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Telecommunications Policy 27 (2003) 351–370

TELECOMMUNICATIONS POLICY

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Wireless Internet access: 3G vs. WiFi?☆

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Abstract

This article compares and contrasts two technologies for delivering broadband wireless Internet access services: "3G" vs. "WiFi". The former, 3G, refers to the collection of third-generation mobile technologies that are designed to allow mobile operators to offer integrated data and voice services over mobile networks. The latter, WiFi, refers to the 802.11b wireless Ethernet standard that was designed to support wireless LANs. Although the two technologies reflect fundamentally different service, industry, and architectural design goals, origins, and philosophies, each has recently attracted a lot of attention as candidates for the dominant platform for providing broadband wireless access to the Internet. It remains an open question as to the extent to which these two technologies are in competition or, perhaps, may be complementary. If they are viewed as in competition, then the triumph of one at the expense of the other would be likely to have profound implications for the evolution of the wireless Internet and structure of the service-provider industry.

Keywords: Internet; Broadband; Wireless; 3G; WLAN; Ethernet; Access; Spectrum; Economics; Industry structure

1. Introduction[1]

The two most important phenomena impacting telecommunications over the past decade have been the explosive parallel growth of the Internet and mobile telephone services. The Internet

☆An earlier version of this paper was presented at the symposium "Competition in Wireless: Spectrum, Service, and Technology Wars" that was held at the University of Florida on February 19–20, 2002 cosponsored by the Global Communications Consortium at the London Business School and the University of Florida's Public Utility Research Center, Center for International Business Education and Research, and Public Policy Research Center.

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[1]We would like to acknowledge financial support from the MIT Research Program on Internet and Telecoms Convergence and helpful comments from our colleagues, especially, Sharon Gillett, Shawn O'Donnel, and John

0308-5961/03/$ - see front matter
doi:10.1016/S0308-5961(03)00004-1

brought the benefits of data communications to the masses with email, the Web, and eCommerce; while mobile service has enabled "follow-me-anywhere/always on" telephony. The Internet helped accelerate the trend from voice- to data-centric networking. Now, these two worlds are converging. This convergence offers the benefits of new interactive multimedia services coupled to the flexibility and mobility of wireless. To realize the full potential of this convergence, however, we need broadband access connections. What precisely constitutes "broadband" is, of course, a moving target, but at a minimum, it should support data rates in the hundreds of kilobits per second (kbps) as opposed to the 50 kbps enjoyed by 80% of the Internet users in the US who still rely on dial-up modems over wireline circuits, or the even more anemic 10–20 kbps typically supported by the first generation of mobile data. While the need for broadband wireless Internet access is widely accepted, there remains great uncertainty and disagreement as to how the wireless Internet future will evolve.[2]

The goal of this article is to compare and contrast two technologies that are likely to play important roles: third-generation mobile (3G) and wireless local area networks (WLAN). Specifically, we will focus on 3G as embodied by the IMT-2000 family of standards[3] versus the WLAN technology embodied by the WiFi or 802.11b standard, which is the most popular and widely deployed of the WLAN technologies. We use these technologies as reference points to span what we believe are two fundamentally different philosophies for how wireless Internet access might evolve. The former represents a natural evolution and extension of the business models of existing mobile providers. These providers have already invested billions of dollars purchasing the spectrum licenses to support advanced data services and equipment makers have been gearing up to produce the base stations and handsets for wide-scale deployments of 3G services. In contrast, the WiFi approach would leverage the large installed base of WLAN infrastructure already in place.[4]

In focusing on 3G and WiFi, we are ignoring many other technologies that are likely to be important in the wireless Internet such as satellite services, LMDS, MMDS, or other fixed wireless alternatives. We also ignore technologies such as BlueTooth or HomeRF, which have at times

(*footnote continued*)
Wroclawski who were kind enough to provide comments to an earlier draft. Additionally, we would like to thank participants in the workshop Competition in Wireless: Spectrum, Service, and Technology Wars, University of Florida, February 20, 2002, and Eli Noam and Bertil Thorngren who were kind enough to point us towards additional relevant work in the area.

[2] Defining what constitutes broadband is contentious, and in any case, is a moving target. For the purposes of collecting data, the FCC defines broadband as offering 200 kbps in one or both directions. Technically, the FCC does not define "broadband" but rather "high-speed" to refer to services offering 200 kbps in at least one direction and "advanced services" or "advanced telecommunications capability" to refer to services offering 200 kbps in both directions (see, pp. 4–5 of *Third Report,* In the matter of inquiry concerning the deployment of advanced telecommunications capability to all Americans in a reasonable and timely fashion, and possible steps to accelerate such deployment pursuant to Section 706 of the Telecommunications Act of 1996, Federal Communications Commission, CC Docket 98-146, February 6, 2002).

[3] The International Telecommunications Union's (ITU) Study Group International Mobile Telecommunications (IMT-2000) has designated a series of mobile standards under the 3G umbrella (see http://www.imt-2000.org/portal/index.asp for more information).

[4] For example, the Yankee Group estimates that over 12 million 802.11b access points and network interface cards have been shipped globally to date with 75% of these shipped in the last year (see Zawel, 2002).

been touted as potential rivals to WiFi, at least in home networking environments.[5] Moreover, we will not discuss the relationship between various transitional, or "2.5G" mobile technologies such as GPRS or EDGE, nor will we discuss the myriad possibilities for "4G" mobile technologies.[6] While all of these are interesting, we have only limited space and our goal is to tease out what we believe are important themes/trends/forces shaping the industry structure for next-generation wireless services, rather than to focus on the technologies themselves.[7] We use 3G and WiFi as shorthand for broad classes of related technologies that have two quite distinct industry origins and histories.

Speaking broadly, 3G offers a vertically integrated, top–down, service-provider approach to delivering wireless Internet access; while WiFi offers (at least potentially) an end-user-centric, decentralized approach to service provisioning. Although there is nothing intrinsic to the technologies that dictates that one may be associated with one type of industry structure or another, we use these two technologies to focus our speculations on the potential tensions between these two alternative world views.

