Open Wireless vs. Licensed Spectrum: Evidence from Market Adoption

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Abstract

This paper addresses the long standing spectrum policy question surrounding how much of the future of wireless innovation will depend on exclusively-licensed spectrum, allocated by auction and traded in secondary markets, relative to how much will utilize bands in which open (unlicensed, dynamic frequency sharing, license-by-rule etc.) wireless systems are permitted. I review evidence from eight wireless markets: mobile broadband; wireless healthcare; smart grid communications; inventory management; access control; mobile payments; fleet management; and secondary markets in spectrum. I find that markets are adopting open wireless strategies in mission-critical applications, in many cases more so than they are building on licensed strategies. Eighty percent of wireless healthcare; seventy percent of smart grid communications; and forty to ninety percent of mobile broadband data to smartphones and tablets use open wireless strategies. Open technologies are dominant in inventory management and access control. For mobile payments, current major applications use open wireless, and early implementations of mobile phone payments suggest no particular benefit to exclusive-license strategies. Fleet management is the one area where licensed technologies are predominant. However, UPS, owner of the second largest commercial fleet in the U.S., has implemented its fleet management system (trucks; not packages) with an open wireless strategy, suggesting that even here open wireless may develop attractive alternatives. By contrast to these dynamic markets, secondary markets in licensed spectrum have been anemic.

Market deployments of wireless technologies suggest that open wireless strategies follow the innovation model of the Internet, applied to wireless communications. Licensed-spectrum, by contrast, replicates the telephone system model. A comparison between the United States and Europe smart grid communications markets provides particularly crisp evidence that providing substantial space for open wireless experimentation can result in a significantly different innovation path. Europe uses very little wireless smart grid communications by comparison to the U.S., all of it licensed-cellular. American smart grid communications systems, by contrast, overwhelmingly rely on wireless, three-quarters of it using open wireless systems. One obvious difference between the two systems is that Europe has very little open wireless spectrum allocations below 1GHz; what little there is, is balkanized and subject to highly restrictive power limits; Europe also imposes severe power constraints on devices using its 2.4GHz bands. The United States, by contrast, has a contiguous 26MHz band, 901-928MHz, with less restrictive power limits, which plays a central role in American smart grid communications markets.

As Congress and the FCC seek ways to transition away from older technologies, it is important to recognize that open wireless innovation needs open wireless systems. Legislators and regulators alike should adopt policies explicitly designed to assure that open wireless innovation has at least as much room to grow as licensed-wireless approaches.

Exhaustive auctioning of TV bands, or other bands sought to be cleared for mobile broadband under the National Broadband Plan, will restrict the freedom to operate that has harnessed an open, Internet-like model of innovation to wireless technologies in other, open bands. In the TV bands this is particularly troubling, given that open wireless operation in these bands could address limitations that open solutions have faced in providing wider, more continuous coverage, limitations caused by regulatory constraints in other open wireless bands.

The political economy of decision-making in this area is skewed. Those who seek exclusive licensing internalize the full benefit of exhaustive auctioning. Those who support open spectrum cannot internalize more than a small portion of openness because the policy they lobby for excludes ownership by any one firm or alliance. The former will systematically out-lobby and out-bid the latter.

Even honest congressional efforts to maximize auction revenue undermine the efficiency of mobile markets and provide a subsidy to mobile broadband carriers, financed by what is effectively a tax farming scheme. Carriers are willing to pay for spectrum at auction because it is cheaper to use public spectrum than to invest in building more private cell towers. Dominant carriers are willing to pay even more, because getting an exclusive license lets them foreclose competitors and exercise pricing power. Selling that pricing power maximizes short term government revenue, but effectively creates a tax farming scheme, much of whose revenue goes to subsidize mobile broadband roll-out in an inefficient market structure. As a practical matter, pure revenue maximization sacrifices both innovation in open wireless, and therefore growth; and efficiency in the licensed service markets, and therefore welfare.

Introduction

A series of bills introduced in 2011in Congress[1] and a provision of the American Jobs Act of 2011 that the White House proposed[2] seek to raise revenue by conducting more-or-less exhaustive auctions of TV Bands. Some suggestions would take a similar approach to other bands, currently used by the federal government, that could be released for commercial uses. The primary policy question at stake in these auctions is whether the TV bands will be exhaustively auctioned, so as to raise every cent possible at auction, or whether the Federal Communications Commission would be granted authority to dedicate some of the cleared bands to open wireless uses.

The revenue implications of the decision are quite small. The Congressional Budget Office apparently will score a bill that excludes any open wireless operation as worth about $1 billion more over the next decade than a bill that would not prohibit the FCC from dedicating some bands to open operation. In exchange for that 1 billion dollars, Congress shall have extended the telecommunications-centric innovation model that typified the twentieth century: the Bell System or the French Minitel, for a significant class of wireless innovations, and force the FCC to prohibit experimentation with an Internet model of wireless innovation in these bands. The explosive growth of open wireless devices, technologies, and services over the past decade suggests that even if applications in the newly freed bands would provide a fraction of the benefits offered by WiFi and other present open wireless applications, this choice would prove truly penny wise, pound foolish. Permitting open wireless operation in the TV bands would, moreover, permit innovation precisely in the dimensions that current regulations restricting open wireless innovation prohibit: continuous coverage. The likelihood that new, innovative services will fail to develop in these spaces under these circumstances, given experience with other open wireless bands, is therefore vanishingly small.

Background

For the past fifteen years the major spectrum policy debate has been over which of two major alternatives to traditional command and control licensing was better. One option, "spectrum property," seeks to create markets in exclusive spectrum licenses, initially allocated by auction. These would be designed to offer sufficient flexibility to mimic property rights, and traded in secondary markets that would efficiently allocate them to diverse uses in wireless markets.[3] A first important refinement of this approach would have eliminated auctions for big swaths of spectrum, and replaced them with spot markets in spectrum clearance rights.[4] The primary other alternative to command and control was that bands in which no one had an exclusive license to operate, called "unlicensed wireless," "open wireless," or "spectrum commons," would enable device vendors and service providers to develop markets in sophisticated equipment and network services built on them to deliver reliable connectivity without possessing an exclusive right to transmit.[5] (Here I use "open wireless" to include variants sometimes termed license-by-rule, license-lite, and opportunistic sharing, in addition to unlicensed.) The FCC first began to experiment with this model in the late 1980s.[6] The market created by auctions of licensed-spectrum was a market in exclusive rights to build and use infrastructure. The markets created by open wireless approaches were markets in computation-intensive devices and the networks and services that could be constructed out of them.

In 2002, an FCC Spectrum Task Force reported on these two options as the major alternatives to the traditional command-and-control approach. The Report found that future wireless regulation would have room for all three approaches, old and new, but placed a particular emphasis on auctions and property-like markets as the baseline desirable approach for lower frequencies.[7] A substantial literature developed on the choice between the two options, but reached no theoretical resolution. There was relatively wide agreement that command-and-control was not a desirable option, but the question of how much the FCC and Congress should emphasize property-like exclusive spectrum licenses, and how much they should permit open wireless operation remained unsettled, awaiting experience over the coming years.[8]

The anchor of both the command-and-control and property approaches is the idea that wireless communications "use" spectrum, and that given many potential users, not all of whom can use the spectrum at the same time, spectrum is "scarce" in the economic sense. Some*one* has to control who "uses" that spectrum, or else no one can use it. As a study published in March 2011 by the National Research Council's Computer Science and Telecommunications Board explained, this view is not a correct description of what happens when multiple transmitters transmit. If a thousand transmitters transmit, the "waves" don't destroy each other; no information is destroyed. The only thing that happens is that it becomes harder and harder for receivers to figure out who is saying what to whom as more transmitters operate next to each other. The limitation, or the real economic scarcity, is computation and the (battery) power to run calculations.[9] The regulatory model of command and control was created at a time when machine computation was practically impossible. Exclusive licensing was a way to use regulation to limit the number of transmitters in a band, so as to make it possible for very stupid devices to understand who was saying what. The economic models on which auctions are based were developed in the 1950s and 1960s, when computation was still prohibitively expensive. Practically, thinking about "spectrum" as a scarce commodity still made sense in that era.

As computation becomes dirt cheap, the assumption that spectrum is a stable, scarce resource is no longer the most useful way of looking at optimizing wireless communications systems. The question is more: which configuration of very smart equipment, wired and wireless infrastructure, network algorithms, and data processing will allow the largest number of people and machines to communicate what they want, when they want it, where they want to be? It is possible that a network that includes exclusive control over the radio-frequency channel being used will achieve that result. But it is no longer necessarily so. It may be that the flexibility that open wireless strategies provide, to deploy equipment and networks as and where you please, made of devices capable of identifying the communications they are seeking in the din of a large crowd, will do so more effectively.

Experience in real-world markets suggests that open wireless strategies have indeed been more flexible, and offered more dynamic solutions in several of the most advanced markets that provide or require wireless communications capacity. Actual market deployments strongly suggest that companies selling open wireless devices, or networks and services using such devices, have come to play the lead role. These include wireless healthcare, smart grid communications, and RFID-dependent industries like inventory management or access control. Moreover, in mobile broadband itself, WiFi offloading is fast becoming a critical component of the way in which even the organizations most clearly oriented toward the exclusive licensing model, cellular carriers, handle the fast-expanding demand for broadband data carriage. When the iPhone clogged AT&T's network, it was to WiFi, not to secondary markets in property-like spectrum licenses that the company could turn to a solution. Some markets continue to depend on licensed spectrum approaches as the core approach. These include primarily services that require continuous outdoor connectivity, such as fleet management (keeping tabs on trucks on highways, using primarily GPS), management of assets that move rapidly to diverse locations, like FedEx packages or, most dramatically, communicating irregular findings in cardiac patients subject to continuous monitoring. Even for some of these services, however, there are open wireless alternatives as long as some delay is tolerated. Fleet management, for example, may well be redesigned to make it more amenable to open wireless strategies, and that is indeed what UPS has done for its trucks. While these market segments caution against painting open wireless as ultimately becoming the sole solution, the relatively large role of open strategies suggests that we may need to reverse our orientation from one that assumes that licensed and auctioned spectrum is the core, and open wireless a peripheral complement, to one that sees open strategies as the core, with important residual roles for licensed services, however allocated. The success of open wireless strategies is highlighted by the lackluster performance of secondary markets in spectrum, both in the U.S. where they have been in operation for seven years, and in Australia where they began to function several years earlier.

Open Wireless Allocations Foster Open Wireless Innovation on an Internet model

A review of the solutions developed in the varied markets considered here suggests that the core to the success of open wireless is its innovation model. Innovation in open spaces is built on the same principle as the Internet: freedom to operate around a set of minimal standards. No one needs special permission to deploy and try out an innovation that uses open wireless strategies. Innovation in the licensed space operates on the principle of the old telephone system innovation. One can only innovate in collaboration with the system owner. Using open 900MHz channels, UPS can build its truck fleet management system without having to go to AT&T or Verizon for a solution. Similarly, a company like Silver Springs Networks could build its smart grid RF Mesh without permission or input from anyone. It captured a quarter of the smart grid market. Only 1% of that market is served by a company that depends on a licensed wireless carrier. In Europe, by contrast, there is almost no equivalent to the 900MHz open wireless band, and there has been substantially less use of wireless technology for smart grid communications. What little there is is provided by cellular carriers. Even in the case of mobile broadband, AT&T was able to use an open wireless strategy with greater agility than it was able to expand its licensed-spectrum model. When iPhone was introduced and generated a spike in demand, the rapid solution was introducing WiFi offloading; it worked much more quickly, and offered a more flexible approach, than buying more spectrum from other carriers or spectrum owners. Open wireless innovation is now working on Internet model: from healthcare to smart grids, from inventory management to mobile payments, anyone can innovate, deploy, and if users adopt the technology, win a share of the market.

