Municipal Wireless Broadband: Policy and Business Implications of Emerging Access Technologies

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Abstract

Two trends are converging: growing interest in municipal networking as a response to perceived market failure (inadequate investment/competition in broadband last mile facilities); and revitalized interest in wireless last-mile technologies (BFWA, WiFi, 3G). Historically, the justification for municipal provisioning of "last mile" infrastructure has focused on the natural monopoly aspect of wireline infrastructure (*e.g.*, FTTH or small size of market). Growing interest in WISPs, municipal hot spots, and access to public buildings/space for siting base stations suggest new and expanded opportunities or roles for community ownership of last-mile services. It is clear that wireless technology changes the economics of deploying last mile infrastructure, but it is less clear what this means for public policy towards local community provisioning initiatives. This paper examines the implications of emerging wireless technologies for the policy debate over whether municipalities should be playing an active role in providing last mile broadband services, and if so, what the nature of that role should be. Public involvement in provisioning last mile infrastructure will have a direct impact on private sector competition. We provide evidence of emerging trends and a framework to help structure the policy debate. Our analysis shows that the case for a public role is complex and that the optimal policy is likely to depend critically on the type of wireless infrastructure that is being deployed and the objectives for the system.

I. Introduction

In the United States and abroad, there has been renewed interest in local governments playing a more direct role in providing communications infrastructure and services in their communities.[1] A number of forces have contributed to this trend. First, there is the perception that access to advanced communication services, including

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[1] See, Gillett, Lehr, and Osorio (2003), Barranca (2004), or Clark and Baker (2003).

broadband data services, constitutes essential infrastructure that is critical for the economic and social health of communities. Continuing innovation in computing and communications technology and the growth of the Internet and eCommerce have made data services increasingly important in modern life.

Second, regulatory reform and industry convergence during the mid-1990s has changed the dynamics of competition in last-mile access services. Open access rules have reduced entry barriers and technical and industry convergence have enhanced opportunities for cross-platform competition (*e.g.,* fixed line v. mobile telephone, telephone v. cable television, POTS v. Voice-over-IP).[2]

Third, in spite of the great promise and hopes for increased competition and ubiquitous availability of inexpensive broadband local access services, the crash of the dot.coms and the global recession in telecommunications that began during 2000, raised concern that the private-sector might fail to invest widely enough or fast enough in delivering the needed next-generation facilities.[3]

Fourth, and finally, there is growing awareness that next generation communications infrastructure, capable of delivering a bundle of high-speed services, may be a natural monopoly in at least some communities.[4]

At the same time, the world of wireless services is being transformed with important implications for the entire communications services value chain. Mobile service providers are deploying broadband wireless data services via so-called "3G" networks.[5] At the same time, the proliferation of wireless LAN (WLAN) technologies like WiFi are supporting wireless data services in homes and businesses, and are providing new types of "hot spot" public infrastructure.[6]

Advances in wireless technology (including ultrawideband, smart antennas, multiuser detection theory, and ad hoc routing) have dramatically expanded the range of potential architectures, technologies, and RF frequencies which are available for

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[2] In the United States, the Telecommunications Act of 1996 (TA96) opened last-mile telephone networks to competition with mandatory resale and unbundling provisions. Analogous pro-competitive regulatory reforms were underway around the globe (in the European Community, UK, Japan, etc.).

[3] See Baller and Stokes (2001).

[4] See CSTB (2002) or Lehr and Hubbard (2003).

[5] So-called "2.5G" services that support sub-100kbps data services began to be offered in 2002 (see "Verizon launches first U.S. '3G' Network," 2002). Only recently, however, have true-3G services offering data rates of several hundred Kbps become available in selected markets in the United States (see "Verizon Wireless Makes Strides With Planned BroadbandAccess 3G Network Expansion," 2004); and 4G services offering data rates of several Mbps are beginning to be test marketed (see "Nextel debuts wireless broadband in North Carolina," 2004). At these higher data rates and with coverage that is expected to extend over wide-portions of the mobile carriers serving areas, mobile broadband services will increasingly appear as viable substitutes to fixed line DSL or cable modem offerings.

[6] See Lehr and McKnight (2003) or Werbach (2003).

developing wireless broadband access infrastructure.[7] Convergence of wireless and wired data networks and the trend towards ubiquitous computing are making wireless services an increasingly important component in,[8] complement to,[9] and potential substitute for more traditional telecommunications access infrastructure.[10]

These developments in wireless services are changing the landscape for municipal networking. A better understanding of the intersection of these converging trends will help local governments craft policies for supporting increased access to broadband data services. As we explain further below, wireless may increase *or* decrease local government's incentives to directly invest in providing municipal communication services. On the one hand, the opportunities for new types of competition from investor-owned firms reduce the need for direct government involvement. On the other hand, wireless can enhance opportunities for local governments to promote economic development, expand the accessibility of services it is already providing, and can lower the costs of extending ubiquitous coverage in those areas that remain underserved. In the absence of wireless alternatives, local communities that were interested in providing communications infrastructure were often deterred by the high costs of deploying and servicing wired outside plant facilities. In the "pre-wireless" world, the communities that have been most likely to make the leap into providing telecommunication services have been those with Municipal Electric Utilities (MEUs)[11] accustomed to pulling wire. Wireless expands the range of communities that are finding it feasible to consider offering communication services, and is expanding the range of trajectories by which local communication services are evolving.[12]

Whether municipal entry is desirable – compatible with private sector competition or better than private alternatives – remains a hotly debated question. Incumbent cable television and telephone companies have often opposed municipal entry into communication services as representing an unfair form of government-subsidized competition.[13] On the other side, proponents of local autonomy, community-based networking, and economic development have argued in favor of a larger role for local government in providing communications services.[14] In the United States, a number of

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[7] The diversity in wireless architectures and the implications of such diversity for business models and policy is discussed further below.

[8] For example, WLANs can extend the physical reach of wired infrastructure.

[9] For example, wireless data services expand the range of services that can be offered by 2G voice-telephony mobile service providers.

[10] For example, 3G mobile services may compete with fixed line telephone and broadband data services; or alternatively, broadband wireless fixed access (BFWA) technologies can provide an alternative to the wire-based local access facilities typically deployed by incumbent telephone and cable television operators.

[11] See Gillett, Lehr, and Osorio (2003) and Osorio (2004).

[12] See Sandvig (2004) for discussion of wireless cooperatives. Also, even among MEU communities, wireless is affecting strategies for deploying infrastructure.

[13] See Rizzutto and Wirth (1998) or Sappington and Sidak (2003).

[14] See Baller and Stokes (2001), Strover, Chapman, and Waters (2003), Barranca (2004), or Gonick (2004).

states have passed laws restricting local government entry into communication services and the debate is on-going as to whether public policy ought to promote or restrict municipal entry.[15] Regardless of one's position on this debate, it is important to understand the impact of wireless.

Additionally, when one views a municipal network as an alternative model for "edge-based" network infrastructure to evolve, a better understanding of wireless municipal networking is important for understanding the economics for broadband access and for possible ways in which broadband infrastructure may evolve. For example, the debate over spectrum reform has focused on the benefits of adopting a regulatory regime based on licensed or unlicensed (so-called, "open access") spectrum.[16] This has been cast variously as a debate between "property rights v. commons" or as "service provider-based infrastructure v. end-user controlled networking."[17] The success of WiFi and "free nets," the growth of open source computing, and growing interest in new types of mesh and ad hoc networking technologies are helping to fuel interest in alternative industry structures for supporting our communications infrastructure. At the risk of over-simplification, the debate may be caricaturized as a battle between the traditional service provider business model for providing network services versus one based on end-user equipment. In the former, a service-provider owns a large, fixed/sunk cost network that it uses to provide shared access services to a large number of end-user nodes in return for usage-fees. In the latter, the edge-nodes are both end-users and relay points that may be interconnected into a mesh to provide wide-area connectivity. In the most extreme version, there is no centralized network coordination. Instead, the "network" grows "virally" as end-users add equipment to the network.

In the balance of this paper, we examine the traditional economic justifications for municipal provisioning of local broadband access services (Section II). This provides a basis for understanding how emerging trends in wireless change the decision-making calculus for municipal entry. Next, we describe in greater detail the wireless technology trends that define the space of alternatives within which local governments are formulating broadband policies (Section III), and then discuss some of the many ways in which municipal governments are exploring the opportunities presented by wireless (Section IV).

In Section V, we focus on the implications of these converging trends for policy and industry economics associated with municipal entry into telecommunications services. First, we note that wireless, by lowering costs, helps stimulate demand for municipal investment in computing and communications infrastructure and services,

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[15] In the United States, there has been an intense debate regarding whether the municipal entry into telecommunications is protected under the TA96. A recent Supreme Court decision concluded that municipal entry is not protected under the TA96, which allows individual states to pass legislation blocking municipal entry. A number of states have already passed such legislation and more are in the process of doing so (see, Nixon v. Missouri Municipal League, 2004).

[16] See Lehr (2004).

