

Using WiFi for Cost-Effective Broadband Wireless Access in Rural and Remote Areas

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Abstract

Although a large number of Internet users now enjoy high-speed access, there are still vast geographic regions where broadband services are either prohibitively expensive or simply unavailable at any price. This paper examines the alternatives for using 2.4GHz 802.11b (WiFi) technology to provide fixed broadband access in areas where DSL and cable-based service are frequently not available. We explore the economics of offering wireless broadband services in rural areas consisting of towns, smaller remote communities as well as widely scattered users. We model a network based on realistic demographics, equipment and operations costs, service revenues, customer demand and usage, and to calculate the life-cycle economics in terms of capital investment and profitability. We compare the cost-benefits of using the conventional WiFi technology, as is typically used in metro areas today, with a novel and promising approach based on dynamically steerable beam-forming antennas to increase the coverage and capacity. Our results show that cost-effective, affordable high-speed wireless Internet access can be provided in rural and remote areas.

1. Introduction

The demand for broadband access has grown steadily as users experience the convenience of high-speed response combined with “always on” connectivity. It is anticipated that well over 25 million users will have broadband service in the US by the end of 2003, provided by a combination of DSL, cable modem and wireless access systems [1]. However, these users are predominantly located in urban, metropolitan areas, where the fixed infrastructure is available and has been upgraded to support high-speed Internet services. In rural and remote areas Internet users are less likely to be able to obtain broadband access due to a combination of technology and economic factors and are still using low-speed dial up access, in spite of demand for higher grades of service.

The potential of using fixed wireless for broadband access has been widely discussed [2], [3], [4], [5], and is

being realized in some urban and specialized applications using LMDS [6] and other wireless systems that are appropriate for densely populated areas. The prospect of serving highly rural areas has received only limited attention, and typically for providing narrow-band services [7].

WiFi is already being widely used for enterprise wireless LANs, public “hot spots”, campus wireless networks, and home networks. The potential for using WiFi to extend Internet access to less densely populated and isolated areas is being explored by several entrepreneurial service providers that typically utilize WiFi for “last mile” access and some form of radio link for back haul as well [8]. These small-scale efforts raise the question of whether WiFi is a viable alternative for widespread deployment in typical sparsely populated regions that comprise a large portion of many western states and other areas as well.

In this paper we explore the possibilities of using WiFi cost-effectively in sparsely populated and rural areas. We use a “life cycle” approach, considering both capital and operations costs over a prolonged (e.g., 10-year) study period. Our model takes into account market demand and segmentation, customer adoption and retention (churn) rates, service pricing, as well as technology-based factors such as range, bandwidth, antenna gain, receiver sensitivities and signal strengths. To make the assessment realistic, we model a real rural area: Gallatin County, Montana, which has a population of 71,000 and a land area of over 2600 square miles, roughly twice the size of the state of Rhode Island [9]. We model the entire county, including the major towns, satellite communities, and widely scattered rural population, thereby offering broadband access to all.

We consider first a baseline case where the network consists of APs serving end users in a point-to-multipoint configuration, interconnected to switches or routers using point-to-point wireless back haul. We calculate the economic viability of this network in terms of the net present value (NPV) over a ten-year period, as well as the time to break even. Realistic economic parameters such as the cost of capital, customer service pricing, capital and operations costs, leases, etc. are included. We then vary the model by incorporating novel beam forming and

packet switching technology to assess the cost benefits of innovative approaches.

2. Approach and assumptions

The total service area was categorized into 8 canonical areas (CAs) according to their demographic characteristics: each city or town is taken as an independent CA, all the other rural areas excluding the land covered by national forest are grouped as another CA. Census data are given in Table 1 [10].

We assume two wireless Internet data service categories with asymmetrical upstream and downstream throughputs and corresponding average usage defined as low-speed (512 kbps asynchronous, 5% duty down, 1% duty up, 5 session/hour, 100 seconds /session), and high-speed (1Mbps asynchronous, 5% duty down, 1% duty up, 5 session/hour, 100 seconds /session). The resulting average daily Internet traffic per user is about 0.37G bits and 0.72G bits for low-speed and high-speed respectively. As a comparison, Dartmouth College reports that daily usage of their campus-wide WiFi wireless network averaged 0.32G bits per user in 2001 [11]. Our assumption for the traffic load is reasonable and conservative, anticipating Internet use will increase as time goes on. Additionally we consider an IP voice service at 16 kbps and assume average usage of 3 calls/hour, 180 seconds/call. The voice usage estimate is based on typical call data for telephone networks, where we have assumed the per-user calling rate in the busy hour and call holding times that are widely experienced. Under these conditions, the total voice traffic per user is a small fraction (less than 10%) of the data traffic. Hence the inclusion of voice service in the model has a minor impact on the total cost, provided the costs of interworking of IP-based voice are borne by voice network service providers.

We assume the percentage of high or low-speed data service combined with IP voice service required by the potential users are 20% and 80% respectively, and vary this ratio in a sensitivity analysis. The ratio of total

customers who subscribe to a particular service to the potential users (total population) at a point of time is using a Fisher-Pry (S-shaped) model, assuming an initial penetration of 20%, final penetration of 80%, and that the period to half of the final penetration is 3 years. This adoption rate is similar to that of cell phone users.

These services could potentially be provided by several competing wireless ISPs. The portion of service provided by a particular wireless ISP is modeled using a parameter to characterize market share. In this study, considering the rural demographics, it is likely that fewer wireless ISPs would compete for the market as would in metropolitan areas with high population density and high investment return. Hence we can assume a relatively high market share of 75%. We further assume that in each year, 5% of the subscribers leave the system (churn) and are immediately replaced in addition to any overall market growth. We assume that the cost of Customer Premises Equipment (CPE) will be borne by the end users and is not included in the economic analysis.

The wireless network design tool WirelessSWAT for WISPs [12] is used to model the network structure and evaluate the economics of various scenarios. The model combines the costs and capacities for the wireless network elements, the backhaul links, switches, routers and connection to the Internet. It also includes the cost and expense of the operations support systems (OSS) necessary to provision, maintain and manage the network. The tool then calculates the multi-year financial results, using the demographics, service definitions and assumed values for market share, market penetration and pricing. The tool also calculates the engineering parameters: e.g., the total subscriber traffic, the number of nodes, links and facilities needed to cover the whole service area with sufficient capacity to meet the service demand. These data are then combined to determine the cost to build the network and the cash flows associated with operations and revenues. The model takes the specific characteristics of the technologies into account, but uses averages for the terrain effects. The model does not provide a detailed engineering plan for the network. Rather, it demonstrates the feasibility of the wireless network based on the

Table 1. Demographic information for the cities or towns of Gallatin County

Canonical Area (CA)	Resident Population 2000 Census	Land Area excluding National Forests (mile)	Population Density (persons/sq mile)	Average Annual Growth Rate (%) 1990 to 2000
Amsterdam-Churchill	727	4.09	178	1.9*
Belgrade city	6893	7.2	958	5.0
Bozeman city	31591	13.11	2410	1.9
Four Corners	1828	10.24	179	1.9*
Manhattan town	1396	0.61	2289	3.0
Three Forks city	1728	1.27	1361	3.7
West Yellowstone	1177	0.81	1453	2.6
Rural area	22491	1580.2	15	1.9*
Total	67831	1617.5	41.9	1.9

(*: These data were not given in the Census 2000, the average annual growth rate for the whole Gallatin County was used instead.)

financial and engineering calculation results. Different technologies, services, penetration rates, pricing, etc. can be used to evaluate the sensitivity of the results to the overall network design and to the various service, usage, and financial assumptions.

3. Model

We assume the users are uniformly distributed in each CA and adopt an average of 2Mbps AP throughput. A WiFi AP has a maximum throughput of 11 Mbps, but this high data rate requires a high signal-to-noise ratio, thus leading to a relatively small AP coverage area. Propagation models with maximum range specified according to each of the CAs are adopted. As only three of the eleven specified channels are non-overlapping, we use a frequency reuse factor of three. We assume that each AP will serve a single site, requiring one RF channel. These assumptions are appropriate where system requirements are dictated by the need to cover a large geographical area and when the user demand does not exceed the AP capacity. We explore the validity of these assumptions later. The simplified baseline network in this study is indicated in Figure 1.

Access points connect to Ethernet access switches over a 5.8GHz wireless link. A 100 Mbps wired link is used to connect the Ethernet switches to a central router, which in turn connects to the Internet. Additionally, an AP Management System is included to support the management and operations functions.