What exhaustive auctions risk losing is opening up the TV bands to this freedom to operate in truly open markets, in which innovation can come from anywhere and be deployed by anyone, and consign innovation for wireless networks using these frequencies to the slower, telecoms model of innovation. As we see when reviewing applications in actual markets, seamless coverage is the one dimension along which open wireless systems are weakest, not because of inherent limitations but because of inferior allocations and regulatory constraints imposed to protect incumbent licensees. To deal with these, open wireless systems have had to use information models that can absorb enough delay to function with nomadic access. Open wireless operations in the TV bands, properly designed, could fill precisely that gap.

Evidence from eight markets suggests that open wireless strategies are at the core of most dynamic markets that require wireless communications capacity

Mobile Broadband

The most urgent calls that more spectrum be auctioned to support broadband policy, the so-called "spectrum crunch," cite the move of the Internet to smartphones and tablets, and the need to use more spectrum to deploy 4G mobile broadband networks. Chief among these was the FCC's National Broadband Plan.[10] Actual market practice, however, has seen carriers and consumers rely on the flexibility and the rapidly-growing capacity of WiFi, rather than on secondary spectrum markets, to add capacity and sustain service in the teeth of sharply growing demand.

When AT&T first introduced the iPhone, its design and ease of use caused a major spike in data usage, a spike that challenged AT&T's network beyond its capacity.[11] A fluid secondary market in spectrum should have solved this problem. In part, AT&T indeed tried to address this problem by purchasing additional 700 MHz spectrum from Qualcomm. That transaction is still pending regulatory approval as of this writing. Other firms, Clearwire and the major cable companies, also possess substantial spectrum holdings that AT&T might have acquired to help meet this demand. As described below, however, secondary markets in spectrum have been relatively inflexible and ineffective to meet the rapid increases in demand that smartphones and tablets have imposed. What AT&T in fact did was to shift data traffic to WiFi. In part, the firm bought WiFi hotspots to take a load off its capacity-constrained licensed-spectrum network. More importantly, iPhones connect to WiFi networks wherever

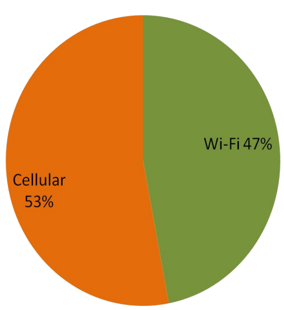

Figure 1a: Share of iPhone data traffic
Source: ComScore Digital Omnivores, Oct. 2011
Green shades denote open wireless; Orange denotes licensed

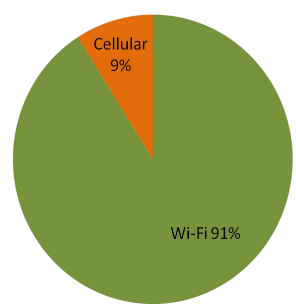

Figure 1a: Share of iPad data traffic

these are available.[12] Customers use home and office WiFi networks extensively to replace the cellular mobile data service. By the third quarter of 2011, AT&T owned 29,000 hotspots around the country; it saw WiFi traffic just on its hotspots increase threefold from the third quarter of 2010.[13] An October 2011 study by ComScore reports that 47% of iPhone page views and 91% of page views using tablets, like iPad, views are accessed over WiFi networks, rather than mobile cellular data networks.[14]

Android devices, both mobile and tablet, relied on WiFi to a lesser extent, but their users used data less intensively than did iPhone and iPad users. It seems clear that AT&T was driven to WiFi early because the iPhone's design invited major changes in data usage; it is possible that as Android interface and the app ecology continue to grow, and as Verizon adopts WiFi offloading, we will see the broader smartphone and tablet market follow the iPhone ratio.

AT&T was driven to early adoption by iPhone. Verizon only announced its plans to offload mobile broadband traffic to WiFi in May, 2011.[15] Various assessments place the combined total use of WiFi by smartphones and tablets in a fairly broad range, but in all events growing very rapidly. Juniper Research found that 63% of traffic by smartphones and tablets is currently carried over WiFi networks, projecting that that share we be close to 90% by 2015.[16] ComScore reported 37.5% of all mobile data was carried over WiFi, and that that percentage was an increase of 3% points in the second quarter of 2011 alone. ComScore also found that 91% of tablet data was carried over WiFi.[17] It is almost certain that this amount of offloading cannot be accounted by use of hotspots. In fact, Cisco's Internet Business Solutions Group found in a 2011 study that only 35% of mobile data use was "on the move," while the remainder was at home (40%) or in the workplace (25%).[18] In that same study, Cisco found that in 2010 31% of all mobile data was offloaded to home WiFi networks alone, not including workplace or hotspot offloading, and projected that percentage to grow to 39% by 2015.[19]

Deploying WiFi as a core element of mobile data networks, both 3G and now 4G, is hardly unique to AT&T or the United States. SFR, the second largest mobile operator in France, has for several years used WiFi to allow any of its mobile customers to use a separate, public portion of their home-broadband customers' WiFi gateways when they are within range. Essentially, it has made every one of its home broadband subscribers a tiny-cell tower serving its mobile broadband subscribers when they pass by them, using open WiFi.[20] SFR was following in the footsteps of another French firm, Free, which began to offer densely nomadic access to all of its subscribers using all of its subscribers' home connections when it failed to get a fourth mobile license in France's spectrum auctions.[21] BT in the UK has now followed a similar strategy with its customers, inviting its subscribers to become members of the FON network, any one of whose members can connect to the home broadband connection of any other members while on the go.[22]

A December 2009 report by Morgan Stanley early predicted the growth of WiFi offloading.[23] It reasoned that WiFi is ten times faster than 3G, and the already-existing 802.11n version of WiFi is twice as fast as the not-yet-deployed LTE networks. Arguing that mobile video is the primary driver of future demand for mobile data, requires high-speed delivery, and is largely a stationary activity, that report emphasized that mobile carriers need to develop a WiFi strategy. A report by HSBC from the same period reached a similar conclusion, skeptical that 4G capacity could scale rapidly enough to meet the faster-growing demand for data from smartphones. It suggested that either WiFi offloading or major capital expenditures on cell towers to make cells smaller would be necessary.[24]

Following this model, a new sector is emerging aimed specifically at offering WiFi offloading solutions to carriers, dealing with, among other issues, handoff between cellular and WiFi components of the network.[25] A particularly interesting example of this market is a deal concluded in July, 2011 between KDDI, Japan's second largest mobile broadband provider, and a California firm, Ruckus Wireless, to build out 100,000 WiFi spots by March 2012 as a central part of its next generation network for serving high-bandwidth mobile broadband offerings to more than 30 million subscribers.[26] The Ruckus architecture installs WiFi hotspots on lamp or utility poles, and directly integrates WiFi into the 3G/4G network. In effect, its architecture treats WiFi and LTE as different parts of the same box delivering small-cell connectivity, with WiFi the first step and LTE added later as needed and available.

The developments of the past two years see a rapidly growing role of WiFi into a basic fact of network planning. A November 2010 Gartner report, for example, states "We expect 3G/4G roaming demand to Wi-Fi to continue to increase. As Wi-Fi installations continue to grow dramatically in the service provider, consumer and enterprise markets, the main issue inhibiting seamless roaming is that there is no mechanism to roam onto properties that are foreign to the smartphone holder's home carrier or other contracted service."[27] In other words, the "crunch" isn't a spectrum crunch, but a lack of agreement about WiFi-enabled devices using their neighbors' WiFi network. This is the problem that Free, SFR, and BT began to solve by making all their subscribers members of the same WiFi roaming network. A similar problem set a barrier to an academic experiment in a 2010 paper, whose authors measured the effects on 3G use of offloading to WiFi networks, using only home WiFi connections that happened to be open for use by anyone, testing Internet connectivity in an automobile driving through a town where only 11% of the geography was covered by a WiFi home network open for passers-by to use. Even under these extremely unfavorable (to WiFi offloading) conditions, the authors were able to use the fact that many applications can tolerate delay between sending or receiving data and having it actually loaded on to the network to reduce loads on the 3G networks by 45%.[28] Needless to say that a model where all WiFi spots are open under a secure sharing protocol, like the one SFR, Free, or BT use, would result in higher coverage and the ability to use much more delay-intolerant applications.

Seeing the growing role of WiFi in the mobile broadband market, carrying half or more of the data, is important because (a) mobile broadband is the market whose needs are most often cited in support of repurposing massive amounts of spectrum from existing uses through auctions;[29] and (b) its carriers and providers are the companies most committed to a licensed carrier model, and therefore, of all the markets we survey here, most resistant to relying on open wireless techniques. WiFi offloading has not yet solved the billing problem—offloaded connections are not billed as part of the subscriber's usage cap, where applicable. Deploying them presents real business challenges to the licensed-spectrum carriers. And yet, the flexibility and scalability of open wireless networks, coupled with the relatively slow deployment and growth through the more traditional licensed cellular models, have driven these firms to adopt open wireless strategies to complement their core business model.

One might argue that the shift to WiFi offloading is itself a function of inadequate availability of licensed spectrum for mobile data. Once the auctions are concluded, this argument would go, the companies will be able to fully provision their customers' needs. But that argument entirely misses what we learn from WiFi offloading about the flexibility and innovation feasible in an open wireless environment. Like the introduction of the iPhone, we have to expect more devices and applications to come down the road that will dramatically increase the demand for capacity. New large allocations of spectrum will undoubtedly provide better service for yesterday's needs and today's; perhaps even tomorrow's. But the day after tomorrow models that depend on licensed-spectrum and large-scale infrastructure will still be as inflexible as they were in response to the iPhone's unexpected effect. And open wireless, whether WiFi, or its next generation if Congress permits it to develop in the TV bands, will be as flexible and dynamic as it was this time.

Smart Grids: How inadequate levels of open wireless allocations can hobble wireless innovation

The smart grid communications market offers a particularly crisp example of how the failure to provide adequate open wireless allocations can hobble wireless innovation. American and European markets have developed along very different trajectories, with the U.S. enjoying far greater and faster deployment of wireless smart grid communications systems, and Europe largely remaining with powerline communications solutions. The difference is not that Europe's cellular carriers aren't interested in serving smart grid markets; they are, and they do. The difference is that Europe has no usable open wireless spectrum below 1GHz, and constrained availability in the 2.4GHz bands, and, as a consequence, no significant open wireless solutions deployed.