[17] See Benkler (2002) or Werbach (2003).

which absent countervailing effects (*e.g.,* regulation that blocks such entry) suggests that the municipal role in providing local communication services is likely to increase. Second, we note that the principal economic justification for municipal provisioning – the "market failure" rationale – is impacted in complex and ambiguous ways by wireless. This suggests a need for further research, and caution when considering evaluating policies that restrict *or* encourage municipal entry. Third, we note that the diversity of wireless options available means that municipalities face a complex decision environment. No single wireless approach is best in all circumstances, and the choices of a technology, architecture, and business model will be interrelated with each other, and with the communities decision horizon and objectives. For example, a community may decide to deploy a MAN-sized Broadband Fixed Wireless Access (BFWA) based on a technology with relatively large cell sizes (as exemplified by the technology from Alvarion) or one based on of the mesh-style technologies associated with smaller, more dense cell sizes (as exemplified by the technology from Tropos, MeshNetworks, or Motorola's Canopy system). Alternatively, the community may limit its role to assisting in the promotion of grass-roots efforts to extend broadband access via viral growth via interconnected private and public hot spots.

Section VI summarizes our key conclusions and suggests directions for future research.

II. Understanding the Municipal Role in Providing Communications Infrastructure

Municipal entry into communication services may be justified economically in three basic ways: (1) as a response to a market failure; (2) as part of the local government's role in providing basic infrastructure services; or (3) as a way to opportunistically take advantage of scale or scope economies afforded by investments or services that were put in place for another reason.

A. Market failure rationale

According to the "market failure" rationale, government intervention may be justified if private alternatives are perceived to be inadequate. The costs of deploying infrastructure and operating services may be too high relative to the revenue that can be expected so that an insufficient number of private sector providers enter the market.

In the most extreme cases, it may be uneconomic for *any* private carrier to offer service. Or, it may be a natural monopoly/oligopoly that results in inadequate service provisioning. In either case, the "market failure to support adequate competitive alternatives" can provide a justification for municipal ownership. Obvious examples of such communities are rural communities (low density so high cost) and economically undeveloped (low ability to pay for services).

In the US, it is rare to find communities without any private sector telephone service, however there are a number of communities that are not served by wired broadband (neither DSL nor cable modem) or video distribution (no cable tv). Among the communities that have private cable or broadband providers, there are a number that are unsatisfied with the quality/price of service from the private carriers, and look to municipally-owned providers to expand competitive choices.

Finally, in light of the need for new investment required to put in place next generation broadband infrastructure (*i.e.,* supporting data rates in the 10s to 100s of Mbps instead of today's generation of DSL/cable modem services which support at most a few Mbps) and in response to the global telecommunications recession that began in 2000 and the collapse of much of the competitive local exchange (CLEC) industry, there is a concern that the private sector will fail to invest in providing for next generation services or that the economics of competition for next generation services will increase the likelihood of a market failure (*e.g.,* while DSL/cable modem-grade broadband *may* be competitive,[18] FTTx may remain a natural monopoly[19]).

Moreover, if there is a natural monopoly, it is unclear where this might occur. For example, it might be in the final access connection or at some point further up the network. For example, the natural monopoly may arise at the level of the individual household connection (the so-called, "last-mile") or it may occur at the point of interconnection with wider-area networks (the so-called, "middle-mile"). In the former case, it may be uneconomic for multiple infrastructure providers to deploy fiber all the way to the home or even into the neighborhood. Because of the high fixed and sunk cost component associated with operating wired local access facilities, whoever deploys first may realize critical first-mover advantages that deter subsequent entry;[20] or alternatively, even if both the cable carrier and local telco deploy neighborhood fiber, it may turn out that the resulting competition ("Bertrand") is so severe that neither carrier can realize revenues sufficient to sustain investment in expanding capabilities and services. If this is the case, municipal ownership of the fiber infrastructure may make sense.

It is also possible that there may be a market failure associated with providing "middle mile" services. For example, while each house may be adequately served with far less capacity than is provided by a FTTH system, there may be significant economies of scope and scale associated with aggregating traffic from multiple homes and connecting these neighborhoods to wider area networks. These backhaul costs are an important operating cost for small-scale ISPs. If the market failure is associated with a "natural monopoly" in middle-mile costs, then it may make sense for the municipality to own the local access backbone infrastructure, and for it to provide this as a platform for

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[18] In the near future, there will be a growing number of deployments of broadband-over-powerlines, 3G mobile services, and enhanced satellite-based wireless data services that will offer alternatives for today's generation of wired DSL/cable modem services at data rates in the range of a few 100Kbps to a few Mbps. The ability of these competitors to scale to higher data rates and the economic viability of sustaining robust competition among higher data rate access platforms (offering speeds in the 10s to 100s of Mbps or even Gbps) remains suspect.

[19] FTTx stands for Fiber-to-the-x where "x" may be the home (FTTH), the curb (FTTC), or to some other location in the neighborhood. Increasingly, traditional wireline carriers and others are deploying fiber transmission facilities that can provide the basis for very high speed feeder and access services.

[20] See Banerjee and Sirbu (2003)

competitive retail entry to provide last-mile and end-to-end service connectivity to individual households or businesses.

The existence of a "market failure" need not imply that the municipality needs to own and operate a local communications network. Indeed, the long-held belief that local telephone services and cable television constituted natural monopolies has justified public utility regulation of incumbent local telephone companies and municipally-franchised cable television operators. While public ownership *is* an alternative, it has been more common to use subsidies and restrictive regulation (*e.g.,* universal service, carrier-of-last-resort obligations, rate of return or price cap retail price regulation) to control the behavior of investor-owned utilities. A similar approach has been common in electric power, where most power is provided by investor-owned utilities; although with power, there are a large number of communities that are served by MEUs.[21] Even when the telephone company has been publicly owned (as was the case in many countries outside the U.S.), its scope of operation and regulation has been national or at least encompassing multiple communities.[22] Thus, the role of local government in providing communication services is relatively new.

Furthermore, even if a local government does decide to invest in local access infrastructure, this does not mean that the municipality needs to provide end-to-end retail services. There are a variety of business models available for how a municipality may offer such services. These include:

- (1) Retail service model: the municipality offers retail services to consumers over infrastructure that it owns and operates. Examples of these include MEUs that are currently offering advanced communication services to local businesses and residences such as BELD in Braintree, MA.[23] With wireless, there are additional community entities (other than an MEU) that could participate in owning and operating such services, including a local educational institution.
- (2) Wholesale service model: the municipality owns and operates a local access network which provides a wholesale access platform for retail ISPs and other communication service providers to use. As noted earlier this may be a complete Metropolitan Area Network (MAN), a back-bone (middle-mile) local access network, or last-mile access network. The "wholesale" service might be limited to dark fiber, or include advanced transport services (*e.g.,* layer 2 VLANs, MPLS VPNs, or routed IP traffic). Under the constraint of state law which requires open access, a number of utilities in Washington state are deploying open access infrastructure (*e.g.,* Grant County, WA).[24]

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[21] MEUs first emerged to provide street lighting over a century ago, and then later, as part of efforts to provide power to under-served (mostly rural) areas (see Osorio, 2004).

[22] There are a large number of small independent local telephone companies in the United States, however most of these are investor-owned, and collectively, these account for a relatively small number of the total access lines served.

[23] See Gillett, Lehr, and Osorio (2003) for numerous examples.

[24] There are many ways in which the wholesale model may be implemented, and the discussion of open access regimes is beyond the scope of this paper. See Gillett, Lehr, and Sirbu (2004, forthcoming).

- (3) Franchisee model: the municipality contracts with a private firm to build and operate the facilities. This is similar to the traditional model of municipally-franchised cable television service, but wireless alters the range of players that might be considered and the architectures/services that might be offered.
- (4) Real estate model: the municipality provides access to conduit or public rights-of-way. In the wired-world, this includes access for stringing or burying cables; while in the wireless world, it includes locations for siting antennas. In this model, the municipality partners with private providers to deliver end-to-end services to consumers.
- (5) Coordination model: the municipality can provide a nexus for demand aggregation (*e.g.,* buyer groups)[25] or for coordinating efforts of community networking (WiFi cooperatives).[26]

The goal of this paper is not to determine whether municipalities should enter, or if they choose to enter, how best to enter. Instead, the goal is to explore how different wireless technologies might impact these decisions.

B. Basic infrastructure rationale

According to the "basic infrastructure" rationale, municipal networks may be justified as just another example of community provision of basic infrastructure services. These are services that are (1) used by everybody and are perceived as essential services; (2) may be a natural monopoly or have a public goods aspect (*i.e.,* excluding non-paying users is costly); and (3) provide important spill-over benefits that are central to or complementary to the role of government. Obvious examples include roads and water and sewage systems. While these *could* be provided via regulated private contractors, such an approach is relatively rare. Other basic infrastructure services include electric power and gas distribution and public transportation. With these services, we see examples of both public and private sector provisioning. For example, while most electric power is provided via investor-owned utilities, there are still a large number of communities with municipal electric companies. Similarly, there are a number of communities with municipally-owned telephone or cable television companies.[27]

Because basic infrastructure is perceived as essential to economic activity (*i.e.,* it is used by most businesses), ensuring adequate access to such services is viewed as necessary to promote economic development goals. Additionally, access to communications and media services is often viewed as important for a number of social goals. For example, it can help maintain community cohesion, support democracy and the functioning of our civil society. Access to advanced communication services can facilitate access and political participation by the elderly or handicapped, can enhance

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[25] See Gillett, Lehr, and Osorio (2003). Typically, local government is one of the heaviest local users of telecommunication services and it can use its monopsony power as an anchor tenant to induce private carriers to provide services.

