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OPEN WIRELESS VS. LICENSED SPECTRUM: EVIDENCE FROM MARKET ADOPTION

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I. INTRODUCTION

The next generation of connectivity will be marked by ever more ubiquitous computing and communications.[1] From health monitoring to inventory management, handheld computing to automobile computers and payment systems, pervasive computing is everywhere — and everywhere depends on wireless communications and therefore on wireless policy. We see this increasing importance in several contexts. The National Broadband Plan calls for the identification of an additional 500 MHz of spectrum for new wireless applications.[2] The new report by the President's Council of Advisors on Science and Technology ("PCAST Report") calls for extensive sharing of government spectrum with civilian users;[3] this report, in turn, informs an already existing broad effort to release federally-controlled frequencies for use by non-federal users, coordinated and managed by the National Telecommunications and Information Administration ("NTIA").[4] Moreover, a series of bills introduced in Congress[5] and proposed by the White House[6] in 2011 ultimately resolved into law that gave the Federal Communications Commission ("FCC") a new

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1. PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, REALIZING THE FULL POTENTIAL OF GOVERNMENT-HELD SPECTRUM TO SPUR ECONOMIC GROWTH 1–7 (2012) [hereinafter PCAST REPORT], *available at* http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf; FCC, CONNECTING AMERICA: THE NATIONAL BROADBAND PLAN 9–10, 22 (2010) [hereinafter NATIONAL BROADBAND PLAN], *available at* http://download.broadband.gov/plan/national-broadband-plan.pdf (describing growing demand for wireless capacity as the "spectrum crunch" and prescribing 500 MHz in additional allocations); YOCHAI BENKLER ET AL., NEXT GENERATION CONNECTIVITY: A REVIEW OF BROADBAND INTERNET TRANSITIONS AND POLICY FROM AROUND THE WORLD 15, 219–228 (2010) [hereinafter BENKLER ET AL., NEXT GENERATION CONNECTIVITY], *available at* http://cyber.law.harvard.edu/sites/cyber.law.harvard.edu/files/Berkman_Center_Broadband_Final_Report_15Feb2010.pdf (reporting on a survey of national broadband plans and underscoring the importance of ubiquitous communications in the next generation).

2. NATIONAL BROADBAND PLAN, *supra* note 1, at XII, 9–10.

3. PCAST REPORT, *supra* note 1, at 7–9.

4. NTIA, AN ASSESSMENT OF THE VIABILITY OF ACCOMMODATING WIRELESS BROADBAND IN THE 1755–1850 MHZ BAND iii–v (2012) [hereinafter NTIA REPORT], *available at* http://www.ntia.doc.gov/files/ntia/publications/ntia_1755_1850_mhz_report_march2012.pdf.

5. Public Safety Spectrum and Wireless Innovation Act, S. 911, 112th Cong. § 2 (2011), *available at* http://www.gpo.gov/fdsys/pkg/BILLS-112s911is/pdf/BILLS-112s911is.pdf; Spectrum Innovation Act of 2011, H.R. __, 112th Cong. §§ 102–03 (Discussion Draft 2011), *available at* http://www.publicknowledge.org/files/docs/DraftHouseRepublicanSpectrumBill.pdf; Middle Class Tax Relief and Job Creation Act of 2012, H.R. 3630, 112th Cong. §§ 6001–703 (2012), *available at* http://www.gpo.gov/fdsys/pkg/BILLS-112hr3630enr/pdf/BILLS-112hr3630enr.pdf.

6. OFFICE OF THE PRESS SECRETARY, THE WHITE HOUSE, THE AMERICAN JOBS ACT 62–91 (2011), *available at* http://www.whitehouse.gov/sites/default/files/omb/legislative/reports/american-jobs-act.pdf.

incentives auction authority to reallocate some of the TV bands to support new wireless data services.[7]

The primary contribution of this Article is to provide evidence in aid of these ongoing efforts to refine spectrum policy in both civilian and federal spectrum. The Article surveys the experience of several leading-edge wireless markets, examining the relative importance of the major policy alternatives available to support the provisioning of wireless communications capacity. I review evidence from seven wireless markets: mobile broadband, wireless healthcare, smