NEW AMERICA FOUNDATION
WIRELESS FUTURE PROGRAM

WORKING PAPER

Working Paper #21 *February 2008*

Wireless Pittsburgh
SUSTAINABILITY OF POSSIBLE MODELS FOR A WIRELESS METROPOLITAN-AREA NETWORK

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Abstract

Many cities are considering the deployment of a wireless metropolitan-area network (WiMAN) based on Wi-Fi technology. Some hope to find the "right" WiMAN policy, but in reality, different policies are appropriate for different cities. City leaders must often balance competing goals, including the desire to maximize the area in which wireless services will be available, to maximize competition among providers, to minimize subsidies from government agencies and non-profit organizations, and to ensure financial sustainability. This paper investigates the extent to which these goals can be met with four basic models: (1) a single citywide monopoly WiMAN provider; (2) facilities-based competition from multiple citywide WiMAN providers; (3) a citywide WiMAN offering wholesale services to competing retail service providers; (4) open competition where multiple providers are free to serve only the more profitable neighborhoods. We estimate costs for constructing and operating a WiMAN in Pittsburgh using a sample architecture.

We develop a regression model to roughly predict subscription rates and revenues based on city demographics, and apply that model to Pittsburgh, Philadelphia, and Minneapolis. Using these rough estimates, we analyze the extent to which competition can be sustained and service can be provided citywide under different models, and with different forms of intervention, such as providing one-time or annual subsidies (from government or non-profit foundations), guaranteeing that city government will be a large customer, advertising wireless services, and facilitating access to locations that are suitable for antenna placement.

For Pittsburgh, we conclude that citywide facilities-based competition is not financially sustainable. Citywide monopoly operation and citywide competition at the retail level are almost equally viable financially, and both appear sustainable, but financial failure is well within our margin of error. Moreover, we show that retail competition can only survive if the City has leverage to prevent the monopoly wholesaler from raising prices to the level that maximizes the wholesaler's profit, as this will end competition. In addition, the City or a powerful third party must provide some form of inducement such as becoming an anchor customer to motivate providers to serve all parts of the city. Otherwise, commercial providers maximize profit by focusing on high-income neighborhoods, leaving much of the city unserved. Finally, we argue that substantial involvement from local government is helpful in some cities but not others. Each city must carefully consider local needs and resources, and state legislatures should refrain from interference.

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Contents

1 Introduction

Press reports from 2006 heralded the age of Wi-Fi-based wireless metropolitan area networks (WiMANs) that promised ubiquitous broadband and an end to the digital divide, all at little or no cost. Press reports of 2007 discussed the impending demise of citywide Wi-Fi. In both cases, reports were exaggerated. While a WiMAN may have many benefits for citizens, local businesses, and municipal government operations, costs can be considerable. Benefits may exceed costs in some cities, and not in others. Moreover, cities can consider a wide variety of policy approaches to cover costs and maximize benefits. The long-term financial outlook for a WiMAN -- and the extent to which it meets the needs of users -- depend heavily on the decisions of policy-makers and the roles played by government agencies, commercial companies, and any participating non-profit organizations. This paper analyzes the impact of various policies and financial models.

In this paper, we use Pittsburgh, PA as a case study for assessing the financial prospects of building a WiMAN and draw conclusions that may prove useful to other cities. This paper describes a methodology for estimating revenues and costs associated with such a network in Pittsburgh. These estimates serve as a basis to analyze four alternative financial models that a city could employ in creating a WiMAN. These four models represent various ways in which the entities involved in creating and operating a WiMAN could be organized. The models considered are: (1) a single citywide monopoly WiMAN provider; (2) facilities-based competition from multiple citywide WiMAN providers; (3) a citywide WiMAN offering wholesale services to competing retail service providers; (4) open competition where multiple providers are free to serve only the more profitable neighborhoods. In general, the roles of vertically integrated provider, wholesaler, and retailer in these four models may be played by city government, commercial companies, or non-profit organizations. The question of whether government should be substantially involved will be addressed separately.

Each model is assessed based on it’s effectiveness in achieving four objectives: 1) maximizing the area in which connectivity is available; 2) maximizing competition in the market, with the goal of achieving better prices and service for users; 3) minimizing subsidies needed to build the network, and 4) ensuring the financial sustainability of the network (i.e., that the revenues generated by the network will exceed the cost of building and maintaining the network and provide a rate of return that is acceptable to the entity or entities participating in the project). Not all of these objectives will be applicable to every WiMAN project, but they constitute a baseline for analyzing each model. The tradeoffs among these four objectives will also be examined. A number of policy levers which policymakers can use to accomplish their goals are also discussed. Where the financial effect of these levers is quantifiable, their effect on the sustainability of the WiMAN is examined.

In section 2, the models considered in this study are described in depth. Section 3 discusses possible policy levers. Sections 4 and 5 describe the estimation of revenue and cost, respectively. In section 6, each model’s ability to be financially sustainable, support competition, and provide services citywide is quantitatively assessed. This appraisal builds on the cost and revenue estimates of Sections 4 and 5, and considers the impact of policy levers from Section 3. Section 7 discusses the role of city government and the paper is concluded in Section 8.

2 Description of WiMAN Models

There are several ways to categorize WiMAN policies into distinct models [2, 3, 4, 5]. For the purposes of this paper, a model is considered to be the economic or business organization of various entities involved in building and operating a WiMAN. This paper considers four WiMAN models: a single vertically-integrated citywide monopoly, facilities-based competition, a single citywide WiMAN offering wholesale services to competing retail service providers, and open competition where multiple vertically-integrated providers are free to serve only the more profitable neighborhoods. Under the models presented in this paper, a government agency, a private corporation, or a non-profit organization may assume the role of operator offering wholesale service, retail service, or both. The requirements for return on investment and profitability may change depending on which type of entity fulfills each of these roles. For example, commercial companies demand a profit commensurate with risk, while government agencies seek irrefutable value for any taxpayer dollars spent. Regardless of who plays these roles, the organizational model remains essentially the same.

- **Monopoly:** In a monopoly model, one citywide monopoly WiMAN provider owns the network, and assumes responsibility for its construction and operation, although it may hire others to fulfill some of these responsibilities. Thus, the monopoly plays both the wholesale and retail roles. For example, Chaska, MN [6] and St. Cloud, FL [7] employ a monopoly model, in which city government owns and operates the WiMAN. Other cities may select one commercial company or non-profit organization to act as a monopoly WiMAN, perhaps by offering exclusive access to light poles and other convenient antenna sites. Municipalities may favor a monopoly model, because it provides ubiquitous coverage and minimizes the cost of deployment and operation, but this model does not support competition.

- **Facilities-based competition:** In a facilities-based competition model, two or more WiMAN providers own and are responsible for operating separate vertically-integrated networks that serve identical or substantially overlapping regions. To the best of our knowledge, no city has employed a duopoly model, possibly because of the high costs of the infrastructure. Municipalities may strive for this model because it allows strong competition, in addition to ubiquitous coverage.

- **Wholesale-retail:** In a wholesale-retail model, one citywide WiMAN offers wholesale services to competing retail service providers. The wholesaler is responsible for building and operating a wireless network that covers the city, and provides services to the customers of all of the retailers. Each retailer must sign up customers, manage accounts, provide customer service, and collect payments. Either the wholesaler provides connectivity between the WiMAN and the rest of the Internet, or each retailer provides this for its own customers. Both the wholesale and the retail roles could be fulfilled by the government, a non-profit organization, or a private company. The wholesaler may or may not offer retail services as well. A number of cities have adopted this model [e.g. 8, 9, 10, 11]. In Philadelphia [10] and San Francisco [9], a commercial company (EarthLink) acts as a wholesaler, and as a retail Internet service provider (ISP). In Philadelphia, EarthLink also cooperates with the non-profit organization, Wireless Philadelphia, with whom they revenue share [10]. Under the Boston Task Force recommendation, the wholesale provider is a non-profit organization that allows any wireless ISP (WISP) to offer retail services, but does not offer its own retail services. The wholesale-retail split model may be favored by municipalities because it provides ubiquitous coverage and some degree of competition, without the cost of building entire WiMANs throughout the same area (as occurs with facilities-based competition).

- **Open competition:** In an open competition model, vertically integrated ISPs are free to serve only the parts of the city they choose, presumably on the basis of profitability. Cities adopt this model by default, unless they create policies to the contrary. This is the only model addressed in this paper in which the WiMAN does not cover the entire municipality. A WiMAN that provides no service to less profitable areas will generally find it easier to achieve financial sustainability and will have less need for subsidies, but obviously at the cost of ubiquity.

3 Leverage and Policy Levers

Certain policy levers can affect the sustainability and risk associated with each of the models discussed above, and these policy levers can help local policymakers influence the characteristics of a WiMAN that is not city-owned. This section describes some potential levers that the government and other organizations with significant leverage can implement. In Section 6, we examine the quantitative effects of some policy levers discussed here.

Policy Levers that Affect First-Year Cash Flow

A government, foundation, or other external entity interested in helping a WiMAN could subsidize or reduce build-out costs. This intervention could come in the form of a one-time cash subsidy from city or state funds, a federal grant, or a donation from a charitable foundation. Donated infrastructure, labor, or a reduction in the institutional costs associated with building the WiMAN, such as the cost of any permits needed, would have the same effect.

Conversely, policy mechanisms can increase the initial investment needed. For example, the government can require expensive permits to access property that the WiMAN requires, such as the location of access points on light poles or public buildings. In effect, this would be a negative subsidy. It is the sum of these actions on first-year cash flow that matters most, and that will be considered in subsequent analysis.

