0.35	*[G]*

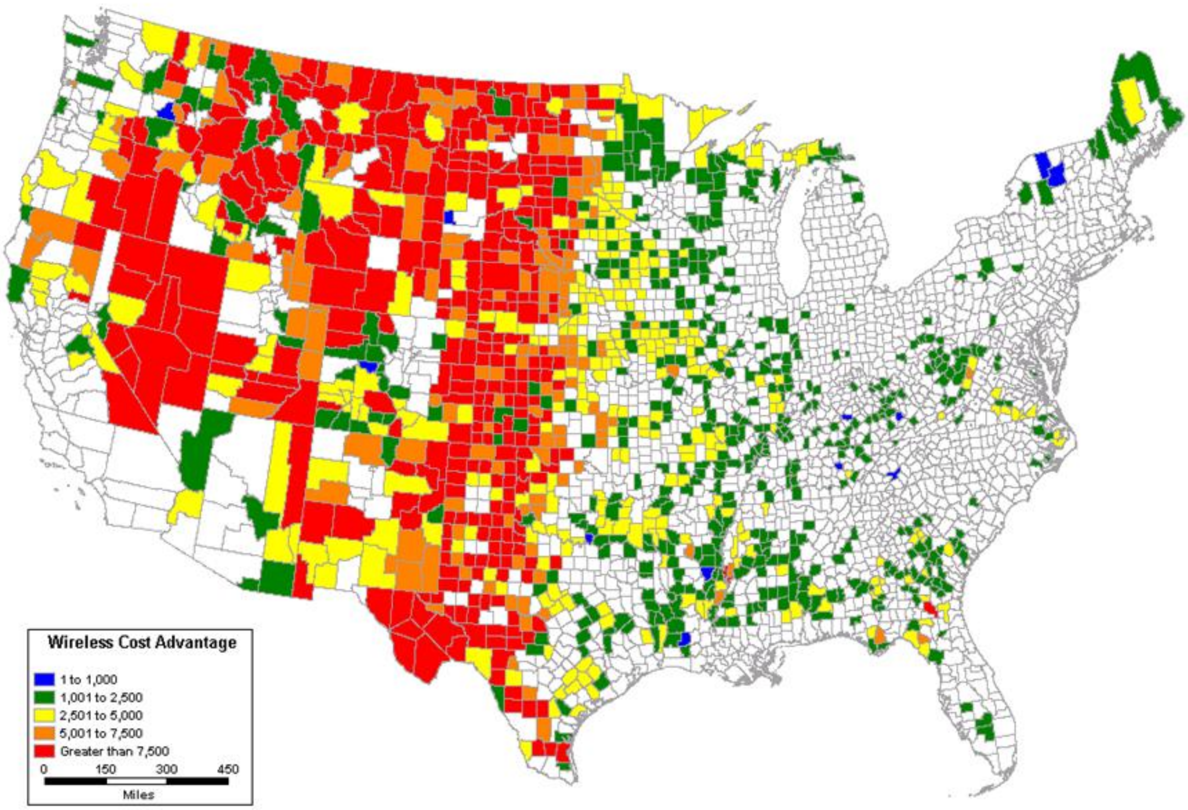
County *[1]*	Pops *[2]*	HH *[3]*	Area *[4]* *Sq. Miles*	Cells in County *[5]*	HH / Cell *[6]*	Subscriber HH *[7]*	Spectrum Cost *[8]* *$ / Cell*	Total Cell Cost *[9]* *$ / Cell*	Cost / HH Covered *[10]* *$ /HH*
Ritchie County, WV	10,343	5,652	453	2	2,826	933	$126,998	$846,998	$300

Source and Notes:
[A] - [G]: Assumed.
[1], [2], [3], [4]: www.census.gov
[5]: [4] / (pi x [D]^2) rounded up.
[6]: [3] / [5] rounded up.
[7]: [6] x [E] rounded up.
[8]: ([F] x [G]) x ([2] / [3]) x [6].
[9]: [A] + [B] + [C] + [8].
[10]: [9] / [6].

Comparison

The fixed cost of deploying a wireless network in a rural area is significantly less than that for deploying a wireline network. This can be seen in Figure 1 below. Figure 1 reports for the rural counties considered (those with less than about 14 households per square mile and total area of at least 100 square miles) the per household cost advantage of wireless over wireline broadband distribution networks. This analysis draws no conclusions about the counties not considered—those without any coloration in Figure 1.

Figure 1: Map of County Price Differentials



As Figure 1 indicates, providing broadband access for significant portions of the United States would be less expensive if access were provided by wireless infrastructure rather than by wireline infrastructure.

In Figure 1:

- The Blue areas indicate a cost advantage of wireless over wireline of up to $1,000 per household passed;
- the Green areas represent cost advantages of between $1,001 and $2,500;
- the Yellow areas represent cost advantages of between $2,501 and 5,000;
- the Orange areas represent cost advantages of between $5,001 and $7,500; and
- the Red areas are cost advantages over $7,500 per household.

In total, the wireless cost advantage covers about 1.7 million square miles, or more than 56% of the U.S. land mass (excluding Alaska).[24] Such infrastructure would cover almost 18 million

[24] 47% of the U.S. land mass including Alaska.

people, more than one-third of the population of nonmetro counties and almost 6% of the total U.S. population.

Three concluding observations deserve note. First, the capacity of the wireline network greatly exceeds that of the wireless network. The broadband connectivity provided over the wireline network uses only a small portion of that network's capacity. (Most bandwidth will likely be used for distributing video programming.) Consequently, the business models, including the nonbroadband services provided, of wireless and wireline networks are different and are affected by many factors other than the ones examined here. Nevertheless, to the extent that policymakers are interested in promoting broadband connectivity in rural areas, this analysis suggests that a wireless network is likely to be a less expensive option.

Second, this model incorporates a cost for spectrum—spectrum accounts for 15% of the cost of the system for Ritchie County, West Virginia shown in Table 5. Although this is a valid economic cost, the assumption of $0.35 per MHz-pop may well overstate the true cost of spectrum in many of the rural areas modeled here. If the alternative to using the spectrum in a rural broadband system were leaving that spectrum idle, then its price should be much lower, potentially near zero. In contrast, one alternative to using additional spectrum in urban areas is to build more cell sites. In this case, spectrum is a substitute for steel and concrete and should be priced in any analysis. However, to the extent that there is idle spectrum available for broadband use in rural areas, the model overstates the cost of spectrum and understates the economic advantage to society of wireless over wired distribution.

Third, the population in many rural counties is unevenly distributed—with a significant fraction residing in small towns and the rest scattered about the county. In such situations the towns probably already have cable modem and DSL service.[25] The policy challenge is providing broadband connectivity to the county residents outside the towns. Because the model treats the

[25] The counties captured in the analysis that indicate a cost advantage for wireless cover 6% of the U.S. population. This represents more than just the population currently unserved by broadband.

county as a whole, it understates the cost advantage of wireless in serving those residing in the more rural parts of such counties.[26]

Summing up, the conclusion of this analysis is conservative in the sense that it understates the economic superiority of wireless. The model includes three elements, each of which causes it to understate the cost advantages of wireless. The model used a relatively low cost for wireline technology; included a significant cost for spectrum even if the alternative is leaving spectrum idle; and did not adjust for the uneven distribution of population within nonmetro counties. But, even with these conservative elements, the model predicts that wireless broadband has fixed capital costs per household served that are more that $7,500 lower than wireline costs in large parts of the Great Plains and Intermountain West.

[26] Malheur County, Oregon is one of the nonmetro counties examined. A third of the county's population lives in the town of Ontario. Cable One offers cable modem service in Ontario and Qwest offers DSL.