[26] See Sandvig (2004).

[27] ANY DATA ON HOW COMMON? HOW MANY OF ICOS ARE MUNICIPALLY-OWNED?

access to educational opportunities, and can support communications between local government and institutions (churches, libraries, recreation) with the citizenry.

While the "basic infrastructure" rationale appears distinct, it may be subsumed as just another example of a "market failure" rationale.[28] For example, the market failure may also arise if the benefits of providing broadband services are not easily appropriated by a private provider. Because of positive network externalities,[29] public goods aspects,[30] and other spillover effects.[31]Therefore, in the balance of this paper, we will focus on the impact of wireless on the incidence and appropriate response to a perceived market failure, while accepting that communities may appropriately regard access to high-speed broadband access services as an important element in basic infrastructure, akin to access to water, power, and roads.[32]

C. Opportunistic rationale

The third rationale – "opportunistic entry" – is associated with situations where the municipality is doing something else that makes it relatively easy (low cost) for them to expand into offering communication services. In effect, the municipality's entry into communication services is able to take advantage of scale and scope economies because only an incremental investment is required to expand into communication services.[33]

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[28] Since economists typically focus on efficiency and generally prefer markets to governments for allocating scarce resources, there is a common presumption that market-based provisioning of services is to be preferred whenever it is feasible. However, efficiency is not the only concern for government and the private-ownership/capitalist paradigm that governs the allocation of most services in the economy is neither the only nor necessarily the most efficient mechanism for allocating scarce resources. Thus, while we do not do so here nor believe that it is generally the case, it is possible to support an economic argument in favor of public ownership of infrastructure *even* when such ownership substitutes for or precludes private ownership.

[29] These arise when the value of the network is higher to each subscriber when the number of subscribers increases. A local broadband network may be more valuable to everyone if it is really ubiquitous. For example, schools and community groups could use such an ubiquitous network and be assured that everyone in the community can be reached, and thereby avoid the cost of providing announcements via other channels. With a new service such as "broadband," early adopters subsidize later adopters and the presence of such positive network externalities may result in a market failure.

[30] A hot-spot zone in a downtown area that encourages increased shopping traffic offers public goods benefits since stores that do not support the hot spots but are in the coverage area and benefit from the traffic will still derive benefit.

[31] Broadband benefits that enhance community quality of life, political participation, and other social goals that may not be translated into potential revenue for a private service provider.

[32] There is a long-standing debate over how much bandwidth is enough. If one takes the view that basic telephone service is all that one needs, then we already have effective competition and ample alternatives in most locales in the United States. Implicit in the discussion here is the belief that the current generation of broadband services are insufficient to meet the "basic infrastructure" standard that will prevail in the future and that additional investment in new infrastructure is needed to meet this demand.

[33] Opportunistic, low-cost entry may also arise as a consequence of some other special circumstances. For example, a community may be able to take advantage of special development funds targeted at IT investments, or of a special circumstance. Examples of the latter include the need to upgrade IT capabilities

The most obvious source of such investments is leveraging off of information technology (IT) investments made for the local governments internal use. For example, the municipality may have installed a backbone fiber network to provide data communication services among government buildings, local schools, and libraries. As IT has become more important in business operations for both private and public enterprises, and with increased interest in eGovernment to increase government efficiency and expand access, local governments have been increasing their investments in IT as part of their normal operations.

Additionally, many MEUs have been motivated to deploy advanced communications infrastructure in order to better manage their electric power business (*e.g.,* SCADA, automatic meter reading, on-line access for customer billing and service).[34] Once this capability is in place, the incremental cost of offering communication services is obviously lower. Electric power deregulation during the 1990s and the threat of increased competition have increased MEUs' interest in tapping new revenue streams and to exploit potential scale and scope economies to lower average costs.

Furthermore, with declines in the cost of deploying fiber optic cable, robust forecasts for the growth in demand for high capacity transport services, and the high cost of installing wired infrastructure (acquiring rights-of-way, digging up streets, and installing conduit), utilities of all sorts (water, electric, gas) and local businesses (campuses, malls, new housing/office developments) have found it opportunistically desirable to install dark fiber when outside plant construction is occurring for other reasons. As we discuss further below, wireless can play an important role in connecting such fiber to end-users and other network services.

In contrast to wired infrastructure which provides connectivity between specific physical locations (where the wire terminates), wireless infrastructure provides a bubble of connectivity that can blur the boundary between public and private infrastructure, or infrastructure installed for one purpose and its extension for use to serve another. For example, many communities already provide wired access to data services for their internal operations, and for the community via wired connections to the schools and public libraries, including public-access terminals for use by students or by the general public. In addition, public safety services (fire, police, and emergency care) all require access to information services, and in many cases, this includes access to mobile data services. Wireless makes it feasible to extend the reach and access to the general

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for an upcoming Olympics; or the desire to deploy an advanced sensor net in communities near the US-Mexico or US-Canada border to enhance Homeland Security.

[34] Osorio (2004) shows that MEUs that have upgraded their facilities to support advanced IT-management of their electric power business are more likely to also offer telecommunication services. Similarly, the cable television operators that were most aggressive early on in offering two-way broadband data services, were those carriers that had earlier been more aggressive in installing two-way capabilities to address the perceived threat from direct broadcast satellite services.

community for services that may originally have been installed solely to serve a specific government office, school, or even, the public safety services.

In the next section, we consider how the landscape for wireless technology is changing. This will provide the basis for addressing how wireless alters the traditional rationales, public policy, and strategies for municipal entry into broadband communication services.

III. Changing Landscape for Wireless Technology

In recent years, wireless technologies have made substantial advances that have made it feasible to deploy wireless communications offering improved capabilities, including supporting higher data rates, offering more flexibility with respect to RF spectrum used, and increased reliability in adverse environments (*i.e.,* improved operation in non-line-of-sight environments, ability to support reliable communication in low signal-to-noise circumstances, reduced power operations). These technologies are being incorporated into a diverse array of wireless services and products, including 3G mobile networks, WLANs, BFWA MAN networks, and satellite nets. End-users and service providers are deploying myriad types of wireless networks (PANs, MANs, and WANs) to complement and substitute for wired infrastructure.[35] All of this wireless technology is changing the landscape for broadband access. To better understand some of the economics of alternative wireless technologies, it is necessary to understand a bit more about the wireless broadband landscape.

A. Understanding the key design parameters

“Wireless broadband” encompasses an almost dizzying array of technologies with widely disparate economic and performance characteristics. Technologies vary across a number of distinct dimensions, including:

- What part of the spectrum they use;
- Antenna characteristics;
- How bits are encoded at the physical layer;
- How multiple users share the available spectrum;
- Maximum bit rate and reach;
- Approach to providing backhaul from a wireless access point; and,
- Price

Each vendor and service provider makes different decisions with respect to these key variables that affect how their product is situated in this multidimensional feature space, resulting in systems with widely varying characteristics. Let us take a closer look at the range of variation along each of these dimensions.

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[35] For example, Wireless Local-Area-Networks (WLANs) using WiFi can complement wired infrastructure by lowering the cost of supporting the last couple of hundred feet of connectivity and by offering mobility. Alternatively, WiFi connected to DSL or Cable modem fixed line services may be a substitute for wide-area 3G mobile data services and BFWA systems can substitute for fixed line local access services.

1. Spectrum

Wireless broadband access systems have been deployed at frequencies ranging from 400 MHz to about 30 GHz. Different parts of the spectrum have dramatically different physical properties.

For example, at 30 GHz, signals attenuate rapidly with distance, are limited by rainfall, and are limited to Line of Sight (LOS) deployments. These frequencies have been used most often as a substitute for high-capacity point-to-point links such as are used by service providers and large enterprise customers to connect backbone nodes or buildings. Because of the relative abundance of unencumbered spectrum at higher frequencies, it is feasible for operators to secure licenses for large bandwidth channels which permits these systems to operate at high bit rates per channel. This is in contrast to the limited bandwidth allocated to each license for such lower frequency services as mobile telephone. In the 1990's, vendors such as Teligent, Winstar, and ART deployed so-called Local Multipoint Distribution Services (LMDS) using these higher frequencies to link office buildings in downtown areas with 150 Mbps or higher speed services that could compete with optical fiber. However, the equipment costs for deploying these technologies were high using earlier generation digital processing technology and the market was limited to large enterprise and service provider customers. Because of these and other difficulties, virtually all of these companies went bankrupt, and LMDS services are no longer expected to play a major economic role.

In recent years, reductions in the costs of high-speed digital processing technology and other improvements have dramatically reduced the costs and performance of wireless point-to-point transmission services that operate in the upper portion of the RF spectrum. For example, the FCC recently issued an order setting forth a liberalized licensing regime for millimeter wave systems which operate above 70GHz[36] and a number of new firms are selling low-cost Free Space Optics systems (*i.e.,* fiber-optic systems that use optical-frequency lasers to transmit through the air instead of through cables) that can be deployed to support Gbps communications using desktop systems costing a few thousand dollars to interconnect downtown buildings.

While the physics of operating at frequencies above 10GHz have not changed, the costs of deploying affordable services have declined substantially and the range of potential uses has expanded.