Policy Levers that Affect Annual Cash Flow

A government or other external entity could also take action to improve annual cash flow by reducing annual cost, increasing annual revenue, or both. This type of intervention could come in the form of annual cash subsidies from city or state funds, federal grants, or a charitable organization. Governments could also offer annual rights of way below market price, or conduct education campaigns that advertise WiMAN services, thereby reducing the burden on the service providers.

More indirectly, city governments or other large organizations could act to increase subscription revenue by making a commitment to become a substantial customer of WiMAN services. In our analysis of Pittsburgh, the city government’s potential uses of a WiMAN that we identified were not sufficient to generate revenues that could cover a significant portion of annual costs, making city government a poor anchor customer. One problem is that many WiMAN uses for city government require large capital investments. For example, a WiMAN may be useful to connect parking meters to a central server [12, 13], but only if the city can afford to replace its existing parking meters. Nevertheless, city government has proved to be an effective anchor customer in some cities. Public safety applications may someday play an important role, since most of the current public safety communications systems in the US do not support broadband [14, 15]. Also, a city could implement a program to subsidize in part or in whole the accounts of those who would otherwise be unable to afford broadband services, in hopes of narrowing the digital divide.

A WiMAN’s annual cash flow could also be negatively affected by the actions of government or an external entity. A government could charge more than the market price for rights of way or leasing properties needed for infrastructure. Levying additional taxes or mandating a profit-sharing agreement are other ways that will have the effect of lowering annual cash flow. EarthLink, the WiMAN wholesaler in Philadelphia, is required to share revenues with the local nonprofit Wireless Philadelphia [10]. As above, it is the sum of these actions on annual cash flow that matters, and will be considered in subsequent analysis.

Balancing the Positive and the Negative

Certain policy levers can also be used to alter the risk profile associated with entering a WiMAN market without changing the overall expected long-term financial outcomes. For example, city government might offer a positive subsidy, while demanding payments from the WiMAN provider(s) that are a fraction of profits rather than revenues, or that are due only after several years of operation.

4 Revenue Estimation

Revenue is an important factor when assessing financial sustainability. The best predictor of revenues from a future WiMAN is revenues from past WiMANs. At this early stage in WiMAN deployment, little revenue data is available. However, subscription levels are sometimes available. Because advertising rates are highly uncertain, we will make estimates assuming a subscription-based revenue model. We were able to find first-year subscription rates for eight WiMANs that derive all of their revenues from subscriptions, as opposed to advertising. (They are listed in [1].) We use regression to predict WiMAN subscription rates in the first year of operation as a function of demographic factors. We then apply that model in Pittsburgh and two other cities to estimate first-year subscription rates, and ultimately revenues.

There is significant uncertainty associated with this approach, because the number of data points is small, because the early adopters may not be entirely representative, and because next year's demand may differ from last year's demand. Nevertheless, we believe that predictions based on what data is available are useful and add new information to other estimates based largely on educated guesses.

It has been shown [16] that Internet usage is correlated with income, age, education, and race, so we predicted WiMAN subscribers per capita and WiMAN subscribers per household using 14 independent variables from the 2000 Census [17], each of which is related to income, age, education, or race.[1] We sought the best single-variable linear models, i.e. those with low p-value, high R^2, and high predicted R^2.

Based on our regression analysis (presented in [1]), median household income is the best single predictor of subscription. Median family income and percentage of population with a high school diploma are also useful predictors. Nearly every independent variable predicted subscribers per household more accurately than subscribers per capita. Thus, the most useful models predict subscribers per household as a function of median household income, median family income, and percentage of population with a high school diploma, respectively.

Table 1 shows the subscription rates at the end of the first year of operation predicted for Pittsburgh using the best model. For comparison, subscription rates are also presented for Philadelphia and Minneapolis, because estimated subscription rates have been published for these two cities in their respective business plans [18, 19]. Results were roughly comparable. Our best prediction, which is based on median household income, is 36% lower than that stated in the Philadelphia business model, and 13% higher than that stated in the Minneapolis business model.

Table 1: Subscriptions per 100 Households

Predictor	Pittsburgh	Philadelphia	Minneapolis
Median Household Income -0.108 + 0.00697 * Household Income (thousand $ / year)	**9.1**	**10.6**	**15.7**
Published Estimates [18, 19]		**14.4**[2]	**13.7**[3]

Revenue is the product of the number of subscribers and average price per subscriber. Ideally, we would use the exact mean price per subscriber from each of the cities in our analysis. However, determining mean price for a city is difficult, because each WiMAN offers a unique set of subscription services at different prices, differentiated by connection speed, extra features, and whether the subscriber is a business or individual. Consequently, we use a best guess average price of $28 per month, with a range from $24 to $32. This is consistent with available data from the 8 cities in our data set. We further assume that subscription levels grow linearly throughout the first year, starting at 0 subscribers, and at a constant percentage per day thereafter.

Revenue growth rate beyond year one is the final input needed. Unfortunately, few WiMAN systems have been operational long enough to yield long-term revenue growth data. The predictions published in the Philadelphia [18] and Minneapolis [19] reports vary drastically. Philadelphia estimates annual growth rates beginning at 40% and slowing to 5% over five years, with an overall annualized subscriber growth rate of 15.4% per year. Minneapolis optimistically estimates its revenue growth will begin at 140% between its first and second years, slowing to 26% after four years, with an overall annualized subscriber growth rate of over 60% per year.

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[1] Some numbers may have changed significantly since the 2000 census, which is a possible source of error.
[2] The business plan [16] estimates 85,000 subscribers. Philadelphia had 590,071 households in the 2000 Census [15].
[3] The business plan estimates revenue of $7.5 million. Assuming a mean price of $28 per month, this corresponds to 22,321 subscribers. Minneapolis had 162,352 households in the 2000 Census [15].

We conclude that there is great uncertainty about the growth potential for WiMAN networks. For our analysis, we will assume that annual growth rate is between 5% and 15%, with a best estimate of 10%. This combined with our regression model based on median household income and a mean price of $28 per month leads to the five-year revenue projection shown in Figure 1.

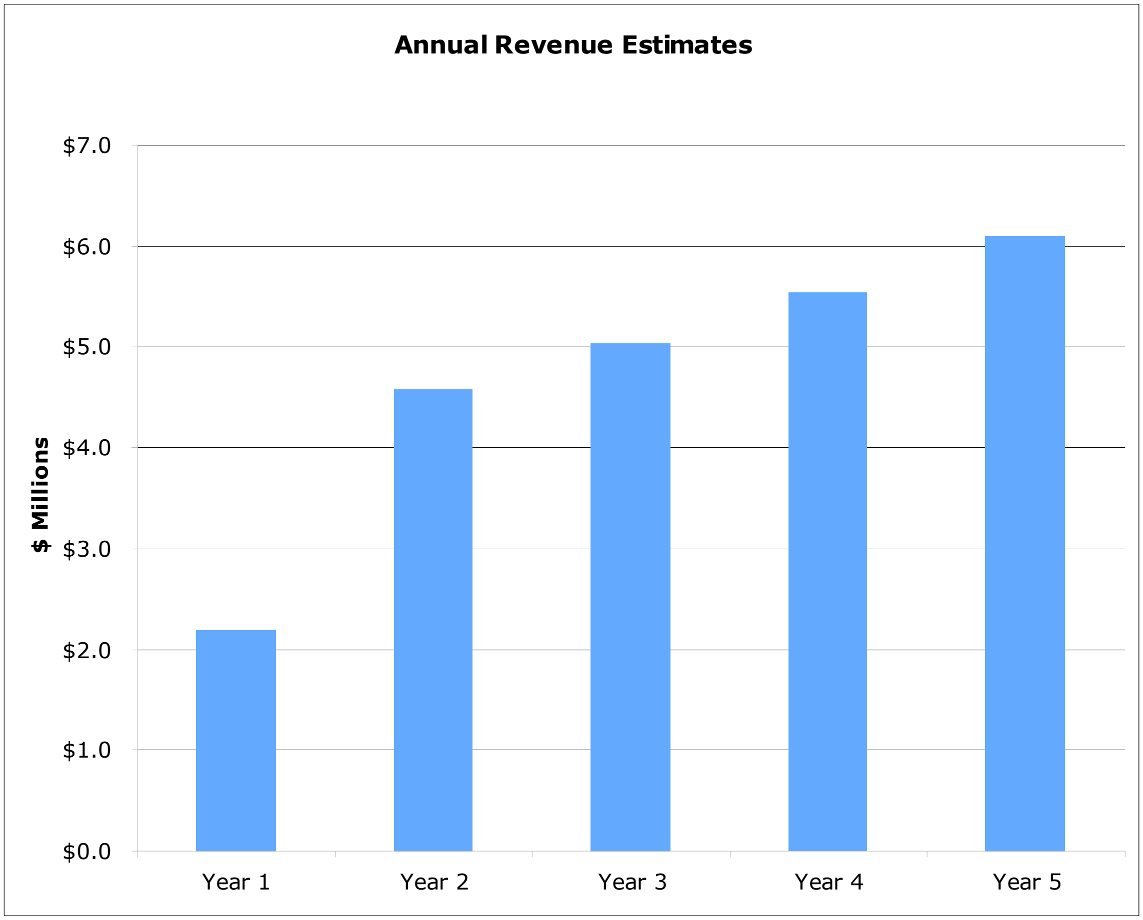

Figure 1: Annual Revenue Estimates for the WiMAN.