The baseline network model is specifically applicable to a densely populated CA, such as Bozeman, where there is an Internet point of presence. Cities and towns with lower populations are modeled with the same network structure from the end users to the Ethernet access switches, and then 5.8GHz wireless links are used to connect the access switches directly with the router located in Bozeman. A separate router in each of these areas is not necessary due to the low total user traffic load. For the rural area, another layer of switches for

aggregation is applied after the first layer of Ethernet access switches to span the large coverage area. Wireless point-to-point links are used to interconnect the switches and communicate with the core router in Bozeman.

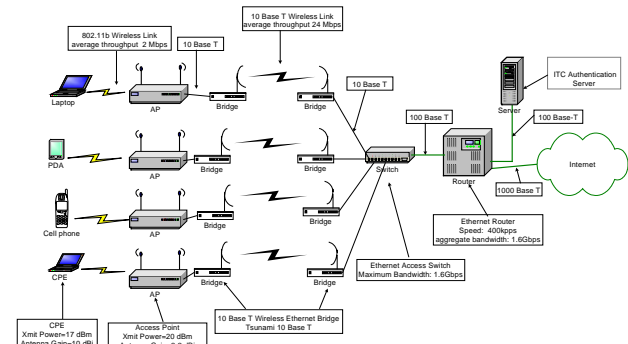


Figure 1. Baseline wireless network structure used in the study

The performance parameters and costs of the network equipment, including both capital and expense, are based on typical, currently available commercial products. Additional costs (e.g., land, tower for the access points, site preparation, installation etc.) were modeled either as one-time capital investment included at the beginning of the study period or as a yearly expense invested at the beginning of each year.

4. Results

4.1. Case A: Baseline case

In the baseline case for the AP, we assume the outdoor propagation range at maximum transmit power setting with a 2.2dBi gain diversity dipole antenna is 800ft (244m)@11Mbps and 2000ft (610m)@1Mbps, typically of available commercial products. Hence we applied an AP coverage area radius of 244 meters for the more densely populated CAs with high average user traffic, and a coverage range of 610 meters for the sparsely populated rural areas. Due to the low population density, the average

Table 2. Baseline case yearly capital costs and expense for each CA and the composite area

CAs	Cost & Expense at Each Year (\$K)									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Amsterdam-Churchill	170	14	14	14	14	14	27	14	14	14
Belgrade City	756	88	115	930	120	122	123	123	99	124
Bozeman City	3147	416	442	444	445	471	423	448	424	400
Four Corners	451	34	34	34	34	59	35	35	59	35
Manhattan town	172	15	28	16	16	16	29	16	16	16
Three Forks City	230	33	21	21	34	22	22	35	22	22
West Yellow Stone	165	12	12	26	13	13	13	26	13	13
Rural area	62011	4963	4988	4989	4990	4991	4992	4993	4970	4946
Composite area	67101	5574	5654	5637	5667	5708	5664	5690	5617	5569

traffic load per AP will typically be lower than 1 Mbps. The performance parameters and costs of wireless backhaul links are based on typical commercial products. Assumed service prices charged to the subscribers, \$45/month for 512 kbps and \$60/month for 1 Mbps are comparable to those currently offered by local ISPs. Table 2 shows the financial results for each CA and for the entire Gallatin County as a composite. These results are based on the assumption that coverage for the entire region is provided in the first year. We consider alternatives, such as building the network in steps over the study period, later in the discussion.

These results show that after the initial capital investment in the first year, the on-going costs are much less, consisting mainly the operating expenses rather than additional capital investment. This indicates that as a whole the wireless network is “coverage-limited” over the entire study period. That is, the initial investment is needed to provide the coverage for the whole area, but on average, the demand per unit area never exceeds the capacity of an AP.

Table 3 gives the NPV for the 10-year study period and the break-even point for each CA and for the composite area. Densely populated areas such as Bozeman and Belgrade have a high return on investment and short period to break even, while the rural area has a negative NPV, indicating that it will not break even in this ten-year study period. The NPV of the composite area is seriously reduced by the investment required to serve the rural area. For the rural area alone, service charges of \$300/month and \$400/month for 512 kbps and 1 Mbps respectively and an unrealistic 100% market share are required to reach a break even point in three years. Figure 2 shows the capital and expense flows of the composite area over the study period. The “Access Sites and Links” cost includes the total cost of APs and the wireless links to the first layer access switches. The backhaul cost here includes the components and links including and above the access switches.