In contrast, at lower frequencies, below say 10GHz, the spectrum is much more encumbered by legacy incumbents and licensees are typically limited to smaller bandwidth channels. However, the spectrum is less susceptible to interference from rainfall and can operate in Non-Line-of-Sight (NLOS) situations (*e.g.,* reach inside buildings to a desktop or mobile antenna), and requires less costly technology.[37] Several

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[36] See FCC Docket WT-146 (2003).

[37] The lower frequency systems require lower speed digital processors which are lower cost. Additionally, the NLOS operation makes it easier to install customer premise equipment in contrast to systems that

bands—at 900 MHz, 2.4 GHz and 5 GHz—are available for unlicensed use, allowing Wireless ISPs (WISPs) to deploy MAN-sized networks without first seeking a license from the FCC, which substantially reduces the entry barriers faced by such carriers. Earlier, a number of service providers sought to deploy MAN-sized wireless networks in the licensed Multipoint Multimedia Distribution Service (MMDS) band at (2.5-2.7 GHz) to support WISP-like services. Sprint and Nextel are the largest license holders for this spectrum.

The lower the frequency, the better the penetration of buildings or of foliage, and immunity to rainfall, but there is less bandwidth available: 28 MHz in the 900 MHz unlicensed band, 85 MHz in the 2.4 GHz band and 300 MHz (soon to be 500 MHz) in the 5 GHz UNII (Unlicensed National Information Infrastructure) band. Maximum power limits set by the FCC are greater in the UNII band, potentially allowing for greater reach.

Thus, different RF frequencies have traditionally been associated with different types of communication services: above 10GHz with point-to-point backhaul transmission, below 10GHz with MAN-sized access networks, narrowband mobile communication services, and shorter-distance WLAN services. With advances in technology, the services have become somewhat less frequency-dependent (*i.e.,* it is possible to support services in multiple frequency bands), but operating in the different bands still implies different costs, architectures, and performance characteristics.

2. Antenna characteristics

Another key design characteristic is the antenna. This is related to the frequency of operation since the size of the antenna is proportional to the wavelength which is inversely proportional to the frequency (*i.e.,* high frequency antennas can be smaller).

The size and shape of the antenna can also affect the range and antenna gain. This has important implications for different applications. For example, mobile phones typically use small “stub-like” omnidirectional antennas that are not very spectrally-efficient (*i.e.,* radiate in all directions instead of just towards the base station) to the large satellite dishes used for Direct Broadcast Satellite (DBS) services. These large larger antennas allow for signals to be focused and sent relatively long distances, but raise costs both for equipment and deployment. A major tradeoff for vendors is whether to rely on fixed antennas mounted on the roof, a small desktop antenna that does not require professional installation, or a simple PC Card that allows for mobile access by a laptop or PDA. Simpler antennas sacrifice signal gain (and therefore reach or bit rate) for ease of deployment or portability.

Base stations, generally being more expensive fixed installations, are more likely to make use of sophisticated antennas (than is subscriber equipment). Beam forming antennas can allow the area around a base station to be divided into sectors, allowing additional frequency reuse among sectors. The number of sectors can range from as few

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require costly antenna positioning on the outside of a home. With NLOS operation, end-users may be able to self-install customer premise equipment which substantially lowers the costs of service adoption.

as four to as many as 24. Such sectorized base stations have been used for a long time in mobile service base stations.

Once again, advances in antenna design have improved the capabilities and affordability of using high-gain, focused antennas in low-cost, portable environments. Capabilities that were previously limited to high-cost service provider base-stations and back-haul applications are increasingly finding use in a wider array of wireless applications. For example, companies like Vivato,[38] Arraycom,[39] Beamreach,[40] and others have recently begun to sell new phased array antennas that allow for a narrow beam to be formed and steered electronically to an individual subscriber terminal. This greatly extends reach and frequency reuse. Additionally, systems with multiple antennas at either the base station or subscriber end (Multi-In Multi-Out or MIMO) take advantage of multipath—signals bounced off of buildings or other obstructions, to provide superior throughput and resistance to fading. Several vendors are developing chips to support MIMO in conjunction with wireless LAN technology.[41]

3. Physical layer encoding

The modulation technique used to encode the signal onto the RF spectrum is also an important design choice. Use of a more complex approach may increase data rate and enhance spectral efficiency (*i.e.,* more bits are sent per Hz of spectrum used), but require higher cost components. Vendors have adopted a number of approaches to physical layer encoding to address these trade-offs. For example, first generation BFWA systems operating in licensed spectrum typically used single carrier encoding with limited robustness in the face of multipath reflections. Alternatively, early unlicensed systems used some form of spread spectrum—either Direct Sequence (DSSS) or Frequency Hopping (FHSS)—in order to meet FCC requirements for sharing the unlicensed band without coordination. Similarly, 3G mobile systems also use direct sequence spread spectrum.

Newer modulation techniques such as Orthogonal Frequency Division Multiplexing (OFDM), support high data rates/spectral efficiency and better multipath immunity at the price of more complex signal processing at the transceiver. Fortunately, Moore’s law has meant that the cost of such processing has continually dropped to where today it can be implemented in single chips. Nevertheless, some vendors, such as Motorola in their Canopy system,[42] have selected very simple modulation schemes, to minimize cost, and maximize rejection of interference from other base stations.

As with the other design features, technical advances have lowered the costs and improved the capabilities of digital encoding schemes, allowing higher data rates to be

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[38] http://www.vivato.net

[39] http://www.arraycomm.com/

[40] http://www.beamreachnetworks.com

[41] (Jones, et al 2003)

[42] http://motorola.canopywireless.com/

supported per Hz of frequency used, but important design tradeoffs remain. The optimal choice of modulation scheme may depend on whether the spectrum being used is to be shared on an uncoordinated (unlicensed) basis or is licensed, and also on whether the subscriber is fixed or mobile. For example, DSSS has distinct advantages over OFDM for mobile applications; whereas OFDM has advantages over DSSS for higher data rate transmission for fixed location services.

4. Sharing the spectrum and/or the channel.

There are also many ways in which spectrum may be shared among multiple users and the choice of sharing mechanism has important implications for the cost and service quality of supporting different types of traffic in different types of network architectures (*e.g.,* large or small cell sizes, symmetric or asymmetric traffic, isochronous or asynchronous traffic).

For example, in 3G mobile networks, each user's signal is separated by the use of a different spreading code, or Code Division Multiple Access. Spreading the signal reduces the number of bits per Hz and thus limits the maximum bit rate of each user in a given channel bandwidth. Separate frequency bands are used for upstream and downstream, fixing the amount of capacity available for transmissions in each direction (Frequency Division Duplexing). By contrast, wireless LAN systems use Time Division Duplexing (TDD) where the same frequency band is used for transmission in both directions. This allows dynamic adaptation to varying levels of asymmetry in upstream and downstream traffic. Which is better depends on the type of traffic that is to be supported. For example, the 3G approach might be better if your goal is to share the traffic among a large number of users with similar and predictable service use requirements (*e.g.,* to support two-way voice communications or streaming broadcast media); while the WLAN approach may be better if traffic is more heterogeneous (*e.g.,* P2P data communications among multiple PCs).

Broadband Wireless Fixed Access (BFWA) systems more often are designed around Time Division Multiple Access. In these systems, a single high bit rate channel is shared among multiple subscribers by interleaving their transmissions in time. Given bursty traffic, a user can occasionally take advantage of the peak rate of the channel, but as more users share the channel, the average bit rate available to each user declines. In wireless LAN systems, this sharing is based on random access; in others, the base station allocates capacity upon request to each subscriber and can tightly control the Quality of Service given to each user.

Channel sharing and physical layer techniques that depend on very short propagation delays between the base station and the subscriber or limited multipath delay spread, may perform poorly as distances are increased.[43] Thus, the sharing mechanism must be optimized for the expected reach of the system.

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[43] (Chayat, 2002)

Channel sharing overhead can be reduced if each user can transmit a large packet whenever she has a turn. However, this can lead to longer delays between successive channel accesses, which may interfere with latency sensitive applications such as Voice over IP or video conferencing. Many first generation systems opted for channel efficiency, whereas newer systems are designed to support smaller frames and provide better performance for delay sensitive applications.

5. Maximum bit rate and reach

Wireless systems also differ with respect to the maximum bit rate that can be supported. For a given average power level, sending more bits per second means less energy per bit, which in turn means more sensitivity to noise at a given distance from the base station or access point. System designers can increase reach by decreasing bit rate. Indeed, many systems, such as wireless LANs, automatically adjust the bit rate downward for far away clients as the signal strength declines with distance. Alternatively, the additional energy per bit at lower bit rates can enable the use of smaller antennas, or reception inside a building. Early broadband fixed wireless systems operated at fixed bit rates, but newer systems typically adapt the transmission rate to each user as needed. Still, vendors optimize the overall design for different assumptions about antennas, bit rate and reach.

6. Backhaul

When deploying a broadband wireless system, one must consider more than the wireless link from a base station to a user. Base stations themselves must be linked back to a city or regional node and from there tied in to the larger Internet. Some vendors provide systems only for the last wireless link. Others, provide products designed to reduce backhaul cost as well. Motorola Canopy sells point-to-point wireless radios to backhaul traffic from its multipoint base stations. Other vendors integrate DSL modems with a wireless access point to reduce the cost of using DSL for backhaul. There are WLAN access points that can bridge to Homeplug networks that deliver data over power lines, for backhaul within a home.