We believe that the wireless future will include a mix of heterogeneous wireless access technologies. Moreover, we expect that the two worldviews will converge such that vertically integrated service providers will integrate WiFi or other WLAN technologies into their 3G or wireline infrastructure when this makes sense. We are, perhaps, less optimistic about the prospects for decentralized, bottom–up networks—however, it is interesting to consider what some of the roadblocks are to the emergence of such a world. The latter sort of industry structure is attractive because it is likely to be quite competitive, whereas the top–down vertically integrated service-provider model may—but need not be—less so. The multiplicity of potential wireless access technologies and/or business models provides some hope that we *may* be able to realize robust facilities-based competition for broadband local access services. If this occurs, it would help solve the "last mile" or "last kilometer"[8] competition problem that has bedeviled telecommunications policy.

2. Some background on WiFi and 3G[9]

In this section, we provide a brief overview of the two technologies to help orient the reader. We will discuss each of the technologies in turn.

2.1. 3G

3G is a technology for mobile service providers. Mobile services are provided by service providers that own and operate their own wireless networks and sell mobile services to end-users,

[5] See Parekh (2001). There are myriad proprietary and alternative public WLAN technologies that might be used to support broadband mobile access.

[6] Enhanced data rates for global evolution (EDGE) and general packet radio service (GPRS) are two interim technologies that allow providers to offer higher data rates than are possible with 2G networks and provide a migration path to 3G, see Carros (2001).

[7] Finally, we should note that the discussion here is US centric. Regulations regarding the use of unlicensed spectrum differ by country. Nevertheless, most of the points made here regarding alternative models for offering wireless broadband Internet access are applicable in many countries.

[8] Hereafter, we will refer to this as the "last-kilometer" problem to maintain consistent metric units.

[9] For an introduction of to the different technologies (see Dornan, 2002).

usually on a monthly subscription basis. Mobile service providers[10] use licensed spectrum to provide wireless telephone coverage over some relatively large contiguous geographic serving area. Historically, this might have included a metropolitan area. Today it may include the entire country. From a user perspective, the key feature of mobile service is that it offers (near) ubiquitous and continuous coverage. That is, a consumer can carry on a telephone conversation while driving along a highway at 100 km/h. To support this service, mobile operators maintain a network of interconnected and overlapping mobile base stations that hand-off calls as those customers move among adjacent cells. Each mobile base station may support users up to several kilometers away. The cell towers are connected to each other by a backhaul network that also provides interconnection to the wireline public switched telecommunications network (PSTN) and other services. The mobile system operator owns the end-to-end network from the base stations to the backhaul network to the point of interconnection to the PSTN (and, perhaps, parts thereof).

The first mobile services were analog. Although mobile services began to emerge in the 1940s, the first mass-market mobile services in the US were based on the advanced mobile phone service (AMPS) technology. This is what is commonly referred to as first-generation (1G) wireless.[11] In the 1990s, mobile services based on digital mobile technologies ushered in the second generation (2G) of wireless that we have today. In the US, these were referred to as personal communication systems (PCS)[12] and used technologies such as time division multiple access (TDMA), code division multiple access (CDMA) and global system for mobile-communications (GSM). From 1995 to 1997, the FCC auctioned off PCS spectrum licenses in the 1850–1990 MHz band. CDMA and TDMA were deployed in various parts of the US, while GSM was deployed as the common standard in Europe.[13] The next generation or 3G mobile technologies will support higher bandwidth digital communications and are expected to be based on one of the several standards included under the International Telecommunications Union (ITUs) IMT-2000 umbrella of 3G standards.

The chief focus of wireless mobile services has been voice telephony. However, in recent years there has been growing interest in data services as well. While data services are available over AMPS systems, these are limited to quite low data rates (<10 kbps). Higher speed data and other advanced telephone services are more readily supported over the digital 2G systems. The 2G systems also support larger numbers of subscribers and so helped alleviate the capacity problems faced by older AMPS systems. Nevertheless, the data rates supportable over 2G systems are still quite limited, offering only between 10 and 20 kbps. To expand the range and capability of data

[10] Some of the larger mobile operators in the US are AT&T Wireless, Verizon Wireless, Cingular, and Sprint PCS; in Europe, some of the larger mobile operators include Orange, Vodafone, France Telecom, T-Mobile, Telefonica Moviles, and Telecom Italia Mobile.

[11] The FCC licensed two operators in each market to offer AMPS service in the 800–900 MHz band.

[12] In the US, it was originally hoped that the PCS spectrum licenses would be used to provide many new types of wireless communication and data services, not just the type of highly mobile service for which it has been used principally to date. In Europe, GSM was adopted as the 2G standard for mobile networks and began to be deployed in the early 1990s, before the PCS spectrum was auctioned in the US; in the US, different service providers adopted multiple and incompatible standards for their 2G service offerings.

[13] The European Telecommunications Standards Institute published the GSM standard in 1990 and by 1995 it had become the de facto standard in Europe. This is in contrast to the US where multiple incompatible standards were adopted.

services that can be supported by digital mobile systems, service providers will have to upgrade their networks to one of the 3G technologies. These can support data rates from 384 kbps up to 2 Mbps, although most commercial deployments are expected to offer data rates closer to 100 kbps in practice.[14] While this is substantially below the rates supported by the current generation of wireline broadband access services such as DSL or cable modems, it is expected that future upgrades to the 3G or the transition to 4G mobile services will offer much higher bandwidths. Although wireline systems are likely to always exceed the capacity of wireless ones, it remains unclear precisely how much bandwidth will be demanded by the typical consumer and whether 3G services will offer enough to meet the needs of most consumers.

Auctions for 3G spectrum licenses occurred in a number of countries in 2000 and the first commercial offerings of 3G services began in Japan in October 2001. More recently, Verizon Wireless has starting offering "3G" service in portions of its serving territory (although this is not true-3G service).[15]

2.2. WiFi

WiFi is the popular name for the wireless Ethernet 802.11b standard for WLANs. Wireline local area networks (LANs) emerged in the early 1980s as a way to allow collections of PCs, terminals, and other distributed computing devices to share resources and peripherals such as printers, access servers, or shared storage devices. One of the most popular LAN technologies was Ethernet. Over the years, the IEEE has approved a succession of Ethernet standards to support higher capacity LANs over a diverse array of media. The 802.11x family of Ethernet standards are for wireless LANs.[16]

WiFi LANs operate using unlicensed spectrum in the 2.4 GHz band.[17] The current generation of WLANs support up to 11 Mbps data rates within 100 m of the base station.[18] Most typically,

[14] The lower data rates associated with most early 3G commercial offerings are due in part to the technology, but may also be due to market demand. As discussed further below, it is unclear how much bandwidth is required for "broadband data"; however, it is clear that these lower speed 3G offerings are substantially slower than WiFi offerings can support.