In 2009 cellular broadband, licensed wireless, or open wireless networks were seen as significant alternatives for smart grid development.[30] At the time, Gartner had listed automated meter reading in smart grids as the largest application area for cellular machine-to-machine (M2M) uses,[31] although other observers already saw that the actual companies, landing actual contracts with utilities in the United States, where overwhelmingly relying on open wireless mesh technologies.[32] The only significant company in this sector that relies on cellular M2M in the U.S. market is SmartSync, using AT&T's network. According to a 2011 analysis of the smart grid communications market by Pike Research, SmartSync accounted for only 1% of U.S. smart grid communications markets. All but one of the major companies serving smart grid communications devices deploy open wireless systems, mostly mesh networks, combining 900MHz, 2.4GHz, as well as in some cases amateur band transmission to deliver robust, mission critical, secure services to the nation's electric utilities as they

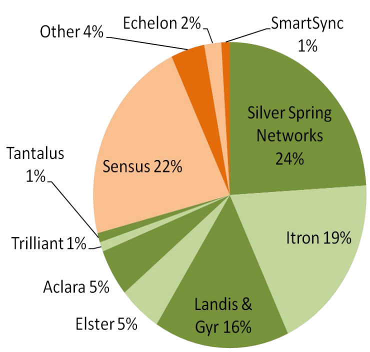

Figure 2: Smart Grid Communications U.S. Market Shares by Firm
Green shades denote open wireless, orange shades licensed
Market share source: Pike Research Smart Grid Deployment Tracker, 1Q11
Technology characterization: Author

were deploying smart grid technologies. A single major provider in this market, Sensus, uses its own licensed spectrum. It serves 22% of the market (Figure 2).[33]

Using a different measure, AMI node shipments (that is, shipments of nodes that make up the metering infrastructure) allows us to compare the U.S. to Europe. In Europe wireless smart grid communications play a much smaller role than they do in the US. Only 15% of the market is wireless; the rest uses communications over the utility's own power lines. This wireless market is served solely by cellular carriers. In the United States, by contrast, 97% of AMI nodes shipped in the first quarter of 2011 were wireless.[34] Of these 77% were for RF mesh open wireless solutions, and only 2% were for cellular 2G/3G/4G solutions. The market share of nodes shipped for use in licensed, non-cellular deployments is slightly lower than current market share of Sensus, the primary firm currently using that approach in its deployments. The difference is easily observable in Figure 3. Moreover, the North American markets are more rapidly deploying advanced metering infrastructures capable of interfacing with a home area network. Of nodes shipped, 75% in north America were advanced, whereas such meters accounted for only 28% in European markets.

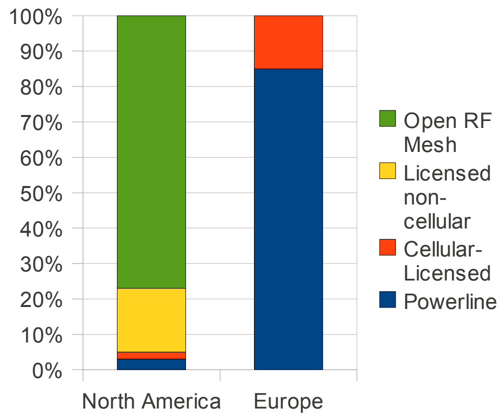

Figure 3: AMI node shipments, Q1 2011
Source: Pike and Fisher

What might account for this stark difference? A November 2011 market analysis located the difference in the regulation of open wireless devices. "Throughout the EU, communications in the unlicensed 868 MHz and 2.4 GHz bands are restricted to a lower power level and must use frequency- or channel-hopping technologies to be approved for use. As a result, private wireless mesh technologies have been relatively slow to take off in this region, opening the door for cellular communications, particularly to link the gateways or concentrators that aggregate and backhaul data from smart meters to the utility. "[35] This is consistent with an observation by a senior VP of Trilliant, one of the companies deploying open wireless mesh architecture in the U.S., and cellular-based models in Europe,[36] and with the observation that Landis and Gyr, one of the largest global providers, using licensed-cellular models in European deployments and open wireless mesh networks in North America.

The basic point is that Europe (ITU Region 1) takes a vastly different approach to regulating the ISM bands (industrial, scientific, medical) than does North America (ITU Region 2) below 1GHz. The United States has a contiguous 26MHz band, between 902-928 MHz, in which anyone capable of operating in the presence of others, no matter what application they are serving, is allowed to do so. Devices transmitting in this band play a major part in North American smart grid wireless communications deployments. By contrast, Europe offers only 3MHz for non-specific applications, broken into two 1.5MHz bands, one at 868MHz chopped up into tiny subslivers with various different limitations, and the other at 433MHz. This tiny bit of spectrum is subject to much lower power limits than those imposed in the U.S. Europe also imposes substantially lower power limits on its 2.4GHz ISM band.[37]

Few cases provide so clear an example of the different innovation paths that different policy attitudes toward open wireless can set. Europe's suspicious, not to say miserly, attitude toward open wireless, particularly below 1GHz, and even in the 2.4GHz range, has led to slower adoption of wireless communications in its smart grid infrastructures. America's openness to experimenting with a more robust open wireless allocation has fed substantially faster growth and deployment in wireless smart grid communications systems, mostly provided by communications players who specialized in smart grids and could develop solutions without asking permission—either of the FCC, or of established carriers. This is exactly the power of open innovation over open wireless bands.

Healthcare

The size and social significance the U.S. healthcare sector make it an extremely important market for wireless technologies. The promise of telemedicine, patient monitoring and care have long been touted as an important dimension for the benefits of broadband and mobile connectivity. The choices healthcare providers and patients make with regard to their wireless communications represent not only a large and important market, but also, as with smart grids, a market where these choices reflect decisions about systems whose buyers believe are mission-critical, and, in the extreme case, matters of life-and-death. Perhaps because of this feature it was a medical application that one of the most vocal critics of open wireless approaches used when he mocked the potential of open wireless spectrum by comparing it to the Internet, saying "Classically, the brain surgeon cannot read the life-or-death CT scan because the Internet backbone is clogged with junk e-mail."[38] And yet, WiFi transmitting digital images using Internet protocol is exactly what actual healthcare delivery markets have adopted. As early as 2008, it was already clear that hospitals were buying and deploying open wireless technologies, at the time in particular WiFi, as the core wireless technology for in-hospital *medical grade, mission-critical wireless networks*.[39]

A September 2011 analysis finds about 80% of the healthcare wireless market is served by a range of open wireless technologies; only 17% by licensed, cellular technologies, primarily for phones and smartphones.[40]

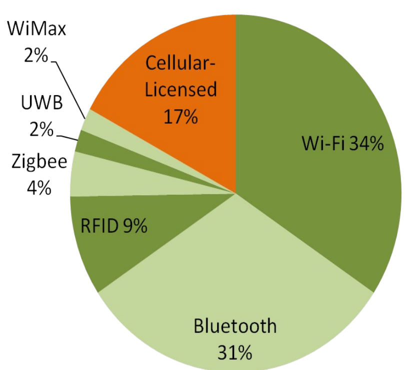

Figure 4: Market share of wireless in healthcare
Source: Kalorama Information
Wireless Technologies in Healthcare, September 2011
Green shades denote open wireless, orange shades licensed

The market in healthcare applications is a large and complex one, beyond what can be described here. It includes anything from patient monitoring systems using wearable sensors, mostly deploying RFID, Bluetooth, or ZigBee technologies, through information systems for patient follow up, records on the move within the hospital, and connecting the wearable sensors to a monitoring station, all of which appear to be heavily based on WiFi. Body Area Networks, sensors embedded in the body or worn closely on it, are all open wireless, largely using mesh-capable ZigBee, although some applications include the possibility of connecting their findings through a cellular network.[41] Within the home and the hospital, the personal wearable and recording devices that receive information from them all use open wireless devices. The WiFi base stations then use wired connections to connect to the Internet, and the communications occur over that network, not over the cellular provider's network.[42] This model can be used for applications as diverse as pill boxes that monitor and alert caregivers that a patient has not taken medications, to a home sensor network that can alert caregivers or healthcare professionals that a patient or person at risk has fallen in their home.[43] Certain companies that focus specifically on highly mobile, continuous monitoring that must be fail safe, like cardiac patient monitoring outside the home, use licensed spectrum. CardioNet, for example, uses open 900MHz communications to communicate from a patient's pacemaker to their mobile device, and then a licensed-spectrum cellular network to communicate irregularities to a monitoring center.[44] Designs based on this model are common in cardiac monitoring: open wireless does the monitoring work, WiFi the preferred offloading pathway where available, but cellular networks offer the critical pathway of last resort where WiFi is unavailable to communicate the results to monitoring healthcare professionals.[45] Inside the home or at the hospital, as well as for monitoring conditions with a less acute profile, which can tolerate periodic transmission, the continuous coverage offered by cellular networks appears to be insufficiently significant to justify its costs.

Machine-to-Machine/RFID/Internet of things

Both smart grids and many mobile health applications are specific verticals in which machines talk to machines (refrigerators to meters, meters to the grid; health monitoring sensors to a handheld analyzing the observations). Other verticals that have similar features include access control (your security systems talks to its sensors; your access card talks to an office door to verify that it can open), inventory management (jeans on the shelf talk to the inventory management system to signal for restocking; containers describe to shippers where they are); fleet management (trucks signal monitoring databases where they are and receive instructions on what route to take to optimize fuel consumption); and mobile payment. Often analyzed together, these markets are sometimes described as cellular M2M (machine-to-machine). M2M is the cellular carriers term for the service as they would perceive it. In 2010 the global market for M2M modules shrank from $996 million in 2009 to $841 million in 2010,[46] while the Yankee group assessed the M2M connectivity revenue at $3.1 billion.[47] By comparison, the RFID (Radio-Frequency ID) global market for that same year was about $5.3 billion.[48]

Asset Management: open wireless RFID is predominant in the market, with important exceptions

RFID is a technology that relies on Part 15 open wireless to communicate data at short ranges using standard communication protocols. It can be used in a variety of market verticals including baggage handling, item tracking, case & pallet tracking, asset management, contactless payment, and ticketing.[49] Most people encounter RFID technologies through item tracking and asset management systems like the one implemented by Wal-Mart,[50] which made a major effort to implement RFID tags throughout its stores and supplier network. The major players in the RFID market include prominent US manufacturers like Motorola and Lockheed Martin's Savi, as well as smaller entities like Alien Technology.[51] This market is fairly competitive, with the top 6 firms in the RFID reader market, for example, holding about 40% of the market.[52] Because of the lower costs associated with implementing asset management solutions that use short range, open wireless Part 15 frequencies — and the localized nature of retail and warehousing asset management — it may be hard for solutions utilizing licensed spectrum to compete on cost in the already thriving competitive market for RFID asset management. Nonetheless, asset management is one area in which licensed-spectrum carriers are recently trying to enter.[53] In particular, where the discrete assets are highly mobile across different locations, and almost continuous monitoring is desirable, licensed-cellular models play a role. An important instance of this is package tracking: where the assets move rapidly between highly diverse locations with no expectation of well-understood periodic check-ins that could support a more nomadic model. FedEx's SenseAware and UPS's DIAD system both rely on licensed-spectrum cellular networks to offer almost continuous connection to packages. As with cardiac patients, a high demand for continuous monitoring and very wide area coverage underwrites a preference for licensed-spectrum wireless networks, because, unlike open wireless, their regulatory framework allows them to operate at high power, and in radio frequencies that allow them to penetrate buildings well.

Access Control: A Range of open wireless Technologies Covers the Market

Another major application of machine-to-machine communications is access control: from garage openers to sophisticated security systems. Major providers include Aiphone Co, ASSA-ABLOY, BIO-key International, DigitalPersona, GE Security, and Honeywell. [54] A wide variety of technologies are employed as well, from smart cards, to biometrics, to key pads. Of these technologies low, open wireless frequency-based smart cards "represent the largest revenue contributor to the card-based electronic access control market."[55] For example, Honeywell — a major producer of access control systems — produces smart card, biometric, proximity, wiegand, key pad, and bar code products for access control. Of Honeywell's two wireless product lines — smart card and proximity — the company relies on unlicensed low frequencies: 13.5 MHz and 125 kHz.[56] ASSA ABLOY, another major producer of access control systems, in its 2010 Annual Report, identified technologies that operate over open wireless spectrum (RFID, NFC, and ZigBee) as important components to the company's success.[57] The use of licensed spectrum does not appear to play a significant role in the access control market, except with regard to remote unlocking features of major automobile telematics providers, OnStar in particular.

Mobile Payments

Mobile payment, or contactless or proximity payment, as it is often called when describing its RFID implementation, is a field where licensed and open wireless are likely to compete directly in the near future. Early implementations in the U.S., however, have relied on open wireless RFID. These include toll collection systems, like EZ-Pass; key-chain contactless payment, like ExxonMobil's Speedpass; and Mastercard's PayPass. Contactless payment is seen as an area of significant growth among RFID implementations.[58] As with other implementations of open wireless under current power restrictions, these first-mover implementations utilize a short wireless hop over open wireless frequencies, such as 13.5MHz,[59] combined with a high-speed wired connection to the point of sale.[60] As with other fields, such as smart grids, the freedom to develop devices in open wireless bands meant that the first contactless payments out of the gate in the U.S. did not depend on licensed frequencies or alliances with mobile carriers, but were implemented where the need and demand arose.

More recently, efforts to integrate contactless payment into mobile phones have emphasized Near Field Communications (NFC), which is an emerging open wireless standard. These include an alliance of mobile carriers, ISIS,[61] that is not yet deployed, and an already deployed application by Google, Citibank. And Mastercard, of Google Wallet on Android.[62] In all these cases the actual local payment is made over open wireless. The degree to which the transaction will depend on real-time connection over a licensed-wireless connection through the phone remains to be seen. For now, the closest precursor, Starbucks' tap and pay, is designed so as not to require verification over a wireless connection. A recent white paper found that 70% of smartphone owners who use tap and pay do so through an app, not a web browser or SMS.[63] The Starbucks App, in turn, stores limited credit locally for communication over barcode (which could be implemented with NFC when this technology is generalized), with nomadic refilling of the card making payment independent of the kind of continuous connection to the network that would benefit from integration with a cellular model.[64]

Mastercard's PayPass, the Starbucks App, and Google Wallet all indicate that there is no technical or architectural need to design mobile phone payments using licensed frequencies. Most points of sale have wired connections to achieve online verification, and for instances where this is not the case, refilling a locally-stored credit buffer is not particularly sensitive to latency, and can be done on a nomadic model without recourse to a continuously connected licensed-spectrum cellular network.

The open innovation model fostered by open wireless meant that the first mobile payment systems in the U.S. were developed not by carriers, but by a range of companies that did not need to wait for licensed carrier implementations. As we look at the emerging efforts of carriers to enter this area, early implementations of payments with mobile phones suggest that there is no particular advantage to using licensed-spectrum approaches, as opposed to open wireless.

Fleet management and automobile telemetry mostly depend on licensed-spectrum approaches
The M2M sector where licensed-spectrum approaches have been most successful and necessary has been fleet management.[65] Transportation currently accounts for about $1 billion of the M2M market, including revenue from wireless and wireline technologies.[66] The best known, cellular licensed-spectrum based implementations of automobile telemetry is General Motors' OnStar. Major players in truck fleet management, Qualcomm and Transics, have used GPS and satellite-based systems. Fleet management and automobile telemetry are particularly difficult for present open wireless strategies to address, because they are often designed to provide and require continuous connectivity with fast moving stock that is dispersed around the country on highways and side roads. This is precisely where the broad coverage of satellite or cellular mobile systems is at its most valuable. All four major cellular carriers offer fleet management services as part of their M2M strategy.[67] Moreover, the largest transaction in licensed spectrum secondary markets over Spectrum Bridge's exchange was to Burlington Northern Santa Fe Railway, for a nationwide 220 MHz license to implement their PTC (Positive Train Control) fleet management system.[68]

One significant exception is UPS's in-house fleet management solution. UPS operates the second largest commercial fleet in the U.S. Rather than turn to a cellular or satellite-based solution, the company developed its own system in-house, relying on 900MHz open wireless spectrum. UPS's implementation highlights the importance of indifference to delay, or latency, in making licensed-spectrum cellular architectures valuable. UPS gathers information about the usage and maintenance-level of its trucks continuously, throughout the day, with on-board short range connections that do not require licensed spectrum. The truck then uploads the data over the 900 MHz range when each truck returns to the garage.[69] UPS's system emphasizes that innovations in the way data uploading and management is done can permit open wireless services to substitute for licensed-spectrum services, except for those applications that really are intolerant of latency and the information flow they require cannot be designed to be more latency tolerant without loss of function.

The importance of licensed-spectrum approaches to fleet management highlights the limitations that current regulations impose on open wireless strategies. Power limits in open wireless bands are not generally designed to protect open wireless devices from each other as much as to protect neighboring licensed services based on those licensed services sensitivities. Because of these regulatory power limits, open wireless devices and networks constructed out of them must be designed to operate at relatively short ranges. The most likely important potential application of a dedicated open wireless band in the TV bands would be to permit innovation and experimentation with wider coverage that could begin to offer alternatives to licensed-spectrum approaches even in very wide area applications that have low tolerance for latency: like fleet management.

Secondary Spectrum Markets

Unlike the markets surveyed above, secondary spectrum markets are not an actual market in systems or applications, but rather a market in spectrum use rights. Theoretically, secondary markets in spectrum allow holders of spectrum licenses fluidly to reassign their rights to others who have higher-value uses for the spectrum.[70] Without fluid secondary markets, there is no reason to believe that any given current allocation of spectrum rights indeed reflects presently-efficient allocation. In the absence of efficient secondary markets, assuming an ideal original auction, a current allocation at best reflects what was efficient at the time of auction, not an efficient present allocation.

The FCC created the framework for the secondary markets in 2003.[71] That regulatory permission for secondary markets in exclusive spectrum licenses led to the creation of public-facing markets, like SpectrumBridge's SpecEx.com and Cantor Fitzgerald's Cantor Spectrum Exchange. Information about the performance of these markets is largely absent, and their performance is highly opaque.

Secondary markets in spectrum have not exactly failed, but it is very difficult to see them as a success story either. In August of 2009, Spectrum Bridge had announced that it had reached a total of $8 million in transactions for spectrum.[72] By July of 2010 it's CTO, Peter Stanforth, made a presentation entitled "*Why Haven't Secondary Markets Been Successful?*"[73] There, Stanforth identified lack of education, fear of interference, lack of incentives against hoarding, and high transactions costs as the primary reasons for the disappointing performance of secondary markets.[74] Similar reasons were expressed in the ten-year review process of secondary markets conducted by the Australian regulator. Australia had implemented secondary markets in spectrum several years before the United States, and its experience with the failure of such markets offers a longer-term view on the same problem, suggesting that Stanforth's diagnosis is largely accurate.[75] A central argument in the theoretical literature arguing that open wireless device markets would be more efficient than spectrum markets was precisely the prediction that information and transaction costs associated with the larger scale, infrastructure-like spectrum markets would be their Achilles heel.[76]

The most glaring secondary market failure is the mobile broadband "spectrum crunch." Clearwire owns, or holds long term leases on, 145 MHz of spectrum, with almost nationwide coverage. Its holdings are nearly as large as those of Verizon and AT&T put together, and the company actively uses a small fraction of its capacity, by one plausible assessment about 10%.[77] At the same time, Comcast, Time Warner, and Cox have substantial holdings in both the AWS bands (bands that mobile carriers also hold or use for mobile data) and, to a lesser extent, 700MHz blocks—entirely unused. Given the known crunch that AT&T faced after the introduction of the iPhone, the continued claims of major capacity crunch driving an extensive search for more spectrum to auction, and the clear knowledge of precisely who the buyers and sellers in this market could be, the spectrum markets theory would have predicted that we should have seen transactions in these frequencies to improve the capacity of the major mobile broadband carriers. These predictions have not in fact materialized. Part of the barrier, as described below, is certainly regulatory. But much of the cause, including the regulatory difficulties, result from problems inherent to the kinds of large-scale markets in infrastructures that licensed spectrum facilitates. First, Clearwire's holdings are at a higher frequency band than those used by AT&T or Verizon. Binding the two systems together would be difficult. Second, Clearwire's holdings are in a contiguous band, while the major carriers built their systems to utilize paired, separated bands. Third, the cable companies appear to value the present rents from their bands less than the option to access licensed wireless capacity at an instant, and appear to be unwilling to sell at any price that the major carriers are willing to pay.

The failure to lease Clearwire's bands underscores the fact that "spectrum" is not itself a distinct input; network architectures, infrastructure devices, and terminals, together with spectrum, are the relevant unit, and this means that the transaction costs associated with adding or subtracting "spectrum" to a licensee's holdings are significant and enough to hamper or even prevent a fluid secondary market.[78] The failure to lease the cable companies' spectrum emphasizes that in a market for very large-grained goods: in this case spectrum allocations of sufficient bandwidth, leased over a sufficient time to build infrastructure and service models around their continued availability, there are likely to be few sellers and few buyers. In these kinds of markets, valuations can differ, time horizons may diverge, strategic considerations can intervene, all interfering with efficient market operation. Another important source of failure, which is tied to the size of the transactions and the shape of the markets but distinct from it is that this sheer size invites regulatory oversight. AT&T has in fact tried to buy spectrum to address its growing needs: agreeing to a 1.9 billion dollar transaction for Qualcomm's 700 MHz holdings. That transaction was still pending approval ten months after it was initially announced, in part held up by concerns over AT&T's other effort to expand its holdings—its proposed merger with T-Mobile. It is possible to interpret the regulatory hurdles to the Qualcomm deal as primary, and the technical and market-size constraints secondary. However, these actually all seem to arise out of the same basic problem: these markets at their most important are not in fact markets that could improve efficiency: markets that allocate little slivers of spectrum, dynamically leased on a moment-by-moment, local-need-by-local-need basis. They are markets in very large, complex, and long term infrastructures. As such, they mostly do not share the characteristics of markets that can in fact be fluid and efficient.

The most enthusiastic proponents of spectrum secondary markets identify three major domains which they see as success stories: MVNO markets, M2M markets, and the spectrum exchanges themselves.[79] The first of these arguments is misplaced. The second, factually contradicted by actual developments in most M2M sectors. And the third, weaker than the stark evidence from the failure of secondary markets to do anything to alleviate the mobile broadband providers' capacity crunch. Mobile Virtual Network Operators, MVNOs do not buy spectrum at all. They buy complete minutes at wholesale from incumbent carriers and resell these minutes at retail to customers. These companies play a very important role in the market for finished cellular services—voice or data. But their business model in no way permits them to reallocate "spectrum" to different uses, to change technology or use type, or to perform functions that secondary markets are supposed to provide to improve the efficiency of spectrum use. They are, after all, buying exactly the use that the incumbent license holder is making, over exactly that licensee's infrastructure, and repackaging or repricing it to customers. While these are clearly beneficial to cellular service consumers, they do not represent a mechanism for reallocating spectrum to more efficient uses.

M2M markets, as we have already seen, are the cellular carriers' version of wireless communications in a range of verticals, from smart grids and medical devices to inventory management or mobile payment. As the detailed reviews of these markets have shown, cellular services play a role in several, but not all of these markets, while open wireless devices and services built with them have been the primary market. In smart grids, cellular M2M accounts for about 1% of the market. In healthcare, that number is closer to 15-18%. While cellular M2M therefore plays an important niche role, like outdoors cardiac monitoring, FedEx package tracking, or most of trucking fleet management that requires continuous outdoor connectivity, broadly speaking it is consistent with a view of secondary markets as a limited success. One example that Mayo and Wallsten use, the Amazon Kindle, provides a nice example because, Amazon was strategically committed to its Whispernet cellular-based service, and bundled the price of the service into the price of the device, and did not include WiFi connectivity. Over the last two years, however, Amazon began to introduce WiFi capabilities into its Kindles. Finally, as Amazon shifted to adding video streaming through its Amazon Prime service to Kindle Fire, it released it's major entry into the tablet market as a WiFi only device.

The final evidence Mayo and Wallsten offer is the steady flow of secondary markets transactions measured in MHz-pop: the number of MHz transferred multiplied by the population in the geographic area covered by the license. They claim that since 2003 about 10 billion MHz pop were transferred in secondary markets every year.[80] MHz-pop is a common measure of the value of transactions in spectrum, but it is hard to assess how important these transfers are to efficient allocation of communications capacity. The AT&T-Qualcomm deal transferred about 2.25 billion MHz-pop.[81] How would we compare this to AT&T's use of WiFi to offload half of its iPhone traffic? Practically, WiFi offloading would count as a transfer of zero MHz-pop, because no license changed hands. Is it conceptually useful to say that when the subscribers of AT&T started to send half of their data traffic over different frequencies and different infrastructure than they used over the licensed bands, reducing the load carried by the licensed parts of the network, and when these open wireless bands started to carry traffic of a new kind, from a new source, using a new kind of device, no "reallocation of spectrum" occurred? From the perspective that sees "spectrum" as a scarce resource that is "used" for communications, something clearly got reallocated. How much? If we take only the 2.4GHz range, ignoring for a moment the WiFi implementations that also use the 5GHz range, and treat is as a nationwide license, the reallocation would equal about 30 billion MHz pop. When Verizon started to use WiFi, a similar amount got transferred once again. We clearly would want to apply some sort of discount factor, for the lack of exclusivity. But the lack of exclusivity did not in fact hamper communications; nor did it reduce the extent to which the 2.4GHz range was redeployed to carry data generated by AT&T customers using their iPhones. The point is not that this calculation gives us the correct measure of the value of the transaction in spectrum terms. The point is that whatever it means to measure transactions in MHz-pop, it does not appear to be a useful measure of what is actually being allocated: the capacity of a given system to complete successfully a given number of communications in a stated time and place. For that, assessments of actual markets, and the relative role that secondary markets play in serving them, is a better measure. And for that impact the evidence remains sparse. Clearwire's initial licensing of the frequencies it now holds is clearly an important instance of secondary markets; so too is its willingness to lease the exclusive use rights to others, such as AT&T. But as we saw, that latter type of transaction has not occurred. If, after FCC approval, AT&T indeed uses the spectrum it purchased from Qualcomm to carry much of its data, and comes to rely less heavily on WiFi, then we will be able to measure in real capacity terms what the relative role of these two models of providing wireless communications capacity has been. Until then the evidence in favor of secondary markets remains sparse, and the general sense that these markets have performed only a limited role in our overall wireless infrastructure development seems warranted.

Licensed-spectrum approaches can postpone infrastructure investment and offer continuous coverage. Open wireless strategies use denser infrastructure and utilize the lumpiness of time/space characteristics of the applications they serve.

Licensed-spectrum and open wireless approaches trade off physical infrastructure for exclusive control over bands.

Licensed services use the exclusivity they acquire in auctions as a substitute for capital investment in physical infrastructure. Buying spectrum allows a carrier to increase the information rates it serves without building more towers, sending more information, to a large number of users, from the same location. Obtaining more spectrum allows licensees to maintain a relatively sparse infrastructure. Open wireless strategies, however, because of regulations intended to protect licensed services, have to build more infrastructure and divide the geographic space. For each geography covered by a given gateway, fewer users require wireless capacity and are served without requiring exclusive control.

To achieve the denser infrastructure, open wireless networks often re-use existing infrastructures, or construct infrastructures ad hoc from the open wireless devices themselves. WiFi offloading in part reuses physical broadband connections to homes, offices, or hotspot locations to provide nomadic broadband access. Mobile payments reuse connections to vendor points of sale. RF mesh architectures build their infrastructure by making the meters dual use. Every electricity meter becomes not only a “user” of the infrastructure to send the data it collected to the network, but also becomes part of the infrastructure as it relays messages from its neighbors' meters to a neighborhood data collection point.

Open wireless strategies use more physical infrastructure to create much smaller “cells,” often doing so by extending the capabilities of existing infrastructure or making dual use of end user devices that double as infrastructure. Licensed strategies postpone the construction of additional physical infrastructure, like investing in more cell-towers, by acquiring more spectrum licenses.

Licensed spectrum allows for applications that need immediate connectivity, continuously, everywhere; Open wireless strategies exploit the lumpiness of most communications requirements.

When mobile health applications were thought to require continuous coverage of patients everywhere, licensed cellular networks seemed the inevitable model for supporting such applications. However, actual wireless healthcare markets deployments suggest that a relatively small number of applications actually have that demand shape. Cardiac patient coverage is the clearest example. Open wireless strategies nevertheless succeeded because many patient demands do not have that shape. They are, instead, lumpy in space, time, or both.

Lumpiness of space: patients with low mobility, both long-term frail and acute, tend to be in the home or in a care facility. They may require continuous monitoring on the time dimension, but only in limited spaces. For these, it turns out that some combination of ZigBee and Bluetooth for continuing monitoring on the body, connecting with WiFi for sending to a monitoring center, with only the very short time delays associated with Internet connections is good enough to serve even hospitals offering mission critical services.

Lumpiness of time. Another application generally thought to require exclusively-licensed cellular service was fleet management. Here the thought is that fleets of trucks and cars are highly mobile and located throughout the highway system. Nomadic access over WiFi or similar open wireless models was thought insufficient. The in-house fleet management system UPS developed shows that timeliness is a function of the task required and the design of the data management system used to complete the task. In UPS's case, continuous data collection was only required very locally, for on-board communications, but its data management requirements were designed to make periodic updating of that data sufficient. With the right data management design n*omadic access (access sometimes, when you are near a connection) is enough when it is available whenever you need it*. Continuous connectivity is unnecessary and inefficient when you only need to update your information less often. For UPS, it might be once a day and the infrastructure for communicating from the car to the data management center can be very sparse. For non-cardiac patients who still need vital signs checked every hour or two, you need a denser infrastructure that can support shorter delays between moments of uploading the data. But you still do not need continuous connection. You need connection when and where you need it, and not otherwise.

When well deployed, licensed-spectrum services offer *Sparse-Infrastructure, Latency-Indifferent* architectures. Those who own exclusive licenses can provide their service while building fewer physical gateways, and can use their superior coverage from that small number of cell towers to offer continuous connectivity for even the most latency-intolerant applications. This model will continue to be of critical importance for applications that really are latency-intolerant and occur away from usable nomadic alternatives.

When well deployed, open wireless services offer *When/Where You Need It Nomadic Gateway (WWYNING)* architectures. They exploit the lumpiness of the communications needs of any given application to deliver the kind of connection needed, when it is needed. By reusing existing infrastructure (such as the reuse of home broadband gateways to offer secure nomadic access to all a carriers' customers in France and the UK) or deploying relatively cheap architecture densely (like AT&T's use of WiFi hotspots, or Ruckus's expected deployment for KDDI), such densely-populated open wireless services can offer near-mobile nomadicity to many of the uses their users demand. As they do so, they reduce the load on their licensed-spectrum services, and reduce the pressure on acquiring more exclusive spectrum rights. The potential benefit of permitting open wireless operations in the TV bands is that relatively good building penetration and higher power feasible for an open wireless band will allow such nomadic gateways to reach more widely, and therefore to serve more delay-intolerant outdoors applications than feasible under current regulatory constraints.

Policy

Auctions authorizations should not require exhaustive auctioning; they should leave the FCC its discretion to provide for open wireless use in reclaimed bands to extend the dynamic innovation model that has led open wireless strategies to serve so many markets and critical infrastructures

Open wireless technologies are at the center of wireless innovation in the most dynamic market segments. Mission critical functions, requiring the highest security and dependability, like wireless healthcare and smart grid communications, are dominated by open wireless services. Inventory management, where cost and reliability are central, is served almost exclusively by open wireless services. Most surprisingly, the mobile broadband market itself showed that open wireless services, WiFi in this case, provide the more flexible and dynamic avenue for market response to unexpectedly high demand.

A series of bills introduced in 2011in Congress,[82] and a provision of the jobs bill proposed by the White House[83] seek to raise revenue by conducting more-or-less exhaustive auctions of TV Bands. Some suggestions would take a similar approach to any bands currently used by the federal government that could be released for commercial uses.

A major policy question in these bills is the extent to which the FCC will retain discretion to continue to permit open wireless operations in newly cleared bands. All versions empower the FCC to "repack" the TV Bands: that is, move TV licensees around so that stations can still transmit their signals, but the total bandwidth allocated to TV broadcast will be less. The bands released by this repacking process would be auctioned. The question is the extent to which the FCC will retain the discretion it now has to assure that some of the reclaimed spectrum will be open for open wireless technological innovation, as opposed to being required exhaustively to auction every sliver of spectrum reclaimed.

Exhaustive auctioning would likely both burden permission that the FCC has already granted to operate in these bands, and eliminate the opportunity to extend the same innovation dynamic we have already seen harnessed by existing open wireless allocations to a new dimension.