In so-called mesh networks, each access point, which serves end users, can also function as a wireless transit node to route traffic from other access points. Thus traffic from a subscriber may go to a first access point and then hop between several more access points before reaching one that is tied in to the wired Internet. Such systems use self-configuring ad hoc routing protocols to determine the best route to a wired access point.[44]

B. Putting the Pieces Together

If we look across the range of vendors and products in the broadband wireless space, we can see that different vendors have located their products in different parts of

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[44] Http://www.tropos.com

this multi-dimensional product space. Indeed, there has been a great deal of ferment in this sector with rapid changes in cost or capabilities along each dimension, and corresponding shifts in product design. As noted by Abernathy and Utterback (1978), in the early phase of a new product market, before the emergence of a "dominant design," there is a great deal of product variety. At the turn of the 20th century automobiles came with internal combustion engines or steam engines, three four or five wheels, front steering or rear steering, and many other configurations before the dominant design of a four wheel vehicle with internal combustion, front wheel steering and rear drive wheels emerged.

At the turn of the 21st century, we are in a similar place with broadband wireless. Many vendors produce incompatible products of proprietary design. They have made very different choices in the design space, according to their respective competences, target market or limitations of the available technology at the time the design was instantiated. Standards have begun to emerge which define "dominant designs" within certain segments of the design space.

1. 3rd Generation Cellular

Third generation designs were the first cellular standards to optimize for data traffic as well as voice. The original cellular model assumed expensive, powerful, sectorized base stations, mounted on towers, and serving a radius of several kilometers. With the growth in cellular usage, base stations have proliferated to realize frequency reuse creating a demand for smaller, less expensive base stations. 3G cellular standardizes on CDMA (either WCDMA or CDMA 2000 EV-DO) for sharing the available spectrum, with a maximum bit rate of roughly 2.5 Mbps to a stationary user, and a few hundred kilobits for a mobile user. User antennas are small, appropriate to handheld devices, and the bit rate and reach are chosen to allow reception within buildings. Frequencies licensed for 3G are typically in the 1.7 –2.1 GHz range, varying by country.

Verizon introduced CDMA 2000 EV-DO in the United States in 2003 with deployments in Washington, D.C. and San Diego. They have indicated plans to roll out in major cities nationwide in 2004. The service offers 300-500 Kbps unlimited use for $80/month.[45] This is competitive with some DSL systems with respect to speed, though not on price, while uniquely providing mobility within the cellular coverage area.

2. Wireless LANs

The IEEE 802.11 committee issued the first standards for wireless local area networks (WLANs) in 1997 and products began appearing shortly thereafter. Just seven years later, vendors expect to sell 30 million units worldwide. The target market for wireless LANs—mobile computers within a building or campus—led to specific design tradeoffs and choices. The initial 802.11—which was rapidly succeeded by the almost identical, but faster, 802.11b—operates at 2.4 GHz, a band designated as unlicensed

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[45] http://news.vzw.com/lead_story/pr2004-01-08.html

worldwide, allowing for international scale economies. Access points and mobiles use simple omnidirectional antennas. Reflecting the low power limits and simple antennas, the reach was set at about 100 meters resulting in bit rates of 11 Mbps over the channel. Physical layer encoding using DSSS provides interference protection against other users of the band (such as cordless telephones) while the channel is shared using contention access and TDD.

Getting its start in warehouses and university campuses, WLAN use quickly spread to residences as a means of linking multiple computers in the home, at lower cost than pulling LAN cabling. The simple design of 802.11b allowed for very low cost access points that could function as a bridge to wired Ethernets.

Two new WLAN standards have been released since 2000. Operating in the UNII band, 802.11a uses OFDM and has a peak channel rate of 54 Mbps. 802.11g also uses OFDM to realize 54 Mbps in the 2.4 GHz band. It is estimated that shipments of 802.11g will surpass 802.11b in 2004[46], with 802.11a trailing far behind. A forum of equipment vendors certifies implementations as interoperable with the trademark Wi-Fi.

The rapid and widespread adoption of 802.11b led many ISPs to attempt to use it for broader metropolitan access. By adding fixed directional antennas for both base stations and subscribers, the reach of 802.11 can be increased to several miles. However, the contention protocol for channel sharing performs poorly with longer propagation delays, and vendors have introduced products that make use of 802.11 standard chips but alter the protocol slightly for improved performance over the wider area. The original 802.11 standard specified a FHSS option that has been used by some vendors of WISP equipment. However, this option requires different silicon than is used by most WLAN equipment, and so does not benefit from the same learning curve.

3. First Generation Broadband Fixed Wireless

First generation BFWA systems varied widely in their designs. Some copied the DOCSIS design used for cable modems, merely shifting the frequencies used for transmission on cable to higher frequency wireless bands, such as MMDS. Some combined FHSS with substantial fixed antennas to realize long reach at bit rates of several megabits per second. Many operated only with direct LOS. Other physical layer technologies that have been used include single carrier (Hybrid Communications), Multi Code DSSS (Wi-Lan) or 3G WCDMA (IP-Wireless). The lack of standardization led to high costs, lack of interoperability, and reluctance by chip vendors to produce low cost, highly integrated components. Many of the first generation equipment vendors have been through bankruptcy or exited the market altogether.

4. Wi-Max

In 2003, the IEEE adopted the 802.16 standard known as Wi-Max to meet the need for standards based BFWA. As with the original 802 LAN standards, 802.16

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[46] http://www.reed-electronics.com/electronicnews/article/CA407177

actually defines a family of standards with options for specific settings. Just as the Ethernet media access control (MAC) layer can run over copper, fiber or coax, the 802.16 MAC is designed to support operation over multiple physical layers, *e.g.* frequencies above and below 11 GHz, using either FDD or TDD, different channel bandwidths, and using either single carrier or OFDM. 802.16a deals specifically with frequencies from 2-11 GHz, specifies OFDM, and is expected to be used both in unlicensed bands (e.g. UNII at 5 GHz) and licensed (MMDS at 2.5 GHz).

Vendors have announced Wi-Max products that will be designed for long reach using roof mounted subscriber antennas, and systems for shorter reach targeted at a laptop with a PC-Card. Bit rates up to 70 Mbps and reach of 30 miles have been claimed, though both numbers will not be realized simultaneously. Indeed, early implementations show a rapid drop off of realizable channel bit rate as the distance increases, dropping to 18 Mpbs at 70 miles.[47]

Variants of the standard targeting mobile users (802.16e) and providing enhanced QoS (802.16b) are already in the works. Redline Communications shipped the first 802.16a compatible equipment in March, 2004. Several chip vendors, including Intel, are working on 802.16a integrated silicon, and low cost subscriber units and access points are expected to become widely available in 2005. Already many of the surviving vendors of first generation BFWA equipment have announced they will move towards Wi-Max compatible products. Vendors touting sophisticated antenna technology, such as MIMO or phased arrays have signaled their intention to apply these to 802.16a compatible products.

The result is expected to be sharply lower costs for BFWA equipment, comparable to what has happened to the Wi-Fi market since the ratification of 802.11b. When 802.16e is adopted, supporting mobile users, Intel has said it expects to do for Wi-Max what it did for Wi-Fi with Centrino—make it a standard feature of virtually all laptops.[48]

If Wi-Max is the future, communities deploying today don't have the choice. Indeed, given the complexity of the standard, and delays by the IEEE in specifying conformance criteria, it may be later than 2005 before interoperable equipment is readily available.

The following figure illustrates the evolution of BFWA technology towards Wi-Max (Alvarion, 2004a).

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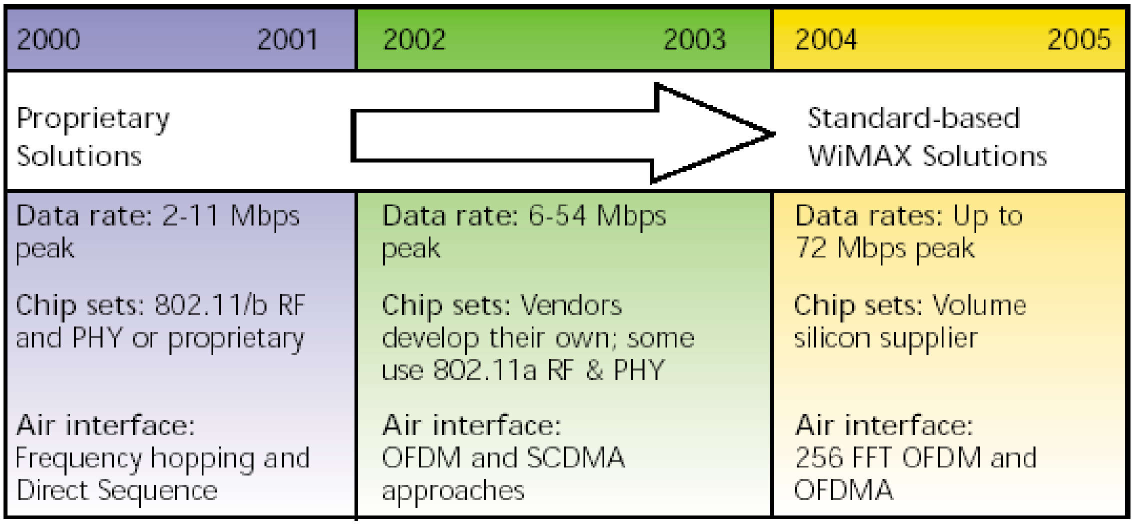
[47] http://www.dailywireless.org/modules.php?name=News&file=article&sid=1968

[48] http://www.computerworld.com/mobiletopics/mobile/story/0,10801,86093,00.html



2000 2001	2002 2003	2004 2005
Proprietary Solutions		Standard-based WiMAX Solutions
Data rate: 2-11 Mbps peak	Data rate: 6-54 Mbps peak	Data rates: Up to 72 Mbps peak
Chip sets: 802.11/b RF and PHY or proprietary	Chip sets: Vendors develop their own; some use 802.11a RF & PHY	Chip sets: Volume silicon supplier
Air interface: Frequency hopping and Direct Sequence	Air interface: OFDM and SCDMA approaches	Air interface: 256 FFT OFDM and OFDMA

Figure 1.