[15] Verizon launched its service in January 2002. The early version of the service promises average data rates of 40–60 kbps with burst rates up to 144 kbps and is based on a CDMA 1XRTT network. This is slower than what is anticipated from full-fledged 3G networks, but is still substantially faster than alternative data offerings from mobile service providers (see Martin, 2002).

[16] IEEE Project 802, the LAN/MAN Standards Committee is responsible for developing the 802 family of standards. Project 802 first met in 1980 and has subsequently specified LAN/MAN standards for a diverse array of networking environments and media. Working Group 802.11 is responsible for WLAN standards. For more information, see http://grouper.ieee.org/groups/802/index.html.

[17] The two most important 802.11x standards are 802.1 1b which operates at 11 Mbps in the 2.4 GHz band and 802.1 1a which operates up to 54 Mbps in the 5 GHz unlicensed spectrum band. Other 802.11x standards include 802.11 g which is expected to offer 22–54 Mbps in the 2.4GHz band; 802.11e which adds quality-of-service support to manage latency which is important for supporting voice telephony; and 802.11x which adds security features.

[18] Although this distance is quite limited, WiFi may be married with other wireless technologies to provide service over greater distances. For example, Motorola offers the Canopy radio system that can support point-to-point links of up to 35 miles and point to multi-point links of up to 10 miles. This could be used to establish an affordable backhaul network for WiFi deployments in rural or less dense areas (see http://www.motorola.com/canopy/ for more information on Canopy).

WLANs are deployed in a distributed way to offer last-hundred-meter connectivity to a wireline backbone corporate or campus network. Typically, the WLANs are implemented as part of a private network. The base station equipment is owned and operated by the end-user community as part of the corporate enterprise, campus, or government network. In most cases, use of the network is free to the end-users (that is, it is subsidized by the community as a cost of doing business, like corporate employee telephones).

Although each base station can support connections only over a range of a hundred meters, it is possible to provide contiguous coverage over a wider area by using multiple base stations. A number of corporate business and university campuses have deployed such contiguous WLANs. Still, the WLAN technology was not designed to support high-speed hand-off associated with users moving between base station coverage areas (i.e., the problem addressed by mobile systems).

In the last 2 years, we have seen the emergence of a number of service providers that are offering WiFi services for a fee in selected local areas such as hotels, airport lounges, and coffee shops.[19] In addition, there is a growing movement of so-called "FreeNets" where individuals or organizations are providing open access to subsidized WiFi networks.

In contrast to mobile, WLANs were principally focused on supporting data communications. However, with the growing interest in supporting real-time services such as voice and video over IP networks, it is possible to support voice telephony services over WLANs.

3. How are WiFi and 3G same

From the preceding discussion, it might appear that 3G and WiFi address completely different user needs in quite distinct, non-overlapping markets. While this was certainly more true about earlier generations of mobile services when compared with wired LANs or earlier versions of WLANs, it is increasingly not the case. The end-user does not care what technology is used to support his service. What matters is that both of these technologies are providing platforms for wireless access to the Internet and other communication services.

In this section we focus on the ways in which the two technologies may be thought of as similar, while in the next section we will focus on the many differences between the two.

3.1. Both are wireless

Both technologies are wireless, which (1) avoids the need to install cable drops to each device when compared to wireline alternatives and (2) facilitates mobility. Avoiding the need to install or reconfigure wired local distribution plant can represent a significant cost saving, whether it is within a building, home, or in the last -kilometer distribution plant of a wireline service provider.

[19] In the US, the coffee chain, Starbucks, is now offering WiFi access from T-Mobile (a subsidiary of Deutsche Telecom, see www.t-mobile.com for more information). T-mobile is planning to offer hot spot coverage in over 70% of Starbucks' North America locations, as well as in a number of airports and hotels. T-mobile acquired the WiFi assets from Mobilestar, an earlier WLAN service provider that went bankrupt in 2001. Other public WiFi service providers include Boingo (www.boingo.com), Wayport (www.wayport.com), Hotspotzz (www.hotspotzz.com, formerly WiFi Metro).

Moreover, wireless facilities can provide scalable infrastructure when penetration will increase only slowly over time (e.g., when a new service is offered or in an overbuild scenario). New base stations are added as more users in the local area join the wireless network and cells are resized. Wireless infrastructure may be deployed more rapidly than wireline alternatives to respond to new market opportunities or changing demand. These aspects of wireless may make it attractive as an overbuild competitor to wireline local access, which has large sunk/fixed costs that vary more with the homes passed than the actual level of subscribership. The high upfront cost of installing new wireline last-kilometer facilities is one of the reasons why these may be a natural monopoly, at least in many locations.

Wireless technologies also facilitate mobility. This includes both (1) the ability to move devices around without having to move cables and furniture and (2) the ability to stay continuously connected over wider serving areas. We refer to the first as local mobility and this is one of the key advantages of WLANs over traditional wireline LANs. The second type of mobility is one of the key advantages of mobile systems such as 3G. WLANs trade the range of coverage for higher bandwidth, making them more suitable for "local hot spot" service. In contrast, 3G offer much narrower bandwidth but over a wider calling area and with more support for rapid movement between base stations. Although it is possible to cover a wide area with WiFi, it is most commonly deployed in a local area with one or a few base stations being managed as a separate WLAN. In contrast, a 3G network would include a large number of base stations operating over a wide area as an integrated wireless network to enable load sharing and uninterrupted hand-offs when subscribers move between base stations at high speeds.

This has implications for the magnitude of initial investment required to bring up WLAN or 3G wireless service and for the network management and operations support services required to operate the networks. However, it is unclear at this time which type of network might be lower cost for equivalent scale deployments, either in terms of upfront capital costs (ignoring spectrum costs for now) or on-going network management costs.

3.2. Both are access technologies

Both 3G and WiFi are access or edge-network technologies. This means they offer alternatives to the last-kilometer wireline network. Beyond the last kilometer, both rely on similar network connections and transmission support infrastructure. For 3G, the wireless link is from the end-user device to the cell base station which may be at a distance of up to a few kilometers, and then dedicated wireline facilities to interconnect base stations to the carrier's backbone network and ultimately to the Internet cloud. The local backhaul infrastructure of the cell provider may be offered over facilities owned by the wireless provider (e.g., microwave links) or leased from the local wireline telephone service provider (i.e., usually the incumbent local exchange carrier or ILEC). Although 3G is conceived of as an end-to-end service, it is possible to view it as an access service.[20]

[20] Traditional mobile services were principally communication services—supporting telephony between two wireless handsets. When used in this mode, it makes sense to conceive of the service as end-to-end with common wireless technologies at both ends. However, when 3G is used for data services such as browsing the Web, it may more appropriately be viewed as an access service.