5 Cost Estimation

In order to determine whether a WiMAN model is financially sustainable, it is necessary to estimate costs. This section estimates initial build-out costs and ongoing costs over a five year period for a WIMAN serving Pittsburgh. We first approximate deployment costs through a survey of systems in other cities. We then estimate both deployment and ongoing costs that would be incurred in Pittsburgh with a sample architecture.

To get a first-order estimate of deployment costs, we surveyed similar systems (as shown in [1]). The mean cost per square mile was $111 thousand for all WiMANs, and a similar $110 thousand if we only consider WiMANs covering more than 20 square miles. If the costs were the same throughout Pittsburgh's 55.5 square miles, this would yield a deployment cost of $6.1 million.

To get a more complete picture that includes both deployment and operating costs, we designed a system for Pittsburgh based on one sample architecture. This may or may not be the optimal architecture for Pittsburgh, but it is a reasonable choice, and it builds upon lessons from a WiMAN that US Wireless currently operates in 2 square miles of Pittsburgh [20]. We chose a Wi-Fi-based system that is a hybrid of a mesh and hierarchical hub-and-spoke design. Numerous mesh networks will operate around the city, each of which includes one or more *relay* points, which aggregates traffic. Each relay is connected via a point-to-point wireless link to an *intermediate site*, and each intermediate site is connected via point-to-point wireless link to the WiMAN's central hub. This hub is connected directly to an Internet gateway.

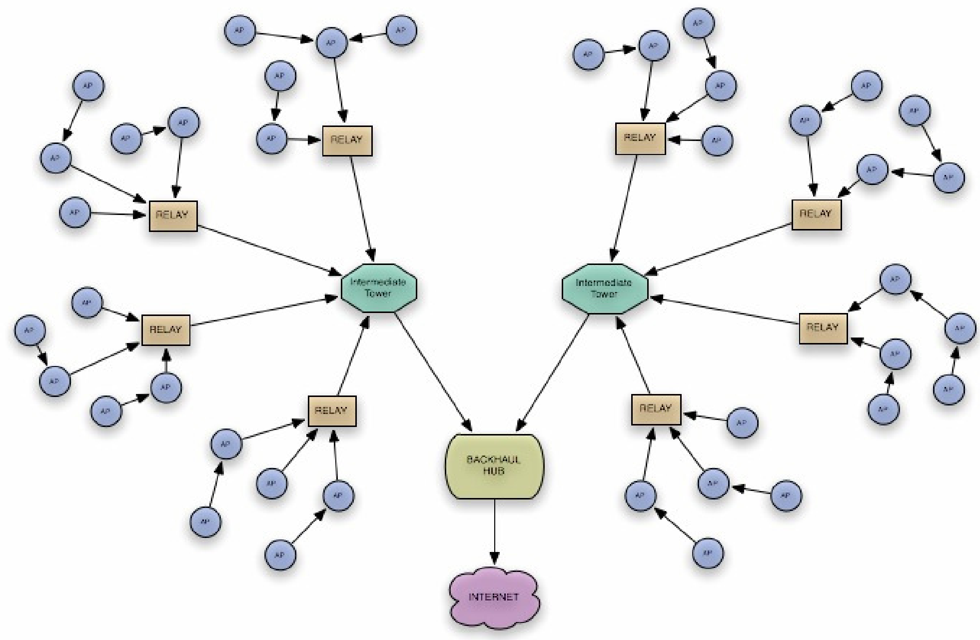

Figure 2: Architecture of the sample system

The total deployment cost is estimated at $6.5 million (based on technical assumptions presented in more detail in [1]). Roughly two thirds of this cost is associated with the access points. Consequently, the assumption about density of access points is particularly important. This number varies greatly, in part because of terrain, types of buildings, and coverage objectives [1]. For example, there were 25 access points per square mile in a WiMAN covering 2 square miles of Downtown Pittsburgh [20]. A much lower access point density will suffice in the rest of Pittsburgh, because Downtown has a particularly high concentration of tall buildings. Based on experience in Downtown Pittsburgh and in other cities, we estimate roughly 19 access points per square mile for a system covering Pittsburgh.

Major operating costs include maintenance staff, leasing fees, advertising and connectivity with the Internet (based on technical assumptions presented in more detail in [1]). Experience with other ISPs shows that advertising and other marketing costs are often higher initially to attract new customers to the network. Based on such experience [21], we assume costs of $1 million in Year 1, $800 thousand in Year 2, and $500 thousand from Years 3 through 5. Since these costs vary from market to market, there is probably greater uncertainty for this portion of cost. However, all these costs combined are small compared to build-out costs. Figure 3 shows total costs, including build-out and operations.

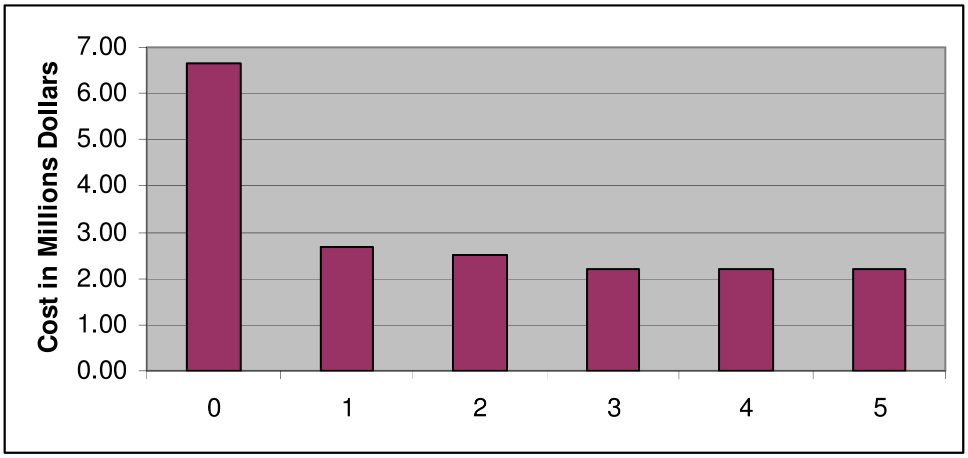

Figure 3: Estimated Yearly Cost of the network, including installation and operating costs

The above figure shows that the costs to build the WiMAN were much greater than annual costs, and these costs must be incurred before revenues can begin. This implies that it will be challenging to find the resources to launch a new WiMAN, and much easier to make the WiMAN self supporting in subsequent years. We also note that the largest part of deployment cost is proportional to the number of access points. This implies that the extent of coverage is an important determinant; because Wi-Fi has a short range, a 5% reduction in coverage can often significantly reduce the number of Wi-Fi access points needed.

6 Financial Sustainability of each WiMAN Model

Based on the cost and revenue estimates above, we assess the likelihood of financial sustainability for each of the four WiMAN models over five years of operation plus one year of build-out using discounted cash flow analysis. For the purpose of this analysis, a model is considered sustainable when the projected revenues exceed projected costs and provide an appropriate return on investment, which might be used as the discount rate. This section includes a discussion of the general methodology for assessing the four business models, one subsection for each of the four business models, and a final section comparing the models.

All values are assessed in today's dollars. The sustainability of each cash flow is assessed by calculating its net present value and modified internal rate of return. This analysis relies on a host of variables, each of which introduces a degree of uncertainty. In evaluating each model, we use a base case in which all variables are set to values that seem most reasonable, and a sensitivity analysis that evaluates the effect of misestimates in the input variables on the final outcome. The key variables and assumptions in these analyses include:

Discount rate: As a base case assumption, we assume a discount rate of 8.25%, which is prime rate at the time of this analysis. Any entity deciding whether or not to undertake the WiMAN project will have to deduce its own cost of capital.

Project timeframe: We assume WiMAN providers will assess sustainability over a six-year time frame (including build-out Year 0), during which today's Wi-Fi technology remains widely used.

Tax: All of the earnings we consider are on a pre-tax basis. In much of our analysis, we only consider time frame to break even, so tax would not be a major issue. However, once the project has broken even, this could be a significant cost.

Revenues: As a baseline, we assume year 1 subscription rate, subscription growth rate (10%/year), and average subscription price ($28/month) are set at levels presented in Section 5.

6.1 City Wide

As described in Section 2, the first model for a WiMAN involves a single Internet service provider (ISP) building, maintaining, operating, and owning a citywide network in Pittsburgh. This ISP will incur all of the costs for the project, as well as receive all of the revenues.

The five-year cost and revenue estimates discussed above yield a net present value (NPV) of $1.85 million, and the cash flow shown in Figure 4. The monopolist would break even in Year 5, where Year 0 is the build-out year. This implies that commercial companies would seriously consider deploying a citywide WiMAN in Pittsburgh under the right circumstances, e.g. if profit is commensurate with risk.