Starting with the work of the Spectrum Task Force in 2002, running through a succession of FCC chairmen appointed by both Republican and Democratic presidents, a series of unanimous FCC actions approved operation of "white space" devices in the TV bands.[84] These devices take advantage of the historical inefficiencies in TV spectrum, and use unused channels without interfering with even the simplest TVs. If TV licenses are packed more tightly to make room for auctioning, and auctioned spectrum is used on a cellular model that does not have the same patterns of under-utilization as TV bands do, the "white spaces" on which this model of open wireless sharing is built will be restricted. In those bands where TV operation continues, there will be fewer unused bands. In the auctioned bands, the shift to cellular broadband architecture will require regulators to protect the new owners of the auctioned bands, whose requirements and sensitivities are very different from those of television. As a practical matter, the range and scope of opportunities for designing and deploying white space devices will likely be diminished.

Beyond white space devices, if Congress does empower the FCC to move broadcasters so as to make it easier to deploy new uses of wireless technologies, it becomes possible to use that change to permit open wireless devices to transmit in some of the cleared frequencies, rather than auction all of the cleared frequencies for exclusive use. A dedicated band in which only open wireless devices would operate, rather than on a shared basis as with white spaces, would allow the development of devices with longer range and higher power. These would be constrained not by the sensitivity of older, less sophisticated services like broadcast, but only by what new devices specifically built for open wireless use can bear. The primary potential benefit of such new devices would be increased area coverage, particularly in built environments. By increasing coverage, these devices could make the kinds of nomadic access we already see from open wireless strategies more seamless. In other words, a dedicated band in these lower frequencies could provide precisely the capabilities that could fill in the primary weakness that current open wireless strategies exhibit because of the regulatory constraints that the protection of licensed services imposes on them—continuous coverage. It would allow open wireless strategies to fulfill the requirements of ever-more time- and space-sensitive applications.

More basically, open wireless strategies have exhibited rapid innovation, filling services that only a few years ago would have been considered to require licensed exclusivity. The freedom to operate and innovate, by anyone for any purpose, that permission to operate without a license provides has allowed the kind of distributed, diverse innovation we have come to associate with computers and the Internet, more than the innovation model of more centralized models. Just as Europe undoubtedly has found out with smart grid communications, failing to provide space for unlicensed operation will dampen innovation in fields that are not necessarily predicted when the decision is made. The most likely outcome of a dedicated band in which open wireless devices and services can operate will be rapid innovation in ways that we cannot well predict.

Given the increasing evidence that open wireless is a technological development pathway of the greatest importance, if Congress indeed grants the FCC the power to hold incentive auctions of TV bands, this authorization must include sufficient flexibility for the FCC to designate some portion of the reclaimed bands to open wireless use, as well as to design the bands remaining for TV service to minimize their effect on white spaces usage.

More generally, as policymakers approach the question of changing uses of wireless capacity from incumbent uses to new uses, Congress, the FCC, and the NTIA should aim to develop approaches that provide adequate capacity for open wireless, or shared access. One recent proposal along these lines is Michael Calabrese's "use it or share it" approach. Calabrese proposes relying on the dynamic characteristics of contemporary radios to permit ad hoc utilization of bands that are not currently being used, for the duration and in the space where they are not used. In particular, he emphasizes spectrum that the FCC warehouses, before allocation; federal spectrum not used, and auctioned spectrum in locations where there is no immediate prospect of construction and utilization.[85]

The political economy overweights licensed approaches over open wireless

Because the benefits of open wireless strategies are widely distributed across multiple sectors and verticals, and the "allocation" gives no set of well-defined companies exclusivity they can leverage, the political economy of these debates is highly skewed. Companies that expect to bid on and and buy spectrum see all the benefits of winning the policy debate, and then the auctions, as internalize benefits. Most companies that would benefit from open wireless networks do not even know that they are affected by spectrum policy, and even if they were, these concerns would likely be trumped by other political needs. Better next-generation open wireless communications will likely provide benefits to companies like PG&E in the smart grid market, Wal-Mart for inventory management, UPS in fleet management, or major hospitals using wireless healthcare systems. But for none of these organizations is spectrum policy a major policy interest of sufficient weight, relative to other matters like energy regulation, employment law, or healthcare regulation, such that they would be willing to trade political favors for it, much less actually bid on keeping spectrum free for any company, established or startup, to come up with the next WiFi or ZigBee.

The positive externalities from open wireless cannot be internalized by any single firm or group of firms. While some technology firms do engage in lobbying for open wireless, the degree of internalized benefits from lobbying to keep spectrum open for anyone to use simply cannot match the internalization practical for companies like Verizon and AT&T when they lobby for exclusive control that they could then own. Overcoming this basic imbalance, which impacts both the political economy of lobbying and the willingness to pay at auction, will be very difficult.

An identical public goods problem bedevils proposals to hold auctions in which companies that want to keep the spectrum open on an unlicensed basis would bid to keep the spectrum open, and if they would outbid companies bidding for exclusive ownership, the bids would be collected and the bands would remain free for anyone to innovate in. As with the lobbying, this proposal suffers from standard public goods problems: the costs would have to be born by a small portion of the many who would reap the benefits. Like national defense, roads and bridges, lighthouses, or public databases, public goods provide enormous social benefits but suffer from systematic underinvestment if left only to private investment that cannot possibly capture all of the benefits.

Auctions designed purely to maximize revenue operate as a tax on American consumers whose revenues subsidize carriers' deployment of mobile broadband

Proposals that seek to maximize auction revenue combine (a) a prohibition on allocating any spectrum to unlicensed with (b) a prohibition on capping the amount of spectrum any given firm can purchase. The argument for both is the same: for (a), any spectrum dedicated to open wireless will not fetch any direct price and spectrum sold, but subject to open wireless operation, will sell for less; for (b), the only time a spectrum cap will have bite is if the company seeking to buy more spectrum is the highest bidder. By definition, cutting off the possibility that the highest bidder will take the auction will lower the expected revenues. The combined effect of these efforts to maximize short-term auction revenue undermines not only innovation in open wireless services, but also the competitiveness of mobile broadband markets as well. The anticipated higher rates American consumers will pay will in part be passed through to the Federal government, but the lion's share will remain in the hands of the major carriers in the form of increased revenues and postponed requirements to make capital expenditures.

Spectrum Auctions Act as a Subsidy to Reduce the Capital Expenditure Needs of Carriers

The FCC's National Broadband Plan explicitly emphasized in its section on “Growing spectrum needs” that “In the absence of sufficient spectrum, network providers must turn to costly alternatives, such as cell splitting, often with diminishing returns.”[86] Understanding this is easy when one considers the success of WiFi offloading described above. Wireless communications capacity combines wired connections to gateways, such as cell towers, hotspots, or home/office WiFi gateways, and a wireless hop from the gateway to the device, such as a licensed band of spectrum or an open wireless hop.

Cellular mobile carriers are willing to pay a price for spectrum at auction because it is cheaper to use public spectrum than to invest in building more private cell towers. Spectrum auctions allow cellular mobile carriers to postpone that capital expenditures that would allow them to split their cells and increase network capacity without adding a single MHz to their spectrum holdings. The difference between the price carriers pay at auction and the capital investment cost they avoid is a public subsidy to these providers, intended to induce them to roll out mobile broadband sooner and at higher capacity than they otherwise would. Government subsidies are sometimes appropriate, but it is important to characterize them as such so as to make the policy choice clear.

Spectrum auctions without caps undermine efficient markets even among licensed services; their function is analogous to tax farming practices in pre-modern states

Spectrum auctions provide an opportunity for dominant incumbents to foreclose competition. Verizon and AT&T currently own 78% of the frequencies in the cellular and 700MHz bands.[87] Because of their propagation characteristics, these lower frequency bands allow these companies to use larger cells. They can build or lease space on fewer cell towers than their competitors who do not hold these frequencies would need to achieve the same coverage. Without frequency allocations in these lower bands, competitors to these two require higher capital expenditure to offer similar levels of service. AT&T underscored this effect in its reply to the Department of Justice's opposition to its acquisition of T-Mobile, arguing that removing T-Mobile as a competitor would have little impact on competition because: "without the spectrum to deploy a 4G LTE network such as that deployed by the other carriers there is no reason to expect a change in [T-Mobile's] undifferentiated competitive significance."[88] At stake in spectrum caps in the TV Bands auction is precisely how many national competitors will be viable. Unlike their smaller competitors, the two dominant firms (the market share of AT&T and Verizon together is over 60% of both subscribers and revenues, and the market in mobile wireless market is considered highly concentrated by the standard antitrust measure)[89] can expect a market foreclosure effect if they acquire enough of the newly-available spectrum. Just as AT&T's Answer in the T-Mobile merger review indicated, without spectrum in these frequencies, the costs competitors face to provide equivalent service are higher. By contrast, competitors buying these licenses cannot shut AT&T and Verizon out, because even if competitors were to buy all the spectrum in the TV bands, the two dominant firms would continue to have sufficient allocations in the cellular and 700MHz bands. The expected rents the dominant firms could collect from a less-competitive market comprise part of the value these firms can capture by buying more of the spectrum, and is necessarily a component of their willingness to pay more in auction. Excluding any open wireless operation from these bands further limits the possibility that competitors could use "Super WiFi" offloading in these bands to keep pace with the dominant players.

Because of the foreclosure effect, when Congress tries to maximize its short term revenues by granting a license to exclude competition, it is effectively engaged in tax-farming on the model used in Rome, Medieval England, or the French monarchy. Removing caps would maximize revenues largely because the dominant carriers spend down some of the rents they anticipate charging consumers in less competitive markets to outbid would-be competitors. What is auctioned is a legal license to exclude competitors from using particularly cost-attractive frequencies to out-compete those who did not purchase such licenses. American consumers would then pay more for their service, as the carriers passed auction costs to customers. But, unlike an excise tax that sets the rate precisely, the precise size of the tax here is a function of the pricing power that the auctions will give the dominant carriers. The carriers will capture that entire gain, transferring through only what they contracted to pay at auction. The effect is equivalent to tax farming practices in the pre-modern state: a private enterprise buys the right to collect taxes by promising the Crown a certain known return, and then it is up to the tax collector to collect at least that amount, and whatever else the tax collector can get away with.

Auctions designed purely to maximize short-term, certain revenues operate as a tax farming scheme that subsidizes mobile broadband providers. They reduce their capital expenditures and give them pricing power to raise their expected revenues from serving more customers. In exchange, the carriers pass through part of these higher revenues to the government, as promised at auction.

Conclusion

The evidence from the most dynamic and critical markets in wireless communications suggests that open wireless technologies have been underrated in the regulatory calculus. Future spectrum policy debates, in particular those surrounding TV band auctions and reallocation of federal spectrum, should secure an adequate development path for open wireless technologies, devices, and services at least as much as they emphasize flexibly-licensed exclusive rights.

The primary way in which open wireless policy contributed to the development of wireless infrastructure is to harness an Internet model of innovation in the wireless space, instead of depending exclusively on an older, telecommunications-carrier model of innovation. The experience of the past two decades strongly suggests that, however scrappy and uncertain Internet innovations may seem at first by comparison to the highly-engineered models of the telcos, these innovations quickly catch up and surpass their competitors. The experience of the last decade suggests that the same dynamic is true for open wireless innovation when compared to innovation dependent on exclusive licensing, even where the latter are allocated by auction, defined flexibly, and subject to secondary markets.