For WiFi, the wireless link is a hundred meters from the end-user device to the base station.[21] The base station is then connected either into the wireline LAN or enterprise network infrastructure or to a wireline access line to a carrier's backbone network and then eventually to the Internet. For example, WiFi is increasingly finding application as a home LAN technology to enable sharing of DSL or cable modem residential broadband access services among multiple PCs in a home or to enable within-home mobility (see, Brown, 2002; Drucker & Angwin, 2002). WiFi is generally viewed as an access technology, not as an end-to-end service.

Because both technologies are access technologies, we must always consider the role of backbone wireline providers that provide connectivity to the rest of the Internet and support transport within the core of the network. These wireline providers may also offer competing wireline access solutions. For example, one could ask whether a local wireline telephone company might seek to offer WiFi access as a way to compete with a 3G provider; or a 3G provider might expand their offerings (including integrating WiFi) to compete more directly with a wireline service provider. Of course, the incentives for such head-to-head competition are muted if the 3G provider and wireline telephone service provider (or cable modem provider) share a common corporate parent (e.g., Verizon and Verizon Wireless or Telefonica and Telefonica Moviles).

Finally, focusing on the access nature of 3G and WiFi allows us to abstract from the other elements of the value chain. Wireless services are part of an end-to-end value chain that includes, in its coarsest delineation at least (1) the Internet back bone (the cloud); (2) the second kilometer network providers (wireline telephone, mobile, cable, or a NextGen carrier); and (3) the last kilometer access facilities (and, beyond them, the end-user devices). The backbone and the second kilometer may be wireless or wireline, but these are not principally a "wireless" challenge. It is in the last kilometer—the access network—that delivering mobility, bandwidth, and follow-me-anywhere/anytime services are most challenging.

3.3. Both offer broadband data service

Both 3G and WiFi support broadband data service, although as noted earlier, the data rate offered by WiFi (11 Mbps) is substantially higher than the couple of 100 kbps expected from 3G services. Although future generations of wireless mobile technology will support higher speeds, this will also be the case for WLANs, and neither will be likely to compete with wireline speeds (except over quite short distances).[22]

The key is that both will offer sufficient bandwidth to support a comparable array of services, including real-time voice, data, and streaming media, that are not currently easily supported over narrowband wireline services. (Of course, the quality of these services will be quite different as will be discussed further below.) In this sense, both will support "broadband" where we define this as "faster than what we had before".

Both services will also support "always on" connectivity which is another very important aspect of broadband service. Indeed, some analysts believe this is even more important than the raw throughput supported.

[21] As noted above, it is possible to integrate WiFi with other wireless technologies to extend coverage which would be necessary in less dense areas.

[22] Wireline here includes fiber optic and hybrid cable/fiber systems.

4. How are they different

In this section, we consider several of the important ways in which the WiFi and 3G approaches to offering broadband wireless access services are substantively different.

4.1. Current business models/deployment are different

As noted above 3G represents an extension of the mobile service-provider model. This is the technology of choice for upgrading existing mobile telephone services to expand capacity and add enhanced services. The basic business model is the telecommunications services model in which service providers own and manage the infrastructure (including the spectrum) and sell service on that infrastructure.[23] End-customers typically have a monthly service contract with the 3G provider and view their payments as a recurring operating expense—analogous to regular telephone service. Not surprisingly, the 3G business model is close to the wireline telephone business. The mindset is on long-lived capital assets, ubiquitous coverage, and service integration. Moreover, telecommunications regulatory oversight, including common carriage and interconnection rules are part of the landscape.[24] The service is conceptualized usually as a mass-market offering to both residential and business customers on a subscription basis. The 3G deployment and service provisioning model is top–down, vertically integrated, and is based on centralized planning and operation.[25] It is expected that 3G services will be provided as part of a bundled service offering, to take advantage of opportunities to implement price discrimination strategies and to exploit consumers' preferences for "one-stop" shopping/single bill service.

In contrast, WiFi comes out of the data communications industry (LANs) which is a by-product of the computer industry. The basic business model is one of equipment makers who sell boxes to consumers. The services provided by the equipment are free to the equipment owners. For the customers, the equipment represents a capital asset that is depreciated. While WiFi can be used as an access link, it has not heretofore been thought of as an end-to-end service. Only relatively recently have WLANs been targeted as a mass-market offering to home users. Previously, these were installed most typically in corporate or university settings. End-user customers buy the equipment and then self-install it and interconnect it to their access or enterprise network facilities. Typically, the users of WiFi networks are not charged directly for access. Service is provided free for the closed user-community (i.e., employees of the firm, students at the university), with the costs of providing wireless access subsidized by the firm or university. More recently, we have seen the emergence of the FreeNet movement and several service-provider initiatives to offer (semi-) ubiquitous WiFi access services.

Participants in the FreeNet movement are setting up WiFi base stations and allowing open access to any users with suitable equipment to access the base station (i.e., just an 801.11b PC card

[23] Of course, more recently we have seen the emergence of non-facilities-based mobile providers. For further discussion, see Linsenmayer, McKinght, and Lehr (2002).

[24] Because of facilities-based competition for mobile services is much more developed than for traditional wireline telephony, mobile service providers are subject to less regulatory oversight, including common carriage obligations.

[25] Eli Noam has discussed how FCC spectrum policy has fostered the perpetuation of vertically integrated wireless service models and how different policies might enable the sorts of alternative business models and industry structure discussed here (see Noam, 2001).

in a laptop). Participants in this grass-roots movement do not charge for use of the access service (either to recover the costs of the wireless access infrastructure or the recurring costs of providing connectivity to the Internet). Because data traffic is inherently bursty and many end-users have dedicated facilities for which they pay a flat rate to connect to the Internet and because they have already incurred the cost of the wireless access equipment for their own needs, FreeNet proponents argue that the incremental cost of supporting access is zero, and hence, the price ought to be also. While this may be true on lightly loaded networks, it will not be the case as FreeNets become more congested and it will not be the case for traffic-variable costs upstream from the FreeNet. Moreover, if migration of consumers from paid access services to FreeNet access is significant, this will cannibalize the access revenues earned by service providers offering wireline or wireless access services. These issues raise questions about the long-term viability of the FreeNet movement. In any case, this movement is playing an important role in raising awareness and helping to develop end-user experience with using wireless broadband access services.

In addition to the FreeNet movement, there are a number of service providers now looking at using WiFi as the basis for wireless access over broad geographic areas.[26] One of the more ambitious efforts is being undertaken by Boingo, which was founded by Sky Dayton, the chairman and founder of Earthlink (one of the largest ISPs in the US).[27] Boingo's business model is to act as a clearinghouse and backbone infrastructure provider for local service providers interested in deploying WiFi access networks. Boingo will sell end-users a monthly subscription service that Boingo would then share with the WiFi network owners to compensate them for deploying and providing the service. Boingo can handle the customer billing and marketing, building out its footprint organically, as more and more WiFi local service providers join the Boingo family of networks. Partners may include smaller ISPs, hotels, airport lounges, and other retail establishments interested in offering wireless access to their clientele.

With respect to deployment, 3G will require substantial investment in new infrastructure to upgrade existing 2G networks, however, when deployed by an existing mobile provider, much of the 2G infrastructure (e.g., towers and backhaul network) will remain useable. For WiFi, it is hoped that deployment can piggyback on the large existing base of WLAN equipment already in the field. In both cases, end-users will need to buy (or be subsidized) to purchase suitable interface devices (e.g., PC cards for 3G or WiFi access).

In contrast to 3G, WiFi wireless access can emerge in a decentralized, bottom–up fashion (although it is also possible for this to be centrally coordinated and driven by a wireline or mobile service provider). While the prevailing business model for 3G services and infrastructure is vertically integrated, this need not be the case for WiFi. This opens up the possibility of a more heterogeneous and complex industry value chain. One impediment to the growth of paid but

[26] Some of the new providers seeking to offer WiFi "hot spot" services at a profit include Mobile Internet Services (MIS), in Japan; WiFi Metro in California; Joltage Networks in New York; and Wayport, Airpath Wireless, and Boingo offering services nationally in the US.

[27] (See Charny, 2001). As of July 2002, Boingo has completed the first phase of their roll-out, with hot spot access being offered in 500 locations, including several major airports (e.g., Dallas/Ft. Worth, Seattle-Tacoma, etc.) and lobby access in many hotels (e.g., Four Seasons, Hilton, Marriott, etc.). Boingo offers several tiers of service, ranging from a la carte service for $7.95 per 24-h connect day to $74.95 per month for unlimited access service (see www.boingo.com for additional information about service availability and pricing).

decentralized WiFi service offerings is consumers' preference for one-stop shopping/single monthly billing. Boingo's model offers one approach to overcoming this resistance. Alternative approaches that are under research consideration (i.e., not commercially viable today) include using some form of micro-payments (e.g., eCash or credit card billing). It is also well known that consumers have a demonstrated preference for flat rate billing, which may cause problems in a decentralized WiFi provisioning model. If backhaul costs are traffic variable (e.g., suppose the rate for Internet connection from base station to the cloud varies with traffic), then offering flat rate service may be perceived as too risky for the base station owner. Once again, Boingo's approach suggests how an intermediary willing to aggregate customers and take advantage of the scale economies associated with serving a larger customer base (e.g., with respect to retail costs and backhaul traffic management costs) can play an important role in facilitating the emergence of decentralized networking infrastructure.

4.2. Spectrum policy and management

One of the key distinctions between 3G and WiFi that we have only touched upon lightly thus far is that 3G and other mobile technologies use licensed spectrum, while WiFi uses unlicensed shared spectrum. This has important implications for (1) cost of service; (2) quality of service (QoS) and congestion management; and (3) industry structure.

First, the upfront cost of acquiring a spectrum license represents a substantial share of the capital costs of deploying 3G services. This cost is not faced by WiFi which uses the shared 2.4 GHz unlicensed, shared spectrum.[28] The cost of a spectrum license represents a substantial entry barrier that makes it less likely that 3G services (or other services requiring licensed spectrum) could emerge in a decentralized fashion. Of course, with increased flexibility in spectrum licensing rules and with the emergence of secondary markets that are being facilitated by these rules, it is possible that the upfront costs of obtaining a spectrum license could be shared to allow decentralized infrastructure deployment to proceed. Under the traditional licensing approach, the licensing of the spectrum, the construction of the network infrastructure, and the management/operation of the service were all undertaken by a single firm. Moreover, rigid licensing rules (motivated in part by interference concerns, but also in part, by interest group politics)[29] limited the ability of spectrum license holders to flexibly innovate with respect to the technologies used, the services offered, or their mode of operation. In the face of rapid technical progress, changing supply and demand dynamics, this lack of flexibility increased the costs and reduced the efficiency of spectrum utilization. High-value spectrum trapped in low-value uses could not be readily redeployed. With the emergence of secondary markets, it would be possible

[28] Additional unlicensed spectrum is available at 5GHz used by the 802.11a technology. Chipsets supporting both 802.11a and 802.11b on a single chip are expected to be available in 2003 to support roaming across both types of networks.

[29] See Hazlett (2001) or 37 Concerned Economists (2001), "The wireless craze, the unlimited bandwidth myth, the spectrum auction faux pas, and the punchline to Ronald Coase's "Big Joke": an essay on airwave allocation policy," AEI-Brookings Joint Center for Regulatory Studies Working Paper 01-01, January 2001; or, Comments of 37 Concerned Economists, in the matter of promoting efficient use of spectrum through elimination of barriers to the development of secondary markets, Before the Federal Communications Commission, WT Docket No. 00-230, February 7, 2001.

for spectrum brokers to emerge or service integrators that could help distribute the spectrum cost to enable decentralized infrastructure investment for licensed spectrum.

Second, while licensed spectrum is expensive, it does have the advantage of facilitating QoS management. With licensed spectrum, the licensee is protected from interference from other service providers. This means that the licensee can enforce centralized allocation of scarce frequencies to adopt the congestion management strategy that is most appropriate.