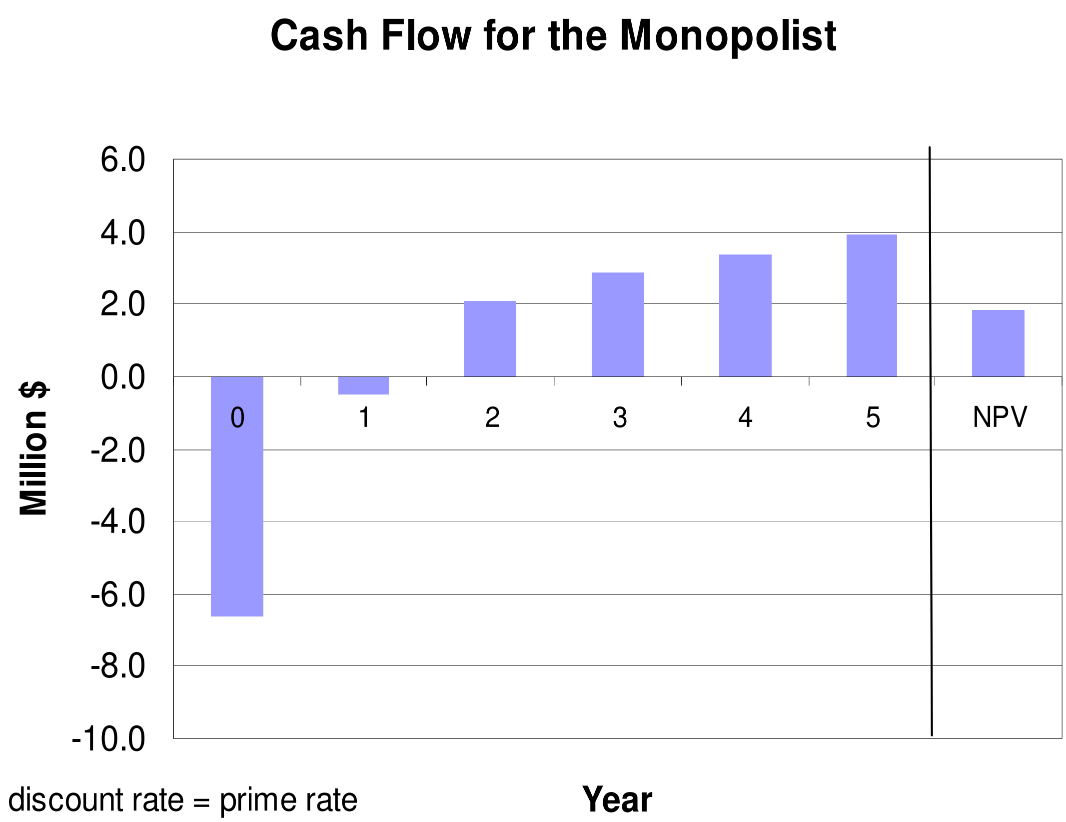

Figure 4: Cash flow and NPV for the monopolist from Year 0 to Year 5.

Figure 5 shows how NPV changes if one of these values varies from baseline assumptions: total installation cost, discount rate, mean monthly subscription price, number of subscribers at the end of Year 1, and annual subscriber growth rate. While a citywide monopoly is sustainable under baseline assumptions, this sensitivity analysis shows that an unsustainable outcome is easily within the margin of error. Although there is some uncertainty associated with deployment cost, any inaccuracies are probably too small to yield a negative NPV. In contrast, uncertainties related to future revenues are substantial, and inaccuracies could easily yield a negative NPV.

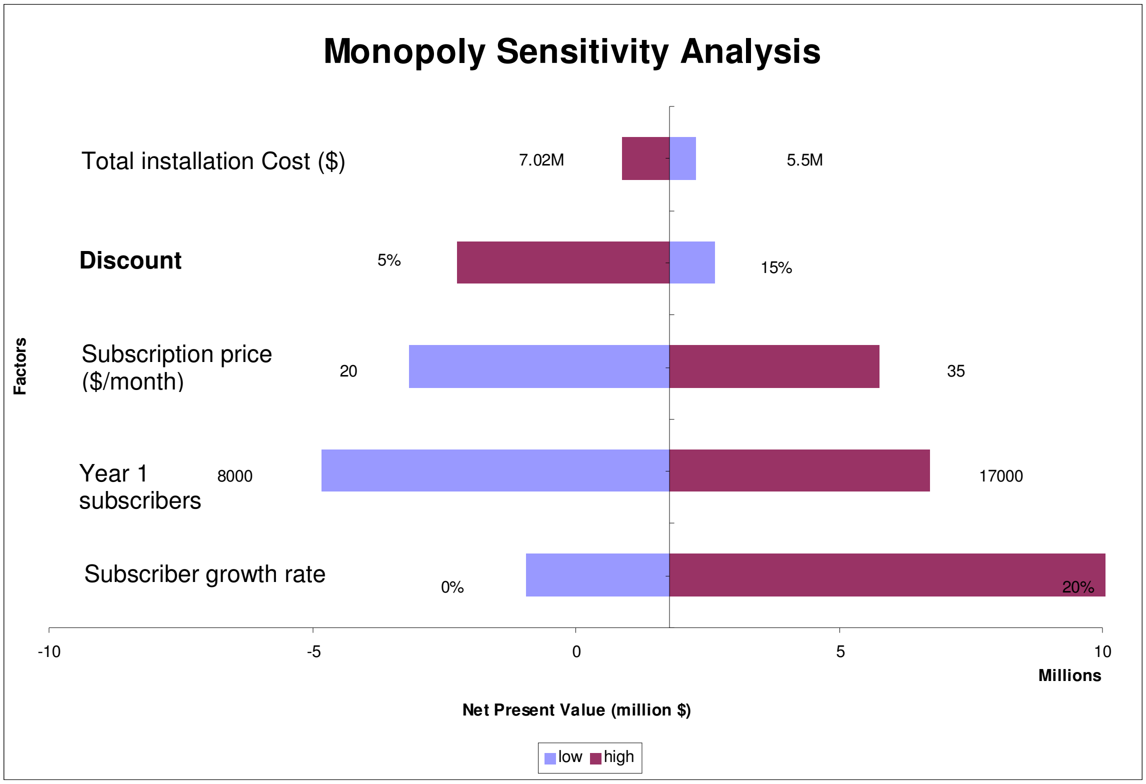

Figure 5: The vertical line represents a monopolist's NPV under baseline assumptions. Each horizontal line shows how NPV changes with one variable, while all other variables remain at baseline.

6.2 Facility-based competition

The facilities-based competition model assumes there are multiple providers that each builds a separate citywide WiMAN. We assume costs for each WiMAN would be the same as for a monopolist. In this scenario, competitors split the same customer base. For simplicity, we assume that the providers split the revenue equally, and that total revenues are the same in this model as in the monopoly model. In reality, the increase in competition may decrease total revenues, which would make our estimate optimistic.

Figure 6 shows the NPV and cash flow for Years 0 to 5 with 1, 2, and 3 competing WiMAN providers under baseline assumptions. With just two competitors, our model predicts a NPV of -$5.5 million per provider. Clearly, citywide competition is not sustainable without some kind of intervention.

As discussed in Section 3, there are a number of ways to improve the sustainability of a WiMAN. Some interventions have the effect of improving year 0 cash flow, such as providing an initial one-time subsidy, or covering some of the provider's initial costs. Other interventions have the effect of improving annual cash flow beginning in year 1, such as becoming a large anchor customer, or giving the WiMAN access to light poles at a price that is below market rates. For two providers to achieve an NPV of 0 after Year 5 under baseline assumptions, a Year 0 intervention must be worth $5.5 million, and an annual intervention must be worth $1.4 million per year. In contrast, a monopoly provider benefiting from the same intervention would reach an NPV > 0 during Year 3, and would be highly profitable after that.

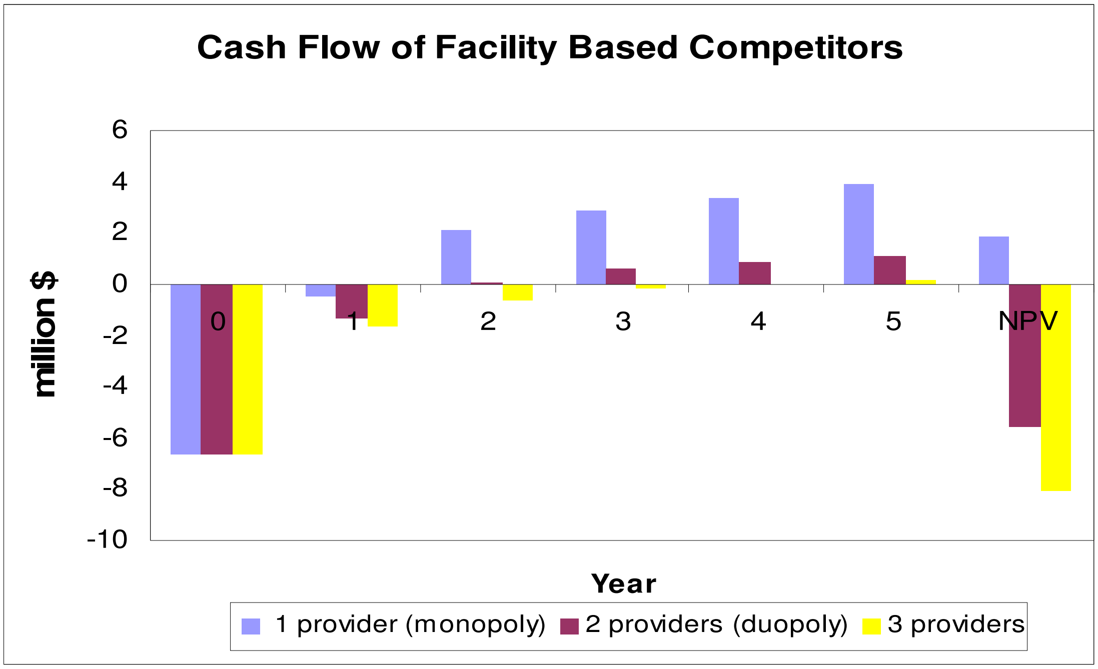

Figure 6: Cash flow and NPV for *each* service provider under facility-based competition with one, two, and three providers.