Figure 2 indicates that the dominant capital investment is in the APs and the wireless links from the APs to the

access switches. The large number of APs means that there is also a large investment in wireless links, further raising the capital cost. After the first year, operating costs, which include leases for AP sites, dominate the expense flow, and the large number of APs drives this number as well. Architectures and deployment strategies that would reduce the number of APs, particularly in the rural areas would make the network more financially attractive.

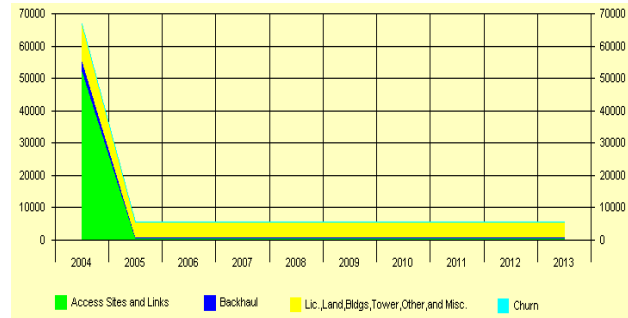


Fig 2. Baseline case capital and expense flows for the composite area in the ten-year study period

4.2. Case B: Baseline case with switched array antennas

We consider an alternative, using recently introduced phased array antenna technology, combined with beam switching to increase the range and capacity of an AP. So called “packet beam” or PacketSteering™ is being introduced for WiFi networks by at least one vendor, Vivato, and shows promise in outdoor and indoor applications [13]. APs equipped with these switched array antennas have a maximum outdoor line-of-sight transmission range of up to 4.2km@11Mbps and 7.2km@1Mbps. Each switched array antenna covers up to 100° in the horizontal plane and up to 3 concurrent WiFi beams provide connections on a packet-by-packet basis with a maximum throughput per channel of 11Mbps. Hence both increased coverage and increased capacity are achievable.

We define Case B, using the assumptions of the

Table 3. Baseline case NPV and years to break even for each CA and the composite area

Items \ CAs	Amsterdam -Churchill	Belgrade	Bozeman	Four Corners	Manhattan	Three Forks	West Yellow Stone	Rural area	Composite area
NPV (\$K)	1217	16391	39033	2954	2746	3605	2213	-38102	30057
Years to break even	2	1	2	2	1	1	2	N/A	8

Table 4. Case B yearly capital costs and expense needed for some of the CAs and the composite area

CAs	Cost & Expense at Each Year (\$K)									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Bozeman City	700	331	284	431	474	436	529	484	591	487
Rural area	4910	646	697	698	700	702	704	706	659	612
Composite area	6522	1127	1134	1375	1348	1325	1534	1392	1427	1276

baseline case and replacing the APs and diversity antennas with APs integrated with switched array antennas. Four AP/switches are needed per coverage and each AP/switch connects to a common Ethernet hub at the location of a single AP in the baseline case. Wireless links are used to connect to the access switches and the remainder of the network infrastructure unchanged. Table 4 gives the financial results for Case B. Figure 3 shows the total expenditure flows graph of the composite area for this case.

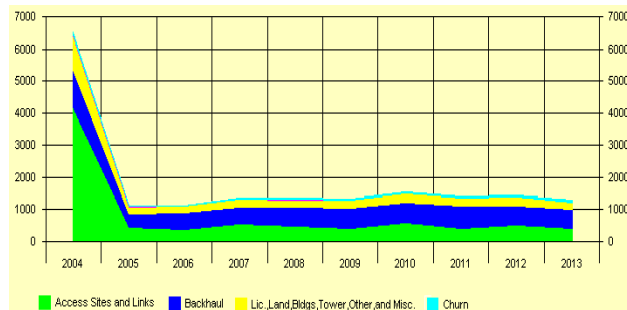


Fig 3. Case B capital and expense flows for the composite area in the ten-year study period

In this case, the break-even point for the rural area alone is in 2 years, while the composite area is in 1 year. The NPVs at the end of 10th year for rural and composite areas are \$36.3M and \$108.4M respectively. This is an improvement factor of three over the baseline case for the composite area and also yields a profitable solution for the rural area taken separately.

Case B has a further advantage in that it needs less initial capital investment and the capital investments are more uniformly distributed over the whole study period. Although the whole network is always coverage-limited, the capital and expense flow graphs for individual CAs indicate that the increase of the AP coverage range in Case B changes the high population density area, such as Bozeman, from coverage-limited to capacity-limited, and after the initial deployment in the 1st year, the deployment of additional APs is capacity-driven as market penetration grows.