In contrast, the unlicensed spectrum used by WiFi imposes strict power limits on users (i.e., responsibility not to interfere with other users) and forces users to accept interference from others.[30] This makes it easier for a 3G provider to market a service with a predictable level of service and to support delay-sensitive services such as real-time telephony. In contrast, while a WiFi network can address the problem of congestion associated with users on the same WiFi network, it cannot control potential interference from other WiFi service providers or other RF sources that are sharing the unlicensed spectrum (both of which will appear as elevated background noise).[31] This represents a serious challenge to supporting delay-sensitive services and to scaling service in the face of increasing competition from multiple and overlapping service providers. A number of researchers have started thinking about how to facilitate more efficient resource allocation of unlicensed spectrum, including research on possible protocols that would enable QoS to be managed more effectively (see, Peha & Satapathy, 1997).

Third, the different spectrum regimes have direct implications for industry structure. For example, the FreeNet movement is not easily conceivable in the 3G world of licensed spectrum. Alternatively, it seems that the current licensing regime favors incumbency and, because it raises entry barriers, may make wireless-facilities-based competition less feasible.[32]

4.3. Status of technology development different

The two technologies differ with respect to their stage of development in a number of ways. These are discussed in the following subsections.

4.3.1. Deployment status[33]

In most OECD countries, cell phone penetration of 2G services is quite high, and consumers have a choice among multiple facilities-based providers in most markets. Additionally, most of the 2G mobile service providers have announced plans to offer 3G broadband data services. Nevertheless, 3G services are emerging only slowly. There are a number of reasons for this, including the high costs of obtaining 3G licenses, the lack of 3G handsets, increased deployment cost expectations, and diminished prospects for short-term revenue.

[30] The power constraints limit the range of WiFi base stations.

[31] For example, interference in the form of elevated noise levels may come from microwave ovens and cordless (non-WiFi) telephones that are common in many homes and operate in the 2.4 GHz spectrum used by WiFi.

[32] The flip side of this is that a licensing regime that creates entry barriers may make the benefits of deploying wireless infrastructure more appropriable which would encourage investment in these services. This, in turn, may increase the likelihood that wireless will offer effective competition to wireline services.

[33] The overall slump in telecommunications has depressed investment across the sector. This affects both the development of 3G and WiFi. The discussion in this focuses on what is different about WiFi and 3G.

In contrast, we have a large installed base of WiFi networking equipment that is growing rapidly as WiFi vendors have geared up to push wireless home networks using the technology. The large installed base of WiFi provides substantial learning, scale, and scope economies to both the vendor community and end-users. The commoditization of WiFi equipment has substantially lowered prices and simplified the installation and management of WiFi networks, making it feasible for non-technical home users to self-install these networks.

However, although there a large installed base of WiFi equipment, there has been only limited progress in developing the business models and necessary technical and business infrastructure to support distributed service provisioning. In addition, many of the pioneers in offering wireless access services such as Mobilstar[34] and Metricom[35] went bankrupt in 2001 as a consequence of the general downturn in the telecom sector and the drying up of capital for infrastructure investment.

4.3.2. Embedded support for services

Another important difference between 3G and WiFi is their embedded support for voice services. 3G was expressly designed as an upgrade technology for wireless voice telephony networks, so voice services are an intrinsic part of 3G. In contrast, WiFi provides a lower layer data communications service that can be used as the substrate on which to layer services such as voice telephony. For example, with IP running over WiFi it is possible to support voice-over-IP telephony. However, there is still great market uncertainty as to how voice services would be implemented and quality assured over WLAN networks.

Another potential advantage of 3G over WiFi is that 3G offers better support for secure/private communications than does WiFi. However, this distinction may be more apparent than real. First, we have only limited operational experience with how secure 3G communications are. Hackers are very ingenious and once 3G systems are operating, we will find holes that we were not previously aware of. Second, the security lapses of WiFi have attracted quite a bit of attention and substantial resources are being devoted to closing this gap. Although wireless communications may pose higher risks to privacy (e.g., follow-me anywhere tracking capabilities) and security (i.e., passive monitoring of RF transmissions is easier) than do wireline networks, we do not believe that this is likely to be a long-term differentiating factor between 3G and WiFi technologies.

4.3.3. Standardization

It is also possible to compare the two technologies with respect to the extent to which they are standardized. Broadly, it appears that the formal standards picture for 3G is perhaps more clear than for WLAN. For 3G, there is a relatively small family of internationally sanctioned

[34] In early 2002, the assets of Mobilestar were acquired by Voicestream Wireless, a member of the T-Mobile International Group, which is the wireless subsidiary of Deutsche Telecom.

[35] Metricom offered wireless services via its Ricochet network that utilized unlicensed spectrum in the 900 MHz and 2.4 GHz band (same as used by WiFi) but it was based on proprietary, non-WiFi compatible technology. Metricom's Ricochet assets were purchased by Denver-based, Aerie Networks, which is hoping to restart the Ricochet national network (for additional information, see www.aerienetworks.com).

standards, collectively referred to as IMT-2000.[36] However, there is still uncertainty as to which of these (or even if multiple ones) will be selected by service providers. In contrast, WiFi is one of the family of continuously evolving 802.11x wireless Ethernet standards, which is itself one of many WLAN technologies that are under development. Although it appears that WiFi is emerging as the market winner, there is still a substantial base of HomeRF and other open standard and proprietary technologies that are installed and continue to be sold to support WLANs. Thus, it may appear that the standards picture for WLANs is less clear than for 3G, but the market pressure to select the 802.11x family of technologies appears much less ambiguous—at least today.

Because ubiquitous WLAN access coverage would be constructed from the aggregation of many independent WLANs, there is perhaps a greater potential for the adoption of heterogeneous WLAN technologies than might be the case with 3G. With 3G, although competing service providers may adopt heterogeneous and incompatible versions of 3G, there is little risk that there will be incompatibilities within a carrier's own 3G network. Of course in the context of a mesh of WLANs, reliance on IP as the basic transport layer may reduce compatibility issues at the data networking level, although these could be significant at the air interface (i.e., RF level). Unless coordinated, this could be a significant impediment to realizing scale economies and network externality benefits in a bottom–up, decentralized deployment of WiFi local access infrastructure.

4.3.4. Service/business model

3G is more developed than WiFi as a business and service model. It represents an extension of the existing service-provider industry to new services, and as such, does not represent a radical departure from underlying industry structure. The key market uncertainties and portions of the valuation that remain undeveloped are the upstream equipment and application/content supplier markets and ultimate consumer demand.