5. *Mesh Networks*

To cover a large metropolitan region there have been three approaches:

- Use a single powerful base station with a long reach to cover the area. However, a large population in the coverage area can mean congestion among users contending for the limited bit rate of a transmitter;
- Use multiple cells, each interconnected to the wired network for backhaul as with 3G cellular
- Use wireless to link end points to each other and then back to the wired Internet.

This last approach is being used by vendors touting mesh networks. In some designs, only base stations can act as wireless routers, handling traffic for both their own clients and other base stations as well. In other designs, every subscriber unit acts as both end point and transit point, greatly increasing the redundancy, but also the complexity of the network.

Metricom with its Ricochet network was the first to use such an approach. More recently, Tropos and MeshNetworks have released mesh network products. There are also grass root efforts, using open source software to build mesh networks out of 802.11 capable end user PCs.

6. *Situating Vendors in Product Space*

As the discussion above makes clear, there is a great deal of product variety in the wireless broadband space. The table below gives some indication of the combinations of attributes selected by various vendors for their products.

Attribute / **Vendor**	**Spectrum**	**Subscriber Antenna**	**Base station antenna**	**PHY layer**	**Sharing**	**Bps and Reach**	**Backhaul**
IP Wireless	UMTS, MMDS	Desktop	Sectorized	WCDMA (3G)	WCDMA	16 Mbps 2.5 km	Wired
Redline	3.5 GHz	Rooftop	Sectorized	OFDM (802.16)	TDMA	≤70 Mpbs ≤70 km	Wired
Motorola Canopy	UNII	Rooftop	Sectorized	Proprietary	TDMA	10 Mbps 2 mi	Point to point wireless
Tropos	2.4 GHz	PC-Card	Omni	802.11b	CSMA/CA	11 Mbps 300 meters	Mesh
Beamreach	MMDS	Rooftop	Phased array	OFDM	TDMA	83 Mbps 35 km	Wired
Vivato	2.4 GHz	PC-Card	Phased array	802.11b	CSMA/CA	11 Mpbs 2 km	Wired

Table 1.

Larger vendors, such as Alvarion, have a portfolio of products covering different parts of the overall product space.

We can make a number of general observations about trends in this space. First, proprietary physical layer choices are giving way to a small number of standards: 3G cellular, 802.11 and 802.16. This is driven by the economics of semiconductor chips implementing these standards. Second, there is a distinct tradeoff to be made between maximizing bitrate and reach by using rooftop subscriber antennas, and reducing costs of deployment by designing for desktop or PC-card antennas that can be purchased and installed by the consumer. Serving PC-card devices well requires that the technology deal with user mobility as well. Third, long reach systems means fewer cells, and typically wired backhaul. Shorter reach systems require more cells and create a demand for distinct middle mile approaches, such as wireless backhaul or mesh networks. In the near term we are likely to see combination approaches, *e.g.*: large cell Wi-Max base stations serving fixed antennas, used as a backhaul technology for 802.11 access points serving mobile users equipped with PC-Cards or antennas built into a laptop PC or PDA. Fourth, newer generation systems, or updates to existing standards, are being designed to handle VoIP and other applications requiring QoS. Finally, systems operating in unlicensed spectrum allow rapid entry by competitive WISPs; however, congestion in the unlicensed band may lead to a preference for licensed spectrum, such as MMDS, for long reach systems. In the near term, congestion in the 2.4 GHz band from 802.11b/g is driving WISPs to the UNII band at 5 GHz.

IV. Municipal Networks Use of Wireless

Not surprisingly, local governments have taken advantage of the advances in wireless technology and are using these technologies to expand the range of services they provide and the locales in which those services are provided. These efforts may be grouped into three classes of efforts: (1) municipal provision of MAN-sized access networks; (2) mobile broadband services for public safety; and (3) community "hot spots." While the first of these has already been occurring in the absence of wireless (*e.g.,* via MEU deployment of broadband services), the latter two are uniquely associated with wireless technologies and, in particular, are providing interesting test cases of the new class of WLAN/MESH-based technologies for building up community access networks.

Additionally, the municipalities that are deploying these wireless networks are utilizing the full spectrum of business models that we described earlier: (1) Retail service model; (2) Wholesale service model; (3) Franchisee model; (4) Real estate model; (5) Coordination model. In the following we provide a brief overview of selected examples of each of these networks to provide examples of the types of activity that are underway.

These wireless networks are also expanding the range of services that can be supported. For example, in addition to supporting broadband access to residences and businesses, these wireless networks can also be used to support sensor networks and location-based services.

A. Municipal wireless MAN-sized access networks

As noted earlier, some municipalities have been providing broadband services based on wired technology (cable or DSL modems). Since such investment is associated with large sunk and fixed costs, it is not surprising that few communities have elected to invest in providing municipal infrastructure, and that the communities that have been most likely to offer telecommunication services are those that already have an MEU. In many cases, the MEU has already invested in an advanced data communication network to support its internal operations. Also, the MEU already has a relationship with residents and businesses in the community and has to maintain customer support and outside facilities maintenance services for its local electric power distribution plant. Typically, the MEU owns or has access to outside structures (poles or conduit) which can be used to deploy the last-mile communications infrastructure. Finally, a number of power companies have been experimenting with using the existing power lines to transmit communication signals, called “Broadband over Power Lines” (BPL).[49] At least one vendor in this space uses BPL for distribution to the neighborhood, and 802.11 for the drop from the power pole.[50]

Wireless technologies expand the set of technical options, and depending on the local circumstances, may offer a substantially lower deployment cost. MEUs may elect to deploy communication services via wireless technology, instead of wireline. For example, Owensboro Municipal Utilities in Kentucky and Wheatland Electric in Kansas, are both deploying BFWA systems using Alvarion’s technology to provide broadband access in their rural communities.[51] The Alvarion technology is based on relatively large cell sites (up to 30 miles at 20 Mbps; up to 70Mbps at shorter distances) which are typical of the traditional architecture employed by an earlier generation of BFWA technologies that were deployed in MMDS (2.1-2.7GHz) spectrum, but which were not successful in the market.[52] The new generation of MAN-sized wireless technologies based on IEEE 802.16 standards (“WiMAX’) offer improved line-of-sight performance and should be able to be deployed inexpensively to provide a robust back-haul capability to interconnect WiFi hot spots or to provide direct end-user connection.[53] Furthermore, with the emergence of public standards for this technology, the industry will benefit from industry-sized scale and scope economies and learning effects that will lower costs and barriers to adoption (*e.g.,* end-user uncertainty, fear of stranding). For example, the costs customer premise equipment should fall much closer to the commodity-level pricing that characterizes WiFi equipment today.

The new wireless technologies are also being deployed to support MAN-sized networks in non-MEU communities and by new types of players. For example, Cumberland, the county seat of Alleghany County in Maryland, formed a non-profit broadband wireless ISP, or WISP, to provide high-speed access services to its rural communities after becoming frustrated with the incumbent wired-carrier, Verizon.[54] WISPs have emerged in a number of rural communities in the United States and abroad.[55]

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[49] Although BPL services have been anticipated for a number of years, they are only now starting to roll-out (see, for example, “Broadband-over-power-line vendor rolls out service,” 2004). There are concerns about the scalability of such services to higher bandwidths and about potential interference with other RF systems (see “Broadband over power lines gets a boost,” 2004).

[50] See http://www.amperion.com/

[51] See Alvarion (2004a).

[52] As discussed earlier, the market was limited given the high price of the equipment and state of data communication markets using technology available at the time, and the earlier MMDS systems offered poor NLOS performance.

[53] While Alvarion is the market leader in offering BFWA equipment, the current generation of systems were deployed before the WiMAX standard was finalized. Wi-Max compatible equipment is not expected until late 2004.

[54] The Cumberland-based non-profit broadband ISP is called AllCoNet (http://www.allconet.org/execsummary.htm) (see Fitchard, 2002).

[55] See Johnston and Snider (2003) for some examples of WISPs.