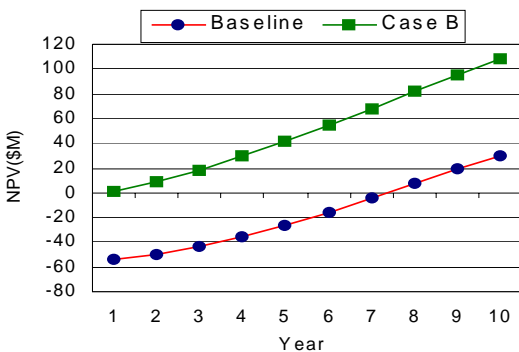


Fig 4. Discounted cash flow graph of the composite area for the two cases

Figure 4 compares the discounted cash flows for the composite area for the two cases. Note that the NPV at the end of year 1 is positive for Case B. From the point view of a real engineering design, case B requires less AP sites than the baseline case, providing advantages in operations and management. Hence, for this specific wireless network, the use of switched array antennas is a cost-effective and favorable approach.

5. Discussion

We consider here the sensitivity of the results to several of the study assumptions. We have tested the robustness of our results to several of the major assumptions. Network equipment costs used in our model are “typical retail prices”, available from vendor web sites. These numbers are an upper bound, as vendors normally offer discounted prices in volume sales to service providers. We have also used static prices, ignoring the trend of more performance at lower cost that is driven by a combination of volume production and Moore’s law. We have tested the sensitivity of our results to our assumptions regarding user preference for low-speed and high-speed services. If a larger percentage of users (we assumed 20% in the baseline case) were to subscribe to high-speed (1 Mbps) access, the traffic load would increase and more network equipment might be required, but at the same time, the revenues would increase. We calculated the impact of this trend for several alternative scenarios: 50% and 80% usage of high-speed service and found that the NPV is more favorable with increased high-speed usage indicating that the network remains coverage-limited. The increased traffic utilizes more of the capacity and generates more revenue without requiring additional investment.

The network roll out strategy may be a key factor in assuring the success of the deployment. In our cases we assumed that the network would be deployed quickly to provide service in the entire coverage area at the beginning of the study period. The results suggest that a phased deployment model, where the network is constructed first in the densely populated areas where the break-even point is short, would be attractive, and revenues could then be used to provide the capital needed to offer coverage in the less profitable rural areas. The results for case B, where the technology provides high-density areas that become capacity limited, indicate the benefits of this approach. Such scenarios require further assessment but are beyond the scope of this study.

Finally, we tested the sensitivity of our findings to a key financial parameter, the discount rate. The value of this factor is determined by a combination of effects including the prevailing interest rates and the risk associated with the investment. We compared the results

for the baseline case, where a 10% discount rate was used, to cases with higher discount rates and found that for the baseline case the composite area will not break even if the discount rate approaches 20%. Under these circumstances, a network operator would likely follow an evolutionary roll out strategy, investing first in the more populated areas and using the return on this initial investment to support investments to cover the more rural area in later years

6. Conclusions

Our results show that with reasonable assumptions for equipment costs, customer adoption rates, services prices and market share, a WiFi-based broadband Internet access network is financially viable in a rural area. Technology alternatives, as evidenced by our case B can improve the cost effectiveness and financial performance of the network. Our results are based on a high-level study, which is technology-based and uses engineering models, but is not a detailed site-specific design, including local terrain factors, necessary to design an actual network. Such a further study would be the next step in developing both a network and business plan.

Several other factors require additional attention. We did not explicitly address issues such as availability and reliability in our network design. We did use costs for network grade equipment but did not impose design constraints such as redundancy to assure service availability comparable to franchised wire line networks. We assumed the use of commercial power and did not include a factor for backup power. Whether this is necessary for Internet service is an open question and outside the scope of this study.

These results point to several areas for further investigation. The potential for offering voice and data services needs additional attention. Our results indicate that this is viable from a capacity perspective, but other issues such as interconnection with the PSTN and the possibility of supporting voice grade service with sufficient quality and associated features requires further study. Our results indicate that alternative technologies have promise in the rural domain but need further examination to be effectively exploited. Finally, we have restricted our study to 802.11b. Other 802.11 technologies, such as 802.11a (at 5GHz) and 802.11g (at 2.4GHz) are now standard and becoming available. The increased capacity offered by these alternatives should be explored.

7. References

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