In contrast, WiFi is more developed with respect to the upstream supplier markets, at least with respect to WLAN equipment which has become commoditized.[37] Moreover, consumer demand—certainly business demand and increasingly residential broadband home user demand—for WLAN equipment is also well established. However, commercialization of WiFi services as an access service is still in its early stages with the emergence of Boingo and others.

Of course, both 3G and WiFi access face great supplier and demand uncertainty with respect to what the next killer applications will be and how these services may be used once a rich set of interactive, multimedia services become available.

There are also some form factor issues that may impact the way these services will be used. Initially, it seems likely that the first 3G end-user devices will be extensions of the cell phone while the first WiFi end-user devices are PCs. Of course, there are also 3G PC cards to allow the PC to be used as an interface device for 3G services, and with the evolution of Internet appliances (post-PC devices), we should expect to see new types of devices connecting to both types of networks.

[36] International Mobile Telecommunications 2000 (IMT-2000) is the project initiated by the ITU to harmonize 3G standardization efforts. There are a number of contending technologies that may be implemented. The GSM-centric countries appear likely to adopt W-CDMA (UMTS); while some CDMA-based carriers in the US and Korea are promoting cdma2000, an incompatible standard. For additional information, see, www.itu.int/imt or www.three-g.net/.

[37] One of the factors holding back 3G deployment is a lack of 3G-capable handsets and other networking equipment.

However, for mobility, we should expect to continue to see constraints on size and power requirements that will impose constraints on the services that are offered. Without an external source of power, end-user devices communicating with a 3G base station at a long distance but with reduced bandwidth or communicating with a WiFi base station at a short distance but at a much higher data rate will both consume batteries quickly. And, adding visual displays and non-voice input capabilities to small cell phones, or telephony capabilities to PCs will present form factor challenges that will need to be addressed.

5. Some implications for industry structure and public policy

In this section we consider some of the implications that emerge from the preceding analysis, as well as offer some speculations on the possible implications for industry structure, competition, and public policy.

5.1. *WiFi is good for competition*

One implication that emerges from the above analysis is that the success of WiFi wireless local access alternatives is likely to be good for local competition. First, if only 3G survives, then it is less likely that we will see non-vertically integrated, decentralized service provisioning. And, the higher entry costs associated with acquiring licensed spectrum and the need to construct a geographically larger network to begin offering service will limit the number of firms that compete in the market. Of course, this does not mean that wireless access services would not be competitive—there may be more than enough competition among existing mobile providers to preclude the exercise of market power. However, there is also the possibility that the few 3G providers will become fewer still through mergers, and when coupled to the market power of wireline local exchange carriers, this could provide a powerful nexus for the continuation of monopoly power in last kilometer facilities. Obviously, the firms that have a potential opportunity to establish such market power—the mobile providers and the local exchange carriers (that own a significant share of the mobile operators)—have a powerful incentive to collude to establish monopoly control over mixed wireless and wireline services.

Second, if both 3G and WiFi survive, then the diversity of viable networking infrastructure strategies will be conducive to greater facilities-based competition.

Third, success of the WiFi service model could help unlock the substantial investment in private networking infrastructure that could be used as the basis for constructing an alternative infrastructure to the PSTN and cable wireline networks. As noted above, this will require adding the necessary business functionality and technical support to enable base station owners to bill for WiFi service. Once this is developed, the opportunity to create novel new ways to leverage the existing infrastructure investment will be increased.

Fourth, if only the WiFi service model survives, then we would expect this to be inherently more competitive because of the lower entry barriers for setting up local access services. The use of unlicensed spectrum means that property rights over the spectrum cannot be used to exclude potential entrants, although congestion—if not appropriately managed—could be just as effective in limiting competition. However, at the margin, the threat of competitive entry would limit the ability of any single or small group of providers from establishing bottleneck control over the last kilometer wireless access infrastructure.

Of course, since the WiFi model does depend on wireline infrastructure to connect to the Internet backbone, it is possible that wireline carriers could effectively leverage their control over wireline access facilities to adversely affect wireless access competition. Since many of the largest mobile service providers are affiliated with wireline providers, there is likely to be an incentive to discriminate against WiFi carriers if these are seen as competitors to either 3G or wireline services.

Fifth, the more flexible nature of the WiFi model means that it can seed a more complex array of potential business models that could fuel competition both at the retail level in services and at the wholesale level in alternative infrastructure. For example, WiFi could emerge as an extension of FreeNets, transmogrified into user-subsidized community networks, or via third party aggregators such as Boingo. These networks could be in direct competition to 3G services.

Another alternative might be for WiFi to be used as the last-hundred meters access technology for alternative local loop facilities (e.g., a municipally owned fiber network). In this mode, WiFi could reduce the deployment costs of overbuilders. A more generalized version of this scenario is any form of subsidized deployment, where the entity subsidizing creation of the WiFi net might be a university (campus net), a government entity (municipal net), or a business (enterprise net). The lower costs of deploying wireless as compared to installing new wireline cabling plant may reduce the adoption costs of such a strategy, thereby increasing the likelihood of their adoption.

5.2. WiFi and 3G can complement each other for a mobile provider

Yet another alternative might be for WiFi to be integrated into 3G type networks. Actually, this seems like the most likely scenario since there are compelling reasons for why these two technologies may be used together.[38]

Each of the technologies has distinct advantages over the other that would allow each to offer higher quality services under disparate conditions. Putting the two together would allow a service provider to offer a wider set of more valuable services.

The obvious adopter of such a strategy would be a mobile firm since it is easier for 3G to adopt WiFi and incorporate it into its networking strategy than for a WiFi facilities provider to go the other way. The reasons for this are several. First, there is the asymmetry in entry costs discussed earlier. Second, the natural ability of the 3G providers to implement bundled service offerings will make them more likely to be able to take advantage of a more complex infrastructure platform that will allow them to offer bundled services.

Integrating 3G and WiFi networks provides the opportunity to offer both ubiquitous coverage with good voice telephony support (still the killer app for interactive communication networks) while providing local “hot spot” connectivity in high demand areas (airports, hotels, coffee shops) or in areas where existing WiFi facilities may be opportunistically taken advantage of (malls, multi-tenant office buildings or campuses). The hot spot connectivity would be attractive to offset the capacity limitations of 3G. The 3G mobile billing and wide-area network management (e.g.,

[38] Indeed, a number of carriers have explored integrating WiFi hot spot technologies into there networks and a growing number of analysts believe that WLANs will be critical components for future 3G networks (see Telecom A.M. (2001), Thorngren (2001), Reuters News Service (2002), or Alven et al. (2001)).

homing, hand-off control, authentication, resource allocation/management, etc.) capabilities could address some of the shortfalls that are limiting the capability of WiFi to evolve into a platform for mass wireless access.