A number of these are investor-owned service providers that serve as franchisees for municipalities wishing to construct a broadband wireless network.[56]

While most of the WISPs are providing retail services directly to end-users, there are some that have adopted an open access/wholesale model. For example, the Franklin Public Power District, an MEU in Pasco, Washington, is providing a wireless broadband open access platform for resale by third-party ISPs because state-law prohibits the MEU from offering retail services.[57]

Finally, a number of municipalities are facilitating entry by investor-owned wireless service providers by providing access to government buildings and schools for antenna siting, and in some cases, by allowing antennas to be placed on street lights and other municipally-owned property for wireless technologies based on small cell sites (short-range wireless technologies, like WiFi). For example, Cerritos California has deployed a WiFi-based MESH network using technology from Tropos Networks.[58]

For communities that do decide to deploy MAN-sized access infrastructure, the wireless technologies are important because they expand the range of players and technical options for leveraging existing investments, thereby helping to lower the costs of a municipal deployment. For example, wireless can be used to economically extend public access to municipal fiber or to local government intranet backbone services.

B. Mobile broadband services for public safety

Public safety services have an obvious need for high-speed mobile data services to allow police, fire, and emergency personnel to access on-line data (*e.g.,* to link to criminal databases and automobile registry data) and communication critical data in real-time (*e.g.,* relay medical information from the ambulance to the hospital). Traditionally, these services have been based on proprietary technologies specially developed to meet the needs of the target service.

With the advances in communications technology, and more recently, with the explosion of interest and services based on WLAN technologies operating in unlicensed spectrum such as WiFi, there is growing interest in implementing public safety systems using such technologies. For example, San Mateo, California, has installed a Tropos WiFi MESH network to support high-bandwidth mobile data access for public safety officers.[59] Although these networks have not been installed to support public access, these could be shared, and by so doing, the costs of deploying broadband local access services in the community could be lower.

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[56] For example, NetStar is a Tennessee-based WISP (see Blackwell, 2002).

[57] See Franklin PUD (2004).

[58] See "Nation's first wireless community broadband service deployed in Cerritos, CA," (2004) and Tropos Networks (2004).

[59] See "California Police Department uses Tropos' mesh network," (2003).

Additionally, mobile wireless technologies that are put in place for use within a government office, may provide the incentive and platform for extending connectivity outside the office. For example, consider the traffic officer who uses a PDA to collect data on illegally parked cars and then uses a wireless connection at the station house to download the information to automate issuing tickets and reduce data entry errors. If this system is expanded to support broadband mobile data while the traffic officer is on patrol, an automatic cross-check can be made of licenses to see if there are any outstanding warrants or other problems that require special action (*e.g.,* booting/towing the car).

C. Community "hot spots"

Another interesting trend has been the deployment of WiFi-based "hot spots" of broadband connectivity in public spaces. Sometimes such investments are justified as opportunistic ways to extend free access to under-used local government intranets, or to enhance the usability of public access terminals in schools and libraries to adjacent areas within the building or in close proximity to the building (in a nearby park). Other times such investments are justified in order to promote economic development. For example, when the mall outside town installs free wireless service in its food court to attract customers, the town may respond by installing WiFi hot spots in the depressed downtown business district to help support economic development there. For example, the cities of Long Beach (CA), San Francisco, Seattle, Jacksonville (FL), and New York have all deployed municipal public hot-spots offering "free" WiFi internet access.[60]

The key attraction of WiFi hot spots is that they can be deployed with very little cost. Most private data networks are under-utilized and can support at least some additional shared use without the primary users seeing any noticeable deterioration in their service quality. WiFi equipment is quite cheap, is easily installed, and is robust. If the goal is to provide free access services in a localized area, WiFi can be quite effective.

Once deployed, WiFi hotspots can be interconnected to provide wider area coverage and agreements to allow hotspot-roaming can allow users to take advantage of WiFi access from multiple hot spot providers. While it is possible to use WiFi to construct a mesh network (*e.g.,* Tropos Networks), this was not anticipated in the original design. Most WiFi hotspots are deployed using backhaul services such as a T1 leased line, cable modem, or DSL fixed line broadband service that would need to be replaced to convert the disparate WiFi hotspots into a wireless mesh. In addition to reworking/replacing the backhaul architecture, it would be necessary to modify the "hot spot" model in a number of other ways if it is to grow up or evolve into a competitor for BFWA networks. Transitioning from a "free" service that offers only "best efforts" service to a carrier-grade platform for wide-area connectivity will require a change in the underlying business model, new technology, and new investment.

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[60] See Markoff (2003).

V. Policy Implications of Wireless for Municipal Networking

Emerging wireless technologies have a number of important effects on the rationale for municipal entry into telecommunications services. First, *ceteris paribus,* wireless increases incentives for local governments to invest in IT and local infrastructure. Second, wireless impacts the "market failure" rationale in ambiguous ways, which means that we cannot conclude at this stage in our research whether wireless supports or harms the economic case in favor of municipal provisioning of local telecommunications services. Third, when municipalities do decide to enter telecommunication services, wireless has a complex impact on the range of business cases and the selection of public policies that would best support enhanced broadband access.

A. Wireless expands municipal incentives to invest in local IT infrastructure

Wireless expands local government demand for and interest in deploying and adopting IT services and infrastructure. By expanding the range of IT-enhanced services that can be offered and their accessibility and usability (*e.g.,* eGovernment access, community building, at-home health care, utility metering, homeland security), wireless pushes out local government's demand curve for IT services.[61] An obvious example that is being widely exploited is installing WLANs in schools and government offices to increase access to existing IT infrastructure and services. Wireless also lowers the costs of supply because it expands the technology choice set. That is, although wireless is not the least expensive technology in all situations, when it is, it lowers the costs of deploying infrastructure.[62] For example, wireless can offer a low-cost alternative to leased line facilities from the incumbent local telephone company for backhaul interconnections between schools, libraries, and other government buildings in the community.

Wireless technology complements other IT investments, increasing demand for fixed line broadband access (*e.g.,* when a home WLAN allows a DSL or cable modem line to be shared in the home) and for mobile computing equipment, services, and applications. Taken together, these "supply" and "demand" effects mean that local governments will invest more in IT services and equipment. The growth of eGovernment and the investments in local government intranets and in broadband content will provide complementary assets that can lower the incremental costs of entry into telecommunication services.[63] This will reduce the cost of "opportunistic" entry.

Thus, *ceteris paribus*, wireless seems likely to increase local government incentives to enter into local telecommunications services and implies that local

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[61] Of course, these could be provided by private sector providers. Higher demand reduces the likelihood of a market failure, but also increases motivation to act if market failure continues.

[62] See Wanichkorn and Sirbu (2002).

[63] For example, local government efforts to implement eGovernment capabilities and services will require building IT-saavy human capital resources that will also be available to support public access networking if the municipality elects to go that way.

government will play a more important role in how broadband access evolves in the future than it has in the past. Of course, this conclusion could be reversed if the trend towards state or federal regulatory prohibitions against municipal participation in telecommunication services continues.

B. Wireless impact on "market failure" rationale is ambiguous

By lowering entry barriers and the costs of deploying local access networks, wireless may decrease the likelihood of a market failure in any particular community, thereby reducing the need for the municipality to provide communication services. Thus, private WISPs are now finding it profitable to offer services in rural communities that are still under-served by wired-providers. And, wireless may offer a low-cost option for new competitors to over-build wired-provider networks, thereby alleviating concerns about insufficient competition.

Alternatively, in those communities that remain unattractive to private providers, wireless may make it feasible for the municipality to provide services – thereby remedying the most severe cases of market failure where even the local government finds it too costly to provide services.

In the first instance, the likelihood of municipal entry justified on the basis of "market failure" is retarded, while in the second instance, it is enhanced. Which effect dominates depends on the nature of the communities under consideration. In the first case, a state policy that precluded municipal entry in markets that will be well-served by private alternatives may be desirable to protect sustainable competition from potential anticompetitive behavior by a municipal service provider.[64] In the second case, a state policy that precluded municipal entry may leave some markets under-served which might otherwise have become affordable for a local government-supported service provider.

Although these trends have opposite effects on the incentives for municipalities to enter communication services, consumers unambiguously benefit from the increased service and coverage afforded by wireless services. Wireless will expand the range of service choices for all customers.

In addition to the above impacts, there is a sense in which wireless may exacerbate a market failure problem if it turns out that FTTx is a natural monopoly (or oligopoly). That is, by lowering the costs of deploying very-high-bandwidth capable services deep into the neighborhood, wireless may accelerate the deployment of such technologies. This could result in the creation of a natural monopoly as discussed earlier. Some preliminary research suggests that wireless is likely to play a critical role in the deployment of next generation broadband access infrastructure that will depend on fiber

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[64] Sappington and Sidak (2003) discuss the incentives for a publicly-owned enterprise to engage in anticompetitive activities. While their analysis does not lead to a conclusion that municipal provisioning of services would be less efficient or more prone to anticompetitive behavior, it does identify the risk posed to sustainable competition from municipal entry.

deployment deep into neighborhoods.[65] On the other hand, if end-user demand for bandwidth is limited, advances in 3G/4G mobile services, wireless-supported BPL services, and BFWA services may eliminate the last-mile bottleneck altogether.