6.3 Wholesale-retail model

The next model we consider consists of one wholesaler which is responsible for the costs of building and operating the citywide wireless network, and multiple retail Internet service providers, each of which are responsible for their own costs for customer service, billing, ISP web sites, and connectivity with the Internet backbone. Since there is some duplication of effort among retailers, total costs increase as the number of retailers increases. For example, each retailer is responsible for its own web site, billing, customer support, and customer acquisition. We assume that total revenue is the same for this model as in the two previous models, and that revenues are split equally among retail ISPs. In general, either the wholesaler or the retailers could provide connectivity to the Internet. Here, we consider the former option. We assume that half of the marketing costs incurred by a monopoly are for the promotion of WiMAN service in general, and can be split equally among the retailer. The other half are for promotion of a specific retailer, and must be duplicated by each retailer.

Under baseline assumptions, the wholesaler would break even with a 5% return on investment at the end of Year 5 if the combined payments from competing retailers equal $2.68 million per year. A 5% rate of return is presumably too low for a commercial wholesaler, but may be acceptable to a non-profit organization.

Figure 7 shows costs incurred by the wholesaler and the total costs incurred by all retailers, under scenarios assuming 1, 2, and 3 retailers, respectively. The figure shows costs for retailers excluding the payments to the wholesaler, and it shows costs for retailers including total payments to the retailer of $3.3 million per year. Clearly, the initial costs for a wholesaler are large, but annual costs are much lower after build-out. Thus, one of the challenges for this model is funding the initial build-out of the wholesaler's network, but the model becomes more viable after that.

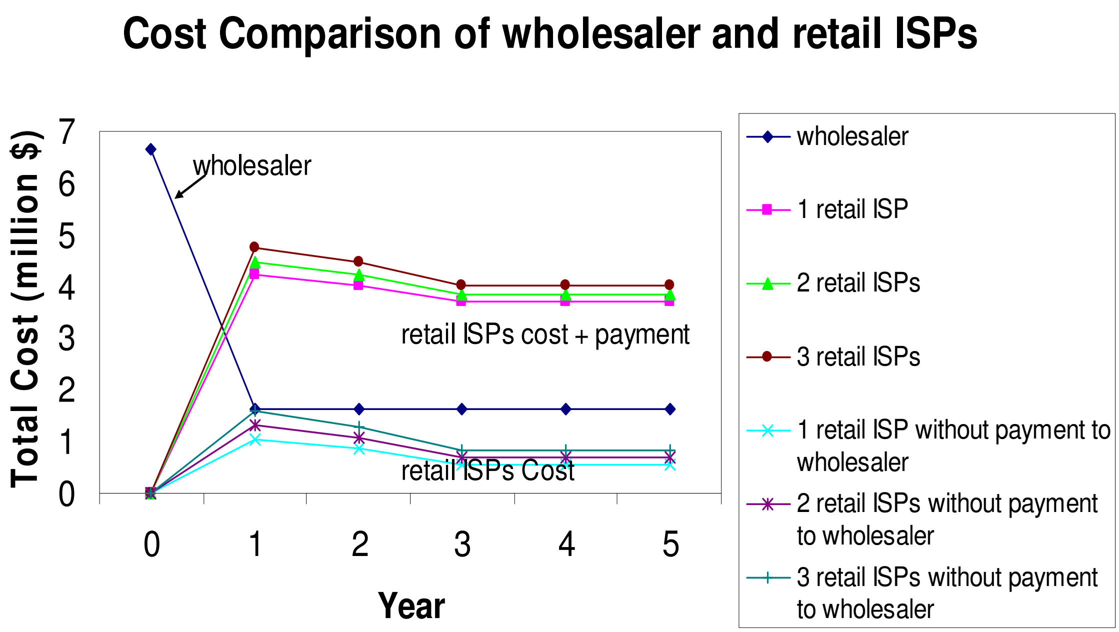

Figure 7: Cost comparisons of wholesaler and retail ISPs. Payment refers to the payment from retailers to the wholesalers.

Figure 7 also shows that increasing the number of retailers has a small impact on total costs, which should alleviate a serious concern about this model. This implies that sustainability under this model should be similar to that of the monopoly model. Moreover, even if the wholesaler accepts a return on investment of just 5%, the majority of a retailer's expenses consist of payments to the wholesaler. Thus, we evaluate the sustainability of retailers in Figure 8 under the more pessimistic assumption that the wholesaler requires an 8.25% return. Still three retailers can show an NPV > 0 at the end of Year 5 under baseline assumptions. This wholesale-retail split may be attractive for cities like Pittsburgh. It offers some degree of competition, and citywide coverage.

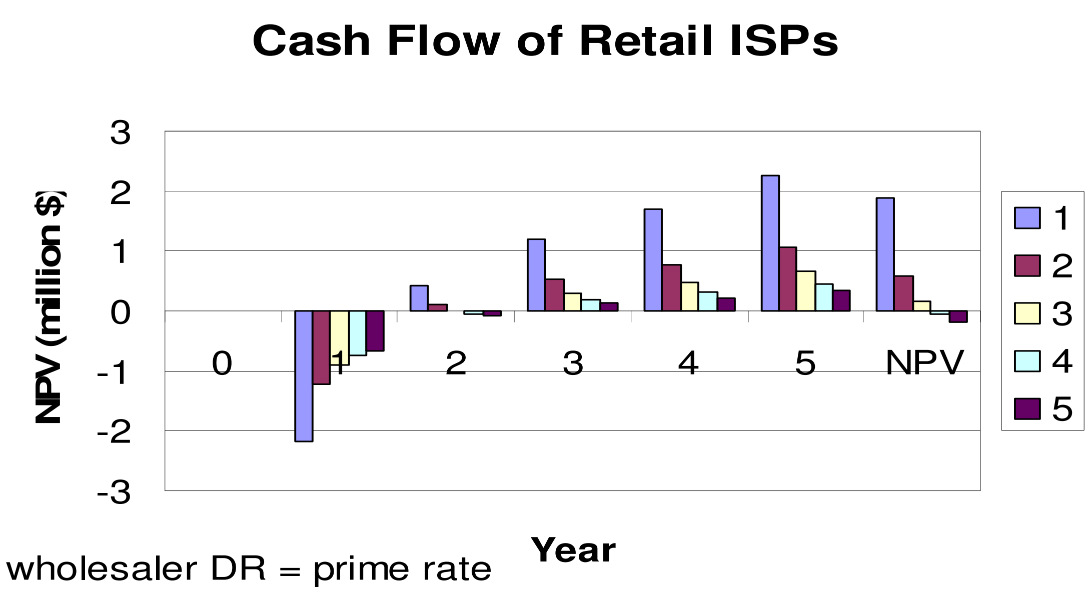

Figure 8: Cash flow and NPV for each retail ISP, where the wholesaler's discount rate is 8.25%

However, if the wholesaler is a commercial company, it may not be satisfied with a 5% or an 8.25% rate of return. Figure 9a shows that the number of sustainable retailers decreases as the payment from retailers to wholesaler increases. Figure 9b shows that a profit-seeking wholesaler has strong incentive to increase these payments until reaching a point where only one retailer remains. Thus, retail competition is unlikely to survive unless the City can somehow motivate the wholesaler to keep its rates sufficiently low. This may be easier if the wholesaler is a non-profit organization.