Adopting such a strategy would offer the mobile provider the opportunity to tap new service markets. For example, allow scheduled high-speed file transfers (e.g., queue email with big attachments for downloading when opportunistically near WiFi hot spot); or, allow more adaptive power management strategies (e.g., switch from WiFi to 3G service to conserve battery power with more graceful performance degradation, or vice versa if external power becomes available). These and other services could increase the revenue opportunities available to the wireless service provider.

Additionally, adopting such a strategy would be defensive. Coopting the competition is a well-known strategy. If WiFi succeeds, then 3G networks that fail to implement WiFi-like functionality will lose service revenues to WiFi enabled competitors.

On the other hand, integrating WiFi into a 3G network may increase deployment costs. The business/service model will be more complex and many adjustments will be required within mobile firms. When set against the potential revenue benefits, however, these higher coordination/adjustment costs do not seem likely to be overly substantial.

5.3. Spectrum policy is key

Obviously, spectrum policy has already had and will continue to play a critical role in how our wireless future evolves. One of the key distinguishing features between 3G and WiFi is the use of licensed versus unlicensed spectrum.

Continued progress towards creating secondary spectrum markets will benefit both 3G and WiFi models. For 3G, secondary markets would allow more flexible management of property rights. Secondary markets would allow spectrum to be reallocated more flexibly to higher value uses and could improve dynamic efficiency. For example, to balance localized supply and demand mismatches.

For WiFi, the emergence of spectrum markets may make it possible to adopt a suitable mechanism for addressing congestion issues. Of course, if implemented in the unlicensed band where WiFi currently operates, this would require additional policy changes to implement a market-based resource allocation process. The appropriate protocols and institutional framework for supporting such a market is an interesting topic for research. It may be easier to implement such a mechanism in a WLAN technology that could operate in a licensed band where there are clear property rights.

5.4. Success of WiFi is potentially good for multimedia content

Multimedia content benefits from higher bandwidth services so the ability to support higher speed wireless access may help encourage the development of broadband multimedia content.

On the other hand, the lack of a clear business model for deploying broadband services over a WiFi network may raise concerns for how content would be paid for and/or digital rights management issues. The digital rights management issues are perhaps more difficult to control (from a content provider's perspective) in a more decentralized, end-user-centric environment than in a centralized service-provider network (i.e., contrast Napster to AOL). The vertical integration model of 3G may offer greater control, which might actually encourage more content production.

This is a complex question that merits additional thought. It is premature to posit which of the two effects are likely to be larger.

5.5. Technical progress favors heterogeneous future

Technical progress in wireless services favors a heterogeneous wireless future. There are several reasons for this. First, with each technology, the rapid pace of innovation means that multiple generations of each technology coexist in the network at the same time. Coupled to this heterogeneity, there is the on-going competition among alternative wireless technologies. All of these share common benefits so to a certain extent, all benefit from advances in basic elements such as modulation techniques, smart antenna design, power management and battery technology, and signal processing technology. However, because the different technologies have asymmetric problems, basic advances affect them differently. This means that in the on-going horse race different technologies are boosted at different times.

Once the world accepts the need to coordinate heterogeneous technologies, the capabilities to manage these environments evolve. For example, the success of the IP suite of protocols rests in large part on their ability to support interoperable communications across heterogeneous physical and network infrastructures. Analogously, developments in wireless technology will favor the coexistence of heterogeneous wireless access technologies.

One of the more important developments will be software defined radio (SDR).[39] SDR does a number of important things. First, it makes it easier to support multiple wireless technologies on a common hardware platform. Second, it makes upgrades easier and more flexible to implement since it substitutes software for hardware upgrades. Third, it facilitates new and more complex interference management techniques. These are useful for increasing the utilization of spectrum.

The implication of all this for WiFi-like strategies appears clear. It improves the likelihood that WiFi will emerge as a viable model. This is further enhanced because the success of WiFi will, perforce, require additional technical progress to resolve some of the issues already discussed (e.g., security, QoS management, service billing). The implications for 3G are perhaps somewhat less clear. The 3G approach is similar to other telecommunication standards approaches (e.g., ISDN, ATM, etc.): it is most successful when it is monolithic. The centralized, top–down approach to network deployment is more vulnerable and less adaptive to decentralized and independent innovations.

6. Conclusions

This article offers a qualitative comparison of two wireless technologies that could be viewed simultaneously as substitute and/or complementary paths for evolving to broadband wireless

[39] Traditional radios are based on dedicated hardware. By implementing the radio technology in software, it becomes feasible to design more flexible radios that may more readily support multiple protocols and may more easily be upgraded/modified to incorporate new protocols or other features. For additional information, see Lehr, Gillett and Merino (2002).

access. The two technologies are 3G, which is the preferred upgrade path for mobile providers, and WiFi, one of the many WLAN technologies.

The goal of the analysis is to explore two divergent world views for the future of wireless access and to speculate on the likely success and possible interactions between the two technologies in the future.

While the analysis raises more questions than it answers, several preliminary conclusions appear warranted. First, both technologies are likely to succeed in the marketplace. This means that the wireless future will include heterogeneous access technologies so equipment manufacturers, service providers, end-users, and policy makers should not expect to see a simple wireless future.

Second, we expect 3G mobile providers to integrate WiFi technology into their networks. Thus, we expect these technologies to be complementary in their most successful mass-market deployments.

Third, we also expect WiFi to offer competition to 3G providers because of the lower entry costs associated with establishing WiFi networks. This may take the form of new types of service providers (e.g., Boingo), in end-user organized networks (e.g., FreeNet aggregation or municipal networking), or as a low-cost strategy for a wireline carrier to add wireless services. The threat of such WiFi competition is beneficial to prospects for the future of last kilometer competition, and will also encourage the adoption of WiFi technology by 3G providers as a defensive response.

Our analysis also suggests a number of areas where further thought and research would be beneficial. These include the obvious questions of how to integrate 3G and WiFi networks or how to add the appropriate billing/resource negotiation infrastructure to WiFi to allow it to become a wide-area service-provider platform. These also include several more remote questions such as which style of technology/business approach is favored by the rapid pace of wireless technology innovation or which is more likely to favor the development of complementary assets such as broadband content.

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