The most immediate implication is that any authorization for the FCC to conduct incentive auctions, and any plans to permit civilian use of federal spectrum, should not limit the FCC's discretion to leave adequate room for open wireless strategies to develop new generations of innovation. In the longer term, successful approaches to identifying bands and sharing rules that would make it legal for increased operation of open wireless devices, networks, and applications should become at least as central a target of the FCC wireless policy as identifying and auctioning bands for exclusive licensing.

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1 S. 911, the Public Safety Spectrum and Wireless Innovation Act; House staff discussion draft, ‘‘Spectrum Innovation Act of 2011.’’

2 American Jobs Act of 2011, Sections 272 *et seq*.

3 Evan R. Kwerel & Alex D. Felker, Using Auctions to Determine FCC Licensees (OPP Working Paper Series, Working Paper 16, 1985); Evan R. Kwerel & John R. Williams, Changing Channels: Voluntary Reallocation of UHF Television Spectrum (OPP Working Paper Series, Working Paper 27, 1992); Gregory L. Rosston & Jeffrey S. Steinberg, Using Market-Based Spectrum Policy to Promote the Public Interest (FCC Bureau of Engineering Technology Working Paper, 1997). The work in the 1990s was built on earlier work in the late 1950s and 1960s and 70s. Leo Herzel, *"Public Interest" and the Market in Color Television Regulation*, 18 U. Chi. L. Rev. 802 (1951); Ronald Coase, *The Federal Communications Commission*, 2 J of Law & Econ. 1 (1959); William K, Jones, *Use and Regulation of the Radio Spectrum: Report on a Conference*, 1968 Wash. L.Q.71 (1968); Arthur S. De Vany, Ross D. Eckert, Charles J. Meyers, Donald J. O'Hara, Richard C. Scott, *A Property System for Market Allocation of the Electromagnetic Spectrum: A Legal-Economic-Engineering Study*, 21 Stan. L. Rev. 1499 (1969); Harvey J. Levin, The Invisible Resource: Use and Regulation of the Radio Spectrum (1971); and Jora R. Minasian, *Property Rights in Radiation: An Alternative Approach to Radio Frequency Allocation*, 18 J. Law & Econ. 221 (1975).

4 Eli Noam, *Taking the Next Step Beyond Spectrum Auctions: Open Spectrum Access*, 33 IEEE COMM. MAG., Dec. 1995, at 66. Noam later elaborated this position. See Eli Noam, *Spectrum Auction: Yesterday's Heresy, Today's Orthodoxy, Tomorrow's Anachronism. Taking the Next Step to Open Spectrum Access*, 41 J.L. & ECON. 765, 778–80 (1998); see also Jon M. Peha & Sooksan Panichpapiboon, *Real-time Secondary Markets for Spectrum*, 28 TELECOM. POL'Y 603 (2004).

5 Yochai Benkler, Overcoming Agoraphobia: Building the Commons of the Digitally Networked Environment, 11 HARV. J.L. & TECH. 287 (1998) ; Lawrence Lessig, THE FUTURE OF IDEAS (2001); David P. Reed, Why Spectrum is Not Property, The Case for an Entirely New Regime of Wireless Communications Policy (Feb. 27, 2001), at http://www.reed.com/dprframeweb/ dprframe.asp?section=paper&fn=openspec.html; see also David P. Reed, Comments for FCC Spectrum Task Force on Spectrum Policy (July 8, 2002), at http://gullfoss2.fcc.gov/prod/ecfs/retrieve.cgi?native_or_pdf=pdf&id_document= 6513202407; Kevin Werbach, *Supercommons: Toward a Unified Theory of Wireless Communications*, 82 Tex. L. Rev. 863 (2004).

6 Authorization of Spread Spectrum systems Under Parts 15 and 90, First Report and Order, Gen. Docket No. 81-413, 50 Fed. Reg. 25234 (June 18, 1985), (adopted May 9, 1985); In The matter of Revision of Part 15 of the Rules Regarding the Operation of Radio Frequency Devices Without An Individual License, First Report and Order, Gen. Docket 87-389, 4 FCC Rcd. 3493 (1989) (adopted Mar. 30, 1989); Amendment of the Commission's Rules to Provide for Operation of Unlicensed NII Devices in the 5 GHz Frequency Range, ET Docket No. 96-102, Report and Order, FCC 97-5 (released Jan. 9, 1997).

7 Spectrum Policy Task Force, FCC, Spectrum Policy Task Force Report (2002) (available at http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-228542A1.pdf) .

8 Chronologically, these include: Thomas W. Hazlett, *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*, 14 HARV. J. L. & TECH. 335 (2001); Gerald Faulhaber and David Farber, Spectrum Management, Property Rights, Markets, and the Commons (2002), at http://assets.wharton.upenn.edu/~faulhabe/SPECTRUM_MANAGEMENTv51.pdf; Yochai Benkler, *Some Economics of Wireless Communications,* 16 HARV. J. L. & TECH. 25 (2002); Stuart Buck, *Replacing Spectrum Auctions with a Spectrum Commons*, 2002 STAN. TECH. L. REV. 2 (2002); Stuart Minor Benjamin, *Spectrum Abundance and the Choice Between Private and Public Control*, 78 N.Y.U. L. REV. 2007 (2003); KEVIN WERBACH, NEW AM. FOUND., RADIO REVOLUTION: THE COMING AGE OF UNLICENSED WIRELESS (2003), *available at* http://www.newamerica.net/files/nafmigration/archive/Pub_File_1427_1.pdf.; Kevin Werbach, *Supercommons: Toward a Unified Theory of Wireless Communications*, 82 Tex. L. Rev. 863 (2004); Ellen P. Goodman, *Spectrum Rights in the Telecosm to Come*, 41 SAN DIEGO L. REV. 269 (2004); Philip J. Weiser & Dale N. Hatfield, *Policing the Spectrum Commons*, 74 FORDHAM L. REV. 663 (2005); Martin Cave, *New Spectrum-using Technologies and the Future of Spectrum Management: A European Policy Perspective*, *in* COMMUNICATIONS: THE NEXT DECADE, at 220 (Ed Richards et al. eds., 2006), *available at* http://www.cullen-international.com/cullen/cipublic/presentations/martin_cave_communications_next_decade.pdf; John M. Chapin & William H. Lehr, *The Path to Market Success for Dynamic Spectrum Access Technology*, IEEE COMMUNICATIONS MAGAZINE, May 2007, at 96.; A more complete chronological bibliography is available at:

http://www.benkler.org/Spectrum_Bibliography.

9 Wireless Technology Prospects and Policy Options, Computer Science and Telecommunications Board, National Research Council. (National Academies Press, March, 2011). pp 53-55.

10 Federal Communications Commission, Connecting America: The National Broadband Plan (2010).

11 Jenna Wortham, *Customers Angered as iPhones Overload AT&T*, New York Times, September 2, 2009, available http://www.nytimes.com/2009/09/03/technology/companies/03att.html.

12 Om Malik, With iPhone, Wi-Fi Use Grows on AT&T Networks, Aug. 20, 2009, available http://gigaom.com/2009/08/20/with-iphone-wi-fi-use-grows-on-att-networks/.

13 AT&T press release, AT&T Wi-Fi Usage Soars With 301.9 Million Connections Made in Third Quarter 2011, (October 24, 2011) (available: http://www.att.com/gen/press-room?pid=21806&cdvn=news&newsarticleid=33140&mapcode=consumer|mk-att-wi-fi)

14 ComScore, Digital Omnivores: How Tablets, Smartphones and Connected Devices are Changing U.S. Digital Media Consumption Habits , October 10, 2011.

15 *Verizon to offload EV-DO, LTE traffic onto Wi-Fi*, Fierce Wireless, http://www.fiercewireless.com/story/verizon-offload-ev-do-lte-traffic-wi-fi/2011-05-20.

16 Juniper Research, Mobile Data Offload & Onload: WiFi & Femtocell Integration Strategies 2011-2015, available http://juniperresearch.com/reports/Mobile_Data_Offload_and_Onload.

17 ComScore, Digital Omnivores.

18 Cisco, Visual Networking Index: Forecast and Methodology 2010-2015, June 2011at 10, available http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-481360_ns827_Networking_Solutions_White_Paper.html.

19 Id., at 11. The Cisco paper lumps home WiFi and femtocells into the 39% category, but adjusting for the Juniper study's finding that femtocell offloading accounted for only 2% of the combined offloading capacity, attributing the entire offloading effect to WiFi is apprpriate.

20 Yochai Benkler *et. al*, Next Generation Connectivity: A Review of Broadband Interent Transition from Around the World 154 (2010), available http://cyber.law.harvard.edu/pubrelease/broadband/.

21 *Id.*, at 153.

22 See http://www.btfon.com/.

23 Morgan Stanley, The Mobile Internet Report 299-304, December 15, 2009.

24 HSBC, The Capacity Crunch : What can mobile telecoms operators do as "Moore's Law Mobile" breaks down? December 8, 2009.

25 Stacey Higginbotham, *Wi-Fi's Coming Identity Crisis*, GigaOm July 2011, available http://gigaom.com/2011/07/05/wi-fis-coming-identity-crisis/ ; Stacey Higginbotham, The Mobile Tsunami Is Near: Blame Netflix & Apple, GigaOm January 2011,http://gigaom.com/2011/01/31/the-mobile-tsunami-is-near-blam e; Elizabeth Woyke, *U.S. Service Providers Preparing Wi-Fi Offload Rollouts* , Forbes 7/5/11. Not all agree, needless to say. For a view that WiFi will remain marginal to the core of next generation mobile broadband see HSBC Global Research, *The Cell Side: Telecoms operators' cellular networks won't be displaced by WiFi, but capex must rise* April 2010.

26 News Release: *KDDI and Ruckus Wireless Debut the World's Largest Mobile Data Offload Network and First Nationwide Wi-Fi Access Service in Japan* , July 5, 2011. http://www.prnewswire.com/news-releases/kddi-and-ruckus-wireless-debut-the-worlds-largest-mobile-data-offload-network-and-first-nationwide-wi-fi-access-service-in-japan-125001254.html.

27 Garnter, Predicts 2011: Network Capacity and Consumers Impact Mobile and Wireless Technologies , November 2010 at 6.

28 Aruna Balasubramanian et al, *Augmenting Mobile 3G Using WiFi* , MobiSys'10, June 15–18, 2010, San Francisco, California, USA .

29 FCC National Broadband Plan, *supra.*

30 Katie Feherenbacher, *What You Need to Know About Network Options for the Smart Grid*, Sept. 14 2009, citing Clint Wheelock of Pike Research.

31 Nick Jones, Leif-Olof Wallin, The Shifting Sands of the Cellular Machine-to-Machine Market, Gartner, September 21, 2009, p. 2.

32 David J. Leeds, GTM Research, The Smart Grid Market in 2010: Market Segments, Applications, and Industry Players (2009), available http://www.greentechmedia.com/research/report/smart-grid-in-2010.