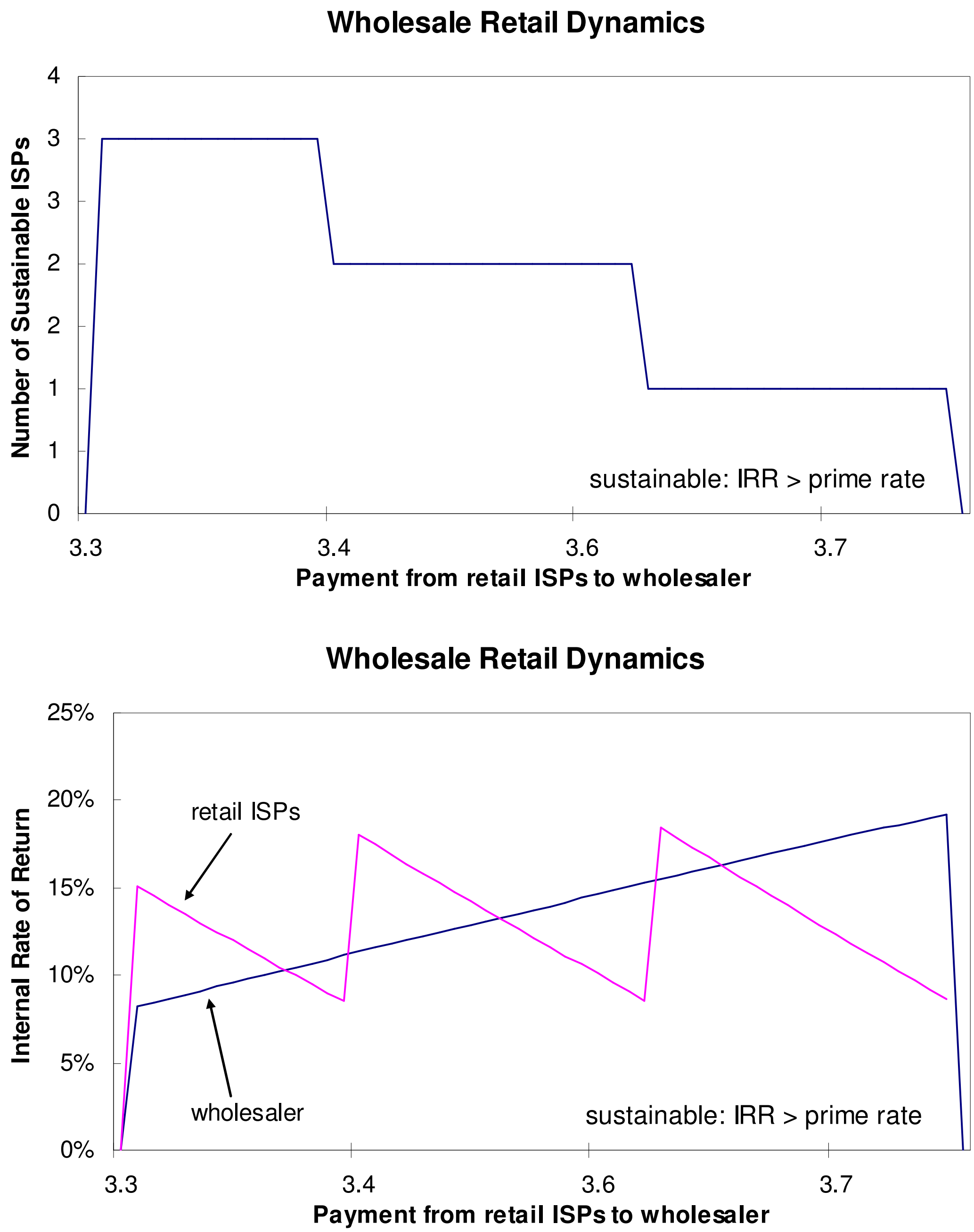

Figure 9: (a) number of sustainable retailers vs. payments from retailers to wholesaler in million dollars per year. (b) internal rate of return for wholesaler and retailers vs. payments from retailers to wholesaler, assuming number of retailers is the maximum sustainable.

6.4 Neighborhood-by-neighborhood competition

In this section, we examine the model in which ISPs are free to choose the neighborhoods where they provide service. To assess sustainability, we assume that 1) the best model in Section 2 designed to predict city subscriber rate can also predict subscriber rate in each of Pittsburgh's 90 official neighborhoods, and 2) the cost per square mile is constant throughout the city and equal to that of the citywide WiMAN. These assumptions are major simplifications and do not reflect the effect of economies of scale, among other factors, so this estimate is strictly a first-order approximation.

Figure 10 shows the cumulative distribution function (CDF) of neighborhood NPV weighted by population and area, respectively, under baseline assumptions. If we assume that neighborhoods with estimated NPV < 0 at the end of Year 5 would not be served, then more than 50% of Pittsburgh's area will be unserved, and 40% of the population. This would constitute a substantial digital divide. The neighborhoods that generate enough revenues to sustain two or more competitors cover roughly 30% of Pittsburgh's area, and are home to roughly 40% of Pittsburgh's population.

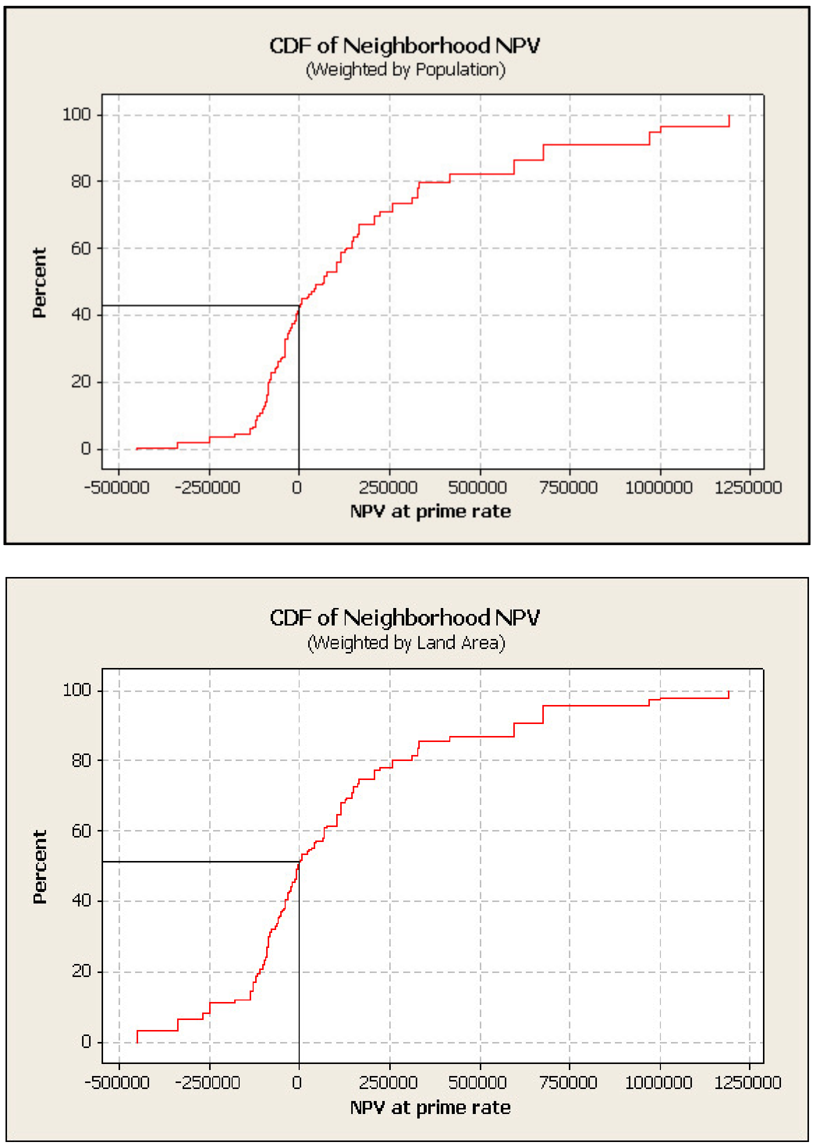

Figure 10: CDF of neighborhood NPV weighted by population (top) and area (bottom).

Given our underlying assumptions, there is significant uncertainty in these results. Further research is required. Nevertheless, these results are consistent with the premise that a commercial provider would choose to serve only a small subset of the city, unless city government or another player can exert some form of leverage or offer some incentive to serve the entire city.

6.5 Model Comparisons

Figure 11 compares the NPV over Years 0 through 5 for each of the citywide WiMAN models discussed above. The wholesale-retail split has a somewhat lower NPV than a monopoly, in part because we are combining the NPV of the wholesaler (which was previously set to 0 at an 8.25% discount rate) and the NPV of the retailers. Nevertheless, the NPV of the wholesale-retail split compares reasonably well considering that the added possibility of competition. In contrast, facilities-based competition citywide is clearly problematic.

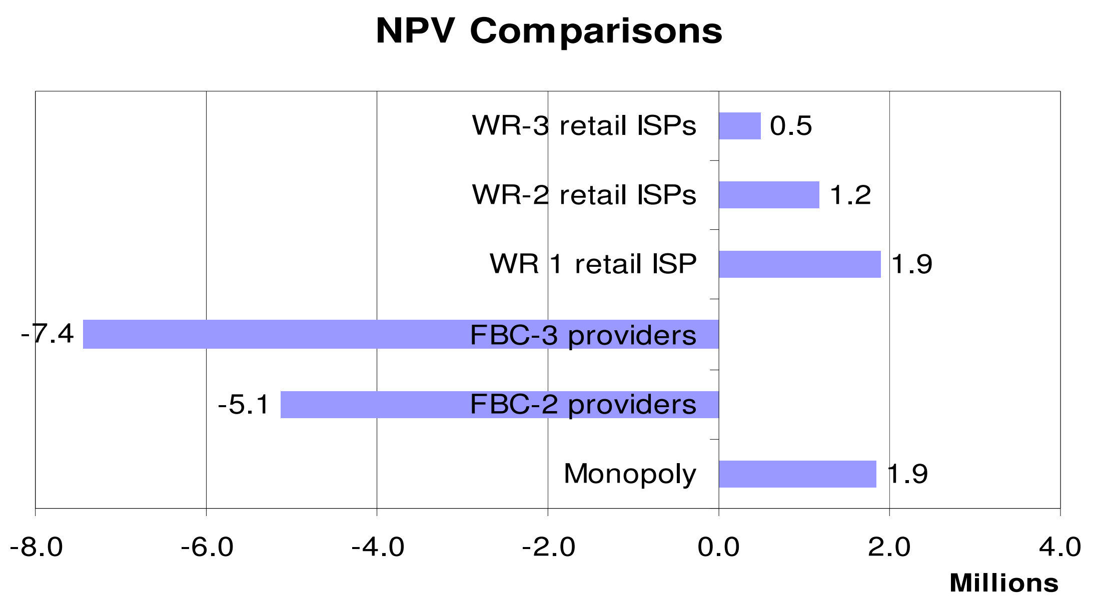

Figure 11: Estimated NPV for a monopoly; facility based competition (FBC) with two providers and three providers; and wholesale-retail split (WR) with one, two and three retail ISPs.

7 What is the Role of the City Government?

The many questions surrounding whether or how a community should establish a WiMAN are complex. The most controversial question is often whether city government should play a substantial role. Opponents of government involvement can argue that commercial service-providers in a competitive market have the greatest incentive to meet the needs of customers and make efficient use of resources. The other side can point out that markets sometimes fail without government involvement, which is why governments provide roads, garbage collection, and K-12 education. Both arguments are correct. Substantial government involvement can be invaluable in some cities and counterproductive in others, depending on local needs and resources.

Government involvement may take many forms, and city leaders should think broadly. For example, if a citywide monopoly is to be established, the project could draw financial resources, staff time and expertise, and useful infrastructure (such as light poles) from city government, commercial service providers, civic-minded non-profit organizations, universities, large regional employers, or combinations thereof. Effective leadership could mean actually building a service provider, or it could mean nothing more than assembling a city's resources from diverse sources and orchestrating their use.

Substantial government involvement should be defined based on *ownership* of the WiMAN infrastructure, as ownership provides a high degree of control and responsibility. Contrary to some of today's distracting rhetoric, a commercially-owned system that is marketed with the official city logo is not likely to place the public interest ahead of profits, any more than a government-owned system that is operated by commercial contractors is guaranteed to be an exemplar of market efficiency. Thus, substantial government involvement means government takes an ownership interest in a WiMAN service provider, or puts significant city resources into a non-profit organization created to provide (wholesale and/or retail) Internet services.

All cities considering substantial involvement should seek answers to the following questions. First, is there a market failure in this city associated with broadband? Second, what is the specific objective that can be achieved through WiMAN deployment? Internet is presumably a means rather than an ends. Many cities cite numerous vague and sometimes self-contradictory objectives, which is equivalent to having no objectives. Third, what resources are available from city government, and from other interested parties?

Here are some of the best reasons for substantial government involvement.

- *Giving this city's government agencies access to a new WiMAN would lead to sizable reductions in public expenditures or improvements in service*. Use of a WiMAN may reduce expenses for public safety agencies, schools, libraries, parking enforcement units, parks services, and other government entities. Some cities have justified the cost of WiMAN deployment based entirely on such cost savings, regardless of any benefits from giving citizens access to the infrastructure. If a city government plans to make a WiMAN a part of essential services, e.g. mission critical communications for police, the city has greater incentive to own the infrastructure, as this is one (but not the only) way to prevent a monopoly service provider from demanding excessive fees that the city cannot refuse. (Indeed, US public safety agencies face similar challenges as a commercial company rolls out a nationwide communications system that is supposed to serve first responders [14, 15, 22, 23].) This justification is probably especially common in smaller towns, where DSL, broadband cable, and 3G cellular services are less available. Our study of Pittsburgh uncovered some potential savings for city government, but these savings were small compared to the cost of WiMAN operations.
- *The presence of a WiMAN in some regions would advance high-priority policy objectives beyond Internet access.* In this case, even those who never use the Internet can benefit greatly from the WiMAN's presence, which can justify use of city resources. Some advocate WiMAN deployment as a means to increase economic development, attract new city residents, attract tourists, or provide educational opportunities. These are good examples of worthy objectives. However, Internet alone is no panacea for any of them. Internet is likely to be more useful as part of a broader plan. For example, many have sought ways to revitalize downtown Pittsburgh. A WiMAN alone is unlikely to achieve this objective, but in combination with serious efforts to improve parking, law enforcement, entertainment, and public transit, wireless Internet services both indoors and outdoors may encourage people to spend time and money in this neighborhood. This partially explains Pittsburgh's decision to build a WiMAN downtown first and consider the options regarding citywide deployment later.
- *A WiMAN can decrease social disparities by giving everyone access to the Internet.* It was once argued that everyone should have access to electricity as a matter of social equity rather than economical efficiency. Some make the same argument for broadband services, and promote WiMAN deployment as the solution. Section 6.5 showed reasons why low-income and sparsely populated neighborhoods may be left behind by WiMAN providers, and DSL and cable providers sometimes do the same. Affordability may also be an issue. However, if this is the primary goal, city leaders should investigate the possibility of less costly interventions that are specifically targeted at the excluded populations rather than the entire city. They should also evaluate whether wireless broadband access alone is the highest priority of the population in question.

And here are some of the worst reasons for substantial government involvement, all of which can be heard in today's debate.

- *Other cities have announced their plans for a WiMAN.* "If they have one, we should have one too."
- *City government can bring Internet services to citizens at lower cost than commercial companies.* There are cases where government provides services at lower cost, but it is hard to defend the general premise that government agencies, with all their obligations to be transparent to the public, are inherently more cost-effective than profit-seeking businesses with all their incentives to cut costs and attract customers. Nevertheless, there are city governments that believe they can provide services at no expense to taxpayers in areas where commercial companies see no possibility of profit, or that believe they can compete in a price war with commercial entities and easily prevail.
- *City government can offer WiMAN services to bring new money into city coffers.* Not only is this hard to do, but proponents may miss the ironic conflict between the goal of raising substantial revenues and the goal of offering services at lower prices than commercial providers.
- *The Internet is wonderful thing.* Food is also a wonderful thing, but grocery stores and restaurants meet citizen needs quite well much of the time. More is needed to justify substantial government involvement (e.g. food rationing to address temporary wartime shortages, subsidized school lunch programs to address economic disparities, etc.).

Clearly, careful assessment is needed to determine whether a given city government should play a substantial role in WiMAN deployment. Local leaders should make these decisions. Unfortunately, there is a movement to prevent them from doing so. Some argue that state law should preempt the wishes of city leaders and citizens. These advocates would require local governments to request permission from the dominant Local Exchange Carrier before adopting certain WiMAN policies. Such a law exists in Pennsylvania [24] and there are variations elsewhere [25]. Some members of Congress have indicated that local autonomy should be restored, but Congress has taken no action to date.

8 Conclusions

Every community must decide whether it is worthwhile to launch a WiMAN, and if so, which model to choose, and what roles should be played by government agencies, commercial companies, and non-profit organizations.

The cost to initially deploy a citywide WiMAN is considerable. Our estimate for Pittsburgh based on one sample architecture was $6.5 million, which is consistent with the cost per square mile in other cities. This initial cost dominates subsequent yearly costs of $2.2 to $2.7 million. We also developed a regression model to predict subscription rates. Our most effective revenue estimates were based on a city's median household income. Using this, we projected significant revenues in Pittsburgh, but given the paucity of directly relevant data, there is great uncertainty in these estimates. This uncertainty will decline as more cities deploy these systems.

Based on our analysis of NPV after five years of operation, we found that both a citywide vertically integrated monopoly and a citywide wholesaler with competing retailers could be financially sustainable in the City of Pittsburgh. However, the high uncertainty related to revenues means that an unsustainable outcome is within our margin of error. This, combined with the high initial costs, imposes a difficult challenge on would-be WiMAN providers in any city, particularly for commercial enterprises. Cities that want to increase the chances of achieving sustainability without running their own WiMAN might adopt interventions that reduce risk. Some such interventions would cost the city little if the WiMAN proves to be financially successful, but may cost a great deal if the WiMAN fails. For example, the City might provide direct funding only in the difficult start-up period or underwrite an initial advertising (or "education") campaign in return for a share of profits after the WiMAN becomes successful or in return for free services for government agencies or low-income households.

The potential for facilities-based competition among citywide providers was more bleak. Even with the uncertainties, it is unlikely that this model is sustainable in Pittsburgh or comparable cities. Indeed, this Wi-Fi-based network appears to have many qualities of a natural monopoly (in a WiMAN market, not a broadband market). This is ironic, given the conventional wisdom that the economics of wireless make it more conducive to facilities-based competition than cable or telephone systems. The reason for this anomaly is that Wi-Fi technology was designed to serve small areas, so blanketing an entire city with Wi-Fi requires a large capital investment. Very different results are possible with another wireless technology that operates at higher power and has greater range. Perhaps WiMAX [26] will someday fill this need. The economics would also be quite different if many Wi-Fi access points were purchased by consumers instead of an ISP, which is technically possible, but raises serious security issues that we are still trying to address [27].

Facilities-based competition may be unsustainable, but retail competition atop a single citywide wholesaler was found to be almost as financially sustainable as a vertically-integrated monopoly. This makes the wholesale-retail split a potentially attractive model for cities like Pittsburgh. A serious concern is that retail competition is highly dependent on rates charged by the wholesaler. We demonstrated quantitatively how a wholesaler maximizes its return by setting this payment at a point where only one retailer survives. Many cities have adopted this model with a commercial wholesaler such as EarthLink. Thus far, retail competition appears viable. However, it is no surprise that a wholesaler would encourage retailers to compete in the early days of a WiMAN, when marketing costs are high and revenues are low. These commercial wholesalers have incentive to raise their fees considerably when more people have subscribed. This danger is probably smaller if the wholesaler is a non-profit organization (as in Boston) or a government agency, but some danger remains. Note also that prohibiting the wholesaler from offering its own retail service, as some have proposed, does little to address the risk.

We have also considered a model where vertically-integrated providers operate only in the neighborhoods where profits are expected. Although the uncertainty in this analysis is considerable, we found that much of Pittsburgh would remain unserved. This is consistent with observation; various groups are now discussing the creation of neighborhood WiMANs in Pittsburgh's more affluent neighborhoods.[4] This implies a risk that Wi-Fi will exacerbate the digital divide rather than reduce it.

The above concerns raise a broader and largely-neglected issue: a city's *leverage*. Listening to the political debate might make one think that government leaders are free to decide what a city's WiMAN will look like, even if it is commercially-run. Will a WiMAN serve low-income neighborhoods? Will it allow competing retailers to operate over its infrastructure, and if so, will it charge those retailers reasonable prices? Will the WiMAN offer free or discounted services to the general public or to certain groups? Will it facilitate convenient access over a larger area by establishing roaming agreements with other WiMAN operators? Reasonable minds may differ on the importance of some of these questions, but we can agree that city government can influence the answers if and only if it has a significant source of leverage.