Finally, wireless may expand the range of situations in which a market failure arises associated with the "basic infrastructure" type of arguments discussed earlier. That is, because wireless broadband results in social returns that exceed appropriable private returns (*e.g.,* economic development benefits of WiFi hotspots in depressed areas or broadband that improves human capital, or furthering non-economic social goals like enhancing community cohesion and political participation). In this case, wireless would accentuate the "market failure" rationale for municipal entry.

C. Wireless impacts the optimal business model for municipal entry into telecommunications services

The diversity of wireless technology options also affects the optimal business model choice for municipalities. While different technologies from different vendors are optimized for different situations, there are usually a number of alternatives that might work in any situation. It is simply not possible to identify an optimal choice without considering the goals and special circumstances in the community.

For example, if the community's goal is to quickly put in place a solution that will provide some high-speed data access at low cost and with a short investment horizon, then a municipal network based on WiFi hot spots may offer an attractive option. Additionally, local government may be able to economically encourage broadband access by helping to promote or coordinate grass-roots efforts to virally deploy ad hoc networks. The local government could encourage community/neighborhood groups interested in building up a broadband mesh network by allowing them to interconnect their mesh at low cost to local government back-haul services, could provide access to public infrastructure and buildings for siting antennas, and can provide an information clearing house/education role to help grass-roots initiatives take-off. One big problem that confronts such grass-roots networks that wish to scale to higher traffic and wider-scale is how to pay for the backhaul interconnection to the Internet.[66]

Alternatively, the community may decide that the need for ubiquitous broadband is too great to leave to a viral/grass-roots growth approach and may decide to deploy a MAN-sized network. Whether it opts for a BFWA-type network based on large cell sites

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[65] See Zhang (2004) provided a discussion of the potential role of wireless in the "100 x 100" project underway at Carnegie Mellon University and several other universities. This project is looking at the challenges for delivering 100Mbps to 100 million homes and 1Gbps to 1 million businesses in the United States.

[66] Most of the back-haul services for such networks are currently provided via wired DSL or cable modem services that are provided on a flat-monthly fee basis so the incremental cost for the DSL/cable subscriber of sharing this connection via a WiFi "hot spot" is limited to the potential congestion which should be negligible as long as traffic is relatively light. If traffic is more intense or if carriers move to usage-based pricing, these costs will have to be paid. The community could elect to tax itself to recover the revenue needed to pay for backhaul costs.

which each cover a relatively large area, or a mesh-type network based on many smaller cell sites that are interconnected will have implications for the way services are deployed and what services are deployed (*e.g.,* supporting voice telephony over a mesh-style network may be more difficult, but a mesh may offer more flexible deployment roll-out). The vendors offering these various technologies have emphasized different performance characteristics and the economic/performance trade-offs vary depending on what the network's principle purpose is.

Finally, if the community is trying to plan for its communication infrastructure needs for the next twenty to thirty years, it may opt for a FTTx system with some form of wireless mesh to provide connectivity to the neighborhood fiber.

Wireless technology continues to evolve and communities that wait will be able to take advantage of newer technologies and lower costs, but at the expense of delaying realization of the benefits of improved communication services. A community that adopts one of the newer, more capable systems before it is standardized risks being stranded with an incompatible system; while a community that fails to adopt a comprehensive plan may find itself with a mish-mash of ad hoc networks that are costly to integrate or evolve into a community-wide network. Communities will be challenged by the need to adopt a strategy that can adapt to changing technology and market needs (*i.e.,* scalable to higher speed bandwidth, wider area coverage, and new services).

The choice of technology also has implications for other aspects of municipal policy. For example, if the municipality opts for a technology based on small cell sites, it will need to install or provide access for lots of antenna sites (*e.g.,* antennas on lamp posts); while if it opts for larger cell sites, it may be able to locate the relatively small number of necessary antennas on a few government buildings. These decisions have implications for outside plant maintenance, customer premise equipment costs, system modification costs, and a host of other characteristics that define what services the municipal network can provide and how these evolve.

Moreover, because municipalities represent an important market for vendors of wireless networks and services – for MAN access networks, public safety networks, hot spots, and hybrids of everything in between – the buying decisions of municipalities will impact which technologies succeed in the market place and so will have feedback implications for the broadband industry more generally. Indeed, the municipalities by representing a concentrated locus of demand that is typically quite cost sensitive can offer an important potential early adopter of wireless technology.

Finally, because wireless technology reduces entry barriers for private service providers as well, wireless may change the types of business models that municipalities may seek to employ if they elect to provide telecommunication services in their communities. For example, they may be more inclined to favor private-public partnerships based on a franchise model wherein the municipality provides preferential access for base station siting and commits to adopting a particular technology for its internal use in return for a WISP-franchisee agreeing to install and operate the municipal wireless network. The municipality can use its wireless strategy to encourage additional infrastructure competition from these new types of last-mile access providers.

In summary, therefore, we should expect to see municipalities experimenting with a diverse array of technologies, and we should not be surprised if 20-20 hindsight allows us to identify many errors *ex post* in the approaches adopted by many of those municipalities that do choose to deploy networks. Fortunately, the low cost of wireless technology and its ability to be implemented incrementally limits the overall risk exposure.

VI. Conclusions

The future of the Internet is broadband, and the future of broadband will involve a large component of wireless services. The high costs of deploying next generation broadband infrastructure are raising questions as to how best to fund the requisite investment. This question is closely related to questions regarding what industry structure will best suit our collective needs for ensuring affordable, universal access to broadband services while at the same time ensuring that consumers have adequate choice and are not at risk from an abuse of unwarranted market power. Furthermore, because broadband requirements and the costs of deploying broadband infrastructure may vary greatly from location to location within a town, across a state, and across the nation, it is unlikely that any “one size fits all” broadband access solution will emerge, or if it does, will be optimal.

In response to these needs, a perception that the private sector may fail to make the requisite investment, offer sufficient choice, or adequate quality of service, and concerns over state and federal regulatory policy for traditional private telephone and cable television service providers has induced a growing number of local governments to consider investing in municipal telecommunication networks to provide broadband access in their communities. The traditional justifications for such a move include concerns that there is a “market failure” that needs to be addressed or that such a move is warranted because of its low incremental cost (given that investments in complementary infrastructure have already been made for another reason). Thus, we have seen a number of rural communities and communities with municipal electric utilities (MEUs) in both urbanized and rural areas decide to offer municipally-provided broadband data services.

At the same time, we are in the midst of a revolution in wireless services that is changing the way broadband services are provided and used, and are impelling convergence of wireless and wireline networks and services. This paper considers the implications of emerging trends in wireless technology for municipal networking. It provides a synopsis of some of the important technical trends and how these are finding their way into municipal network deployments. Additionally, it considers the higher-level implications of wireless technology on the proper or likely role for local governments in providing communication services in the future.

We conclude that wireless technology is likely to increase local government’s demand for and use of IT technology in general, and wireless services in particular, and therefore, local governments will become an even more important player in the last-mile broadband access landscape than they have been heretofore. At the same time, the underlying "market failure" justification for public entry into a market that has previously been served most often by investor-owned firms (at least in the United States) is impacted in ambiguous ways by emerging wireless trends. On the one hand, wireless technologies that lower entry barriers would appear to reduce the likelihood of a market failure and therefore a need for public entry. On the other hand, these same lower costs may make it feasible to address situations where before the failure was so severe as to even have precluded public provisioning. Furthermore, wireless may accelerate the deployment of next generation FTTx systems that, if a natural monopoly, could increase the likelihood that next generation infrastructure will be a natural monopoly. Alternatively, the benefits of wireless may enhance the perception that broadband constitutes essential infrastructure that needs to be provided by government because the social benefits of ensuring adequate access to such services exceed what private carriers can expect to appropriate.

This ambiguity makes it impossible at this stage to conclude whether encouraging or restraining municipal entry into communication services will further or harm the public interest. Public involvement in communication services may be a substitute for or a complement to private provisioning. While traditional incumbent local telephone and cable companies have mostly opposed municipal entry (including lobbying for state laws to block such entry), new types of carriers (WISPs) have obviously benefited from such entry. The impact of municipal entry on private sector alternatives (and visa versa) is complex. Competition from a municipality may work like competition from any other source as a spur to incumbents to lower costs and improve quality. On the other hand, a non-profit government-owned provider may have reduced incentives to be efficient and yet have both the opportunity and incentive to engage in anticompetitive strategies, thereby reducing community access to private alternatives. Empirical research measuring the economic performance (prices, quality, costs, investment) of broadband access services in communities with and without municipal providers will shed useful light on this debate.

Finally, even if a municipality elects to provide telecommunications services, its optimal choice is complex and unlikely to become simpler in the near future in light of on-going wireless trends. Choosing the optimal strategy (network architecture, business model, service model) will depend on local conditions, community goals, and on-going technical and market changes that remain subject to substantial uncertainty. Because this preliminary research suggests that municipalities will have a growing need and desire to confront this uncertainty and to deploy wireless services – for their own internal needs, if not also for their communities – further research is needed. Additional studies of the costs and benefits of deploying alternative technologies are needed that will allow municipalities to make "apples-to-apples" comparisons, and when that is not possible, at least to map the spectrum of wireless options appropriately to local circumstances. These engineering design/cost studies also need to be evaluated with respect to the business model and public policy environment in which the technology will be provided.

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