33 Market shares based on Pike Research Smart Grid Deployment Tracker, 1Q11. Technologies deployed identified through analysis of the technology white papers or other descriptions provided each of the providers noted in that report. "Other" refers to firms whose market share and names are not available for review of the technology; Echelon's technology for wireless, as opposed to data over powerline, is unclear. Landis and Gyr has European deployments that

use cellular GPRS service, but its North American deployments use RF Mesh built of open wireless devices in the 900MHz band.

34 Pike Research, Public Carrier Networks for Smart Grids 2G, 3G, and 4G Cellular Networks for Smart Meters, Distribution Automation, Substation Automation, and Mobile Workforce Communications 19 (Q4 2011).

35 Pike Research, Public Carrier Networks for Smart Grids 2G, 3G, and 4G Cellular Networks for Smart Meters, Distribution Automation, Substation Automation, and Mobile Workforce Communications 16 (Q4 2011).

36 Rob Conant, *Toward a Global Smart Grid - The U.S. vs. Europe*, Electric Light and Power available: http://www.elp.com/index/display/article-display/2702271845/articles/utility-automation-engineering-td/volume-15/Issue_5/Features/Toward_a_Global_Smart_Grid_-_The_US_vs_Europe.html.

37 See Matthew Loy, Raju Karingattil, Louis Williams , *ISM-Band and Short Range Device Regulatory Compliance Overview* (Texas Instruments 2005).

38 Hazlett, *Wireless Craze*, *supra*, at page 491.

39 Steven D. Baker and David H. Hoglund , *Medical Grade, Mission Critical Wireless Networks*, IEEE ENGINEERING IN MEDICINE AND BIOLOGY MAGAZINE , March/April 2008.

40 Kalorama Information Wireless Technologies in Healthcare September 2011.

41 Min Chen et al, *Body Area Networks: A Survey* , Mobile Netw Appl (2011) 16:171–193 .

42 See Dale Wiggins, *Current state of wireless health and lessons learned: Advancing patient care with innovation in wireless connectivity*, Phillips, FDA/FCC Joint Forum, July 26, 2010, Slide 5.

43 Hande Alemdar and Cem Ersoy, *Wireless sensor networks for healthcare: A survey*, Computer Networks 54 (2010) 2688–2710 at 2696-2704.

44 Philip E Ross, *Managing Care Through the Air*, IEEE Spectrum, December 2004; CardioNet Factsheet, available http://www.cardionet.com/media/pdf/Fact%20Sheet%20-%20CardioNet%20Product%20and%20Arrhythmias.pdf.

45 Alemdar and Ersoy, *supra*, at 2703.

46 ABI Research Cellular M2M Momentum (Report) 3Q 2011.

47 Yankee Group, Global Enterprise Cellular M2M Connections Will Nearly Triple by 2015 http://www.yankeegroup.com/about_us/press_releases/2011-04-05.html

48 ABI Research, RFID Market Data" (http://www.abiresearch.com/research/1005061).

49 ABI Research, RFID Annual Market Overview 10 (2009).

50 RFID Journal, *Wal-Mart to Buy 15k RFID Readers; Albertsons 5k* (Apr. 18, 2006).

51 *See* Motorola, "RFID Industry Solutions" *available at* http://www.motorola.com/Business/US-EN/Business+Product+and+Services/RFID/RFID+Industry+Solutions; Savi, "RFID Hardware Overview" *available at* http://www.savi.com/products/rfid/; Alien Technology, "Products" *available at* http://www.alientechnology.com/products/index.php

52 See Motorola, Top Ten Reasons presentation, slide 1.

53 Stephanie Neil, *Verizon Adds Asset Management to M2M Wireless Network*, Managing Automation Mar. 23, 2011, available http://www.managingautomation.com/maonline/exclusive/read/Verizon_Adds_Asset_Management_to_M2M_Wireless_Network_27756738

54 Phillip M. Parker, Icon Group International, *The 2009–2014 Outlook for Electronic Access Control Systems in the Americas & the Caribbean*, 48–49 (2009). In 2008 Parker assessed latent demand for access control systems in the U.S. at about 2.37 billion dollars.

55 Heather Klotz-Young, *State of the Market: Access Control*, SDM, 52–51 (April 2011) (quoting Global Industry Analysts, Inc.).

56 *See* http://www.honeywellaccess.com/products/readers/.

57 ASSA ABLOY, Annual Report 2010, 46 (2010), *available at* http://www.assaabloy.com/Global/Investor_relations/Annual%20report/2010/Annual-Report-2010-Eng-ASSA-ABLOY.pdf

58 ABI Research, RFID Annual Market Overview 10 (2009) (predicting the most growth in revenue for RFID in the contactless payment vertical).

59 See, e.g., Datasheet for Philips' Contactless Reader System noted as a reference chipset for Paypass terminals in Mastercard, Transaction Optimization, For PayPass – M-Chip Terminals, July 7, 2008.

60 *Id.*

61 Shane McGlaun, *AT&T, T-Mobile, Verizon Wireless Showcase Isis Mobile Payments System*, DailyTech (November 16, 2010), *available at* http://www.dailytech.com/ATT+TMobile+Verizon+Wireless+Showcase+Isis+Mobile+Payment+System/article20152.htm.

62 Ryan Kim, *Google Launches Its Wallet Platform to Jumpstart NFC Payments*, GigaOm (May 26, 2011), *available at* http://gigaom.com/2011/05/26/google-tries-to-jumpstart-nfc-payments-with-wallet-platform/.
63 Compete Financial Services, Mobile Money, (White Paper 2011, using Q2 data). Page 4.
64 http://www.starbucks.com/customer-service/faqs/coffeehouse#mobile-card-iphone-app.
65 Tammy Parker, FierceWireless, The M2M Opportunity, *Dots on the Map Provide a Foundation for New Apps*,16 (June 2010).
66 Harbor Research, *Smart Devices and Services Connected by CDMA2000*, 4 (2010).
67 Yankee Group, Anchor Report: A Closer Look at M2M Carrier Strategy 3–7 (2010).
68 Spectrum Bridge, "Recent SpecEx Transactions," *available at* http://www.spectrumbridge.com/specex/transactions.aspx; Robert J. Derocher, *PTC Push, Narrowband Nudge Present Opportunities for Radio Technology Suppliers*, Progressive Railroading (September 2009), *available at* http://www.progressiverailroading.com/ptc/article/PTC-Push-Narrowband-Nudge-Present-Opportunities-for-Radio-Technology-Suppliers--21416
69 Maisie Ramsay, *M2M Moves to the Car*, Wireless Week, 12 (July 2010); *Shelley Mika, Telematics Sensor-Equipped Trucks Help UPS Control Cost*, Green Fleet July 2010, available : http://www.greenfleetmagazine.com/article/2520/telematics-sensor-equipped-trucks-help-ups-control-costs.
70 DeVany, *et. al*, *supra*; Kwerel and Williams, *supra*; FCC Spectrum Taskforce Report, *supra.*
71 Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets, 68 Fed. Reg. 66252 (codified at 47 C.F.R. Parts 1, 24). Updated 2004 by Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets, 69 Fed. Reg. 77522 (codified at 47 C.F.R. Parts 1, 24, 90).
72 *Spectrum Bridge Surpasses $8 Million in Spectrum Transactions, Forecasts Robust Growth*, Fierce Wireless (Aug. 10, 2009), http://www.fiercewireless.com/press-releases/spectrum-bridge-surpasses-8-million-spectrum-transactions-forecasts-robust-growth. The announcement did not mention of the number of transactions, any information about the transacting parties, nor the frequencies sold.
73 Peter Stanforth, CTO, Spectrum Bridge, *Why Haven't Secondary Markets Been Successful*?, Address at the International Symposium on Advanced Radio Technologies (Jul. 30, 2010) [hereinafter Stanforth Presentation], *available at* http://www.its.bldrdoc.gov/isart/art10/slides_and_videos10/SBI-ISART.pdf
74 *Id.*
75 Australian Communications and Media Authority, Spectrum Trading: Consultation on Trading and Third Party Authorizations of Spectrum and Apparatus Licenses (2008).
76 See Benkler, *Overcoming Agoraphobia*, *supra*, ("The high cost of information gathering, and other transaction costs associated with articulating and communicating preferences about the uses of communications infrastructure in an imperfect market, are likely to leave the actual decisions about who may communicate with whom, about what, in what form, and to what effect, where the power to make those decisions is initially located by the institutional framework."); Benkler, *Some Economics of Wireless Communications, 57 et seq.* ("the transaction costs associated with market clearance of property rights will be systematically higher than the transaction costs associated with open wireless network communications.")
77 See Deutsche Bank, Coping with the Spectrum Crunch 24 (Sept. 29, 2011).
78 This is consistent with early critiques of secondary markets. See Benkler, *Overcoming Agoraphobia*, at 57 ("Transaction costs also include the costs associated with switching between uses. ...the equipment that is likely to be deployed for their services will be relatively specialized. A shift will entail the purchase of new specialized equipment. This cost will present a barrier to shifting uses of the transmission right..")
79 *See* John Mayo & Scott Wallsten, *Secondary Spectrum Markets as Complements to Incentive Auctions*, Georgetown University, McDonough School of Business, Economic Policy Vignettes 6 (July 2011), http://www.gcbpp.org/files/Academic_Papers/AP_Mayo_SecondarySpectrum_062011.pdf; John Mayo and Scott Wallsten, *Enabling Wireless Communications*, 22 Info Econ. and Policy 61-72 (March 2010).
80 Mayo and Wallsten, *Secondary Markets in Spectrum*, *Id.*, at 6.
81 Alan Rappeport and Paul Taylor, *AT&T to buy Qualcomm's spectrum for $1.93bn*, Financial Times, Dec. 20, 2010. The number is derived from reports in that article that AT&T's $1.93 billion bought it spectrum at $0.86 per MHz-pop.
82 S. 911, the Public Safety Spectrum and Wireless Innovation Act; House staff discussion draft, ''Spectrum Innovation Act of 2011.''
83 American Jobs Act of 2011, Sections 272 *et seq*.
84 In the Matter of Unlicensed Operation in the TV Broadcast Bands, Second Report and Order and Memorandum Opinion and Order in ET Docket Nos. 02-380 and 04-186, 23 FCC Rcd 16807 (2008); In the Matter of Unlicensed Operation in

the TV Broadcast Bands , Second Memorandum Opinion and Order, (September 23, 2010).

85 Michael Calabrese, *Use it or Share it: Unlocking the Vast Wasteland of Fallow Spectrum* , 39th TPRC Sep. 23-25 2011.

86 NATIONAL BROADBAND PLAN, at p. 77.

87 Federal Communications Commission, Fifteenth Annual Report and Analysis of Competitive Market Conditions With Respect to Mobile Wireless, Including Commercial Mobile Services , June 27, 2011, FCC 11-103.

88 Answer, *United States vs. AT&T*, Case 1:11-cv-01560-ESH , filed 09/09/11, at p. 3.

89 Federal Communications Commission, Fifteenth Annual Report and Analysis of Competitive Market Conditions With Respect to Mobile Wireless, Including Commercial Mobile Services , June 27, 2011, FCC 11-103. Calculating HHI in the mobile industry as 2848.