Leverage can take many forms. One important example is the ability to give a provider access to light poles, and other sites for access points. Our analysis shows that the leasing of this space is a significant part of operating costs. Moreover, the flexibility to place access points at optimal locations decreases deployment costs. However, in many cities (including Pittsburgh), city government directly controls access to only a small fraction of light poles.[5] Alternatively, a city can gain leverage by becoming the WiMAN's anchor tenant, perhaps in combination with other large institutions. Note that it is not enough for the City to eventually make heavy use of WiMAN services as some city governments might prefer. To gain leverage as an anchor customer, the City must enter into a long-term commitment to be a heavy user, ideally well before the WiMAN provider has invested much money in the build-out. In some cases, launching a citywide WiMAN may be a community activity rather than just a government activity. Civic-minded companies and non-profit organizations can play an important role. They can exert leverage by providing funding, granting access to useful resources like light poles or fiberoptic backbones, becoming

[4] For example, merchants in the high-income Pittsburgh neighborhood of Shadyside have established a Wi-Fi system that covers many shops, bars, restaurants, and homes.
[5] In Pittsburgh, many light poles are controlled by the power company, Duquesne Light.

anchor customers, or even becoming a non-profit wholesaler. If city government and other players cannot employ these or other sources of leverage, and will not pay the considerable cost of building a WiMAN, the city should content itself with whatever WiMAN model the market produces. In the long term, this is unlikely to be a wholesale-retail model, or to cover the entire city.

Finally, we note that some city governments have reason to become substantially involved in WiMAN efforts, and some do not. This can depend in part on whether a WiMAN advances high-priority policy objectives that go beyond Internet access, whether city government can significantly cut costs or improve services if a WiMAN were available, and whether the city can find less costly or more compelling ways to address issues of disparity. Ultimately, this should be a local decision and current laws that preempt these local decisions, like the one in Pennsylvania [24] and elsewhere [25], should be overturned.

9 Project History and Acknowledgements

There has been great interest among the leaders and residents of Pittsburgh regarding the possibility of broadband wireless services that serve the entire city. From August to December of 2006, Professor Jon Peha and 21 CMU students conducted a study to provide useful information and analysis to the Pittsburgh City Council, and other city leaders. A subset of that group continued research into Spring and Summer of 2007, and eventually wrote this paper. The author wishes to thank

- Councilman Bill Peduto, who has long been active in this area, who encouraged CMU to conduct a study, who served as the primary representative of our client, the Pittsburgh City Council, and who convened a formal City Council hearing to discuss our results.

- The review panel of our initial study: Rodney Akers (City of Pittsburgh, City Information Systems), Chuck Bartel (CMU Computing Services), Dan Cohen (Cohen Telecommunications Law Group), Michael Edwards (Pittsburgh Downtown Partnership), Richard Emenecker (Comcast), Larry Gallagher (CMU Computing Services), C. D. Jarret (Verizon), Timothy Pisula (US Wireless Online), Frank Polito (Comcast), Jared Roberts (Pittsburgh Technology Council), Howard Stern (City of Pittsburgh, City Information Systems), Chris Sweeney (Three Rivers Connect), Alex Thomson (Houston Harbaugh P.C.), Jason Tigano (Office of Rep. Mike Doyle, US Congress), Jesse Walker (Intel)

- The 21 students who participated in the initial study. Undergraduate project participants: Olivia Benson, Beth Gilden, Safa Maryam Haque, Neal Johnston, Oliver Lim, Elizabeth Lingg, Jeff Mori, Bryan Ovalle, Russell Savage, Shomari Smith, Alan Tan, Ray Terza, Jigar Vora, Bradford Yankiver, Eleanor Zimmermann, Kenny Youn. Graduate student project managers: Srinivas Adavi, Daniel Gurman, Chris Ruch, Steve Sheng.

- The 4 students who continued research beyond Fall 2007, and were thus co-authors of [1]: Beth Gilden, Russell Savage, Bradford Yankiver, Steve Sheng.

10 References

[1] J. M. Peha, B. E. Gilden, R. J. Savage, S. Sheng, B. L. Yankiver, “Finding an Effective Sustainable Model for a Wireless Metropolitan-Area Network: Analyzing the Case of Pittsburgh,” *Proceedings of 35th Telecommunications Policy Research Conference* (TPRC), Sept. 2007. http://www.ece.cmu.edu/~peha/wiman.pdf.

[2] W. Lehr, M. Sirbu, and S. Gillett, "Wireless is Changing the Policy Calculus for Municipal Broadband," *Government Information Quarterly,* vol. 23, pp. 435-453, 2006.

[3] W. Lehr, M. Sirbu, and S. Gillett, "Municipal Wireless Broadband Policy and Business Implications of Emerging Technologies," presented at *Competition in Networking: Wireless and Wireline*, London Business School, April 13- 14, 2004.

[4] S. Gillett, W. Lehr, and C. Osorio, “Local Government Broadband Initiatives” presented at *Massachusetts Institute of Technology Program on Internet and Telecoms Convergence*, September 18, 2006.

[5] Federal Trade Commission, “Municipal Provisions of Wireless Internet,” Sept. 2006. http://www.ftc.gov/os/2006/10/V060021municipalprovwirelessinternet.pdf.

[6] M. Hughlet, “Chaska Wi-Fi Experience Offers Valuable Lessons,” *Government Technology*, 29 April 2007. http://www.govtech.com/gt/articles/100100.

[7] Muniwireless, “One year later, St. Cloud Citywide Wifi network shows impressive results,” March 2007. http://www.muniwireless.com/article/articleview/5762/1/23/.

[8] Boston Wireless Task Force, “Wireless in Boston,” Boston Massachusetts, July 2006. http://www.cityofboston.gov/wireless.

[9] San Francisco Tech Connect, “San Francisco Wireless Network Final Agreement,” January 2007. http://www.sfgov.org/site/uploadedfiles/dtis/tech_connect/process/FinalAmendedNetworkAgreement.pdf.

[10] Muniwireless. “Wireless Philadelphia-EarthLink Contract: an analysis,” April 2006. http://www.muniwireless.com/article/articleview/5130/.

[11] DailyWireless.org, “Portland Chooses MetroFi for 134 Mile Cloud,” *DailyWireless.org*, 18 December 2006. http://www.dailywireless.org/2006/04/12/portland-chooses-metrofi-for-134-mile-cloud.

[12] S. Towns, “Parking Authority Goes Wireless,” *Government Technology,* 24 June 2002. http://www.govtech.com/gt/articles/16994.

[13] “Wifi Parking Meters Help to Cost-Justify Houston Rollout,” *W2i Digital Cities Convention,* March 2006.

[14] J. M. Peha, "The Need for Fundamental Reform in Public Safety Spectrum and Communications Policy." New America Foundation, Working Paper 15, Oct. 2006. http://www.newamerica.net/events/2006/from_tv_to_public_safety.

[15] J. M. Peha, "Fundamental Reform in Public Safety Communications Policy," *Federal Communications Bar Journal*, Vol. 59, No. 2, March 2007, pp. 517-546.

http://www.ece.cmu.edu/~peha/safety.html.

[16] J. B. Horrigan, “Home Broadband Adoption 2006,” *PEW Internet & American Life Project*, 28 May 2006. http://www.pewinternet.org/pdfs/PIP_Broadband_trends2006.pdf.

[17] United States Census 2000. http://www.census.gov/main/www/cen2000.html.

[18] Wireless Philadelphia Executive Committee. “Wireless Philadelphia Business Plan,” February 2005.
http://www.phila.gov/wireless/pdfs/Wireless-Phila-Business-Plan-040305-1245pm.pdf.

[19] City of Minneapolis, “Wireless Minneapolis: Municipal Broadband Initiative Business Case,” Minneapolis Minnesota, Case Study. February 2006.
http://www.ci.minneapolis.mn.us/wirelessminneapolis/MplsWireless_BusinessCase_V3.pdf.

[20] "We're Wi-Fi / Downtown Pittsburgh Rocks the Internet." *Pittsburgh Post-Gazette*, 14 July 2006. http://www.post-gazette.com/pg/06195/705733-192.stm.

[21] M. J. Balhoff and R. C. Rowe, “Municipal Broadband: Digging Beneath the Surface,” September 2005.
http://www.balhoffrowe.com/pdf/Municipal%20Broadband--Digging%20Beneath%20the%20Surface.pdf.

[22] J. M. Peha, Testimony for the House Subcommittee on Telecommunications and the Internet, Hearing on Innovations in Interoperability, March 2007.
http://www.ece.cmu.edu/~peha/safety.html.

[23] U.S. Federal Communications Commission, Second Report and Order, in the Matter of Service Rules for the 698-746, 747-762 and 777-792 MHz Bands. WT Docket No. 06-150, August 10, 2007. http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-07-132A1.pdf.

[24] The General Assembly of Pennsylvania, Pennsylvania, Act 183, 2003.
http://www.legis.state.pa.us/cfdocs/legis/PN/public/BtCheck.cfm?txtType=HTM&sessYr=2003&sessInd=0&billBody=H&billTyp=B&billNbr=0030&pn=4778

[25] A. H. Tapia and J. A. Ortiz, “Municipal Responses to State-Level Broadband Internet Policy,” *Proceedings of 34th Telecommunications Policy Research Conference* (TPRC), Sept. 2006. http://web.si.umich.edu/tprc/papers/2006/554/TPRCfinal_pdf.pdf.

[26] Wimax Forum. http://www.wimaxforum.org.

[27] J. M. Peha. "Emerging Technology and Spectrum Policy Reform." *Proceedings of United Nations International Telecommunication Union (ITU) Workshop on Market Mechanisms for Spectrum Management*, Geneva, Switzerland, January 2007.
http://www.ece.cmu.edu/~peha/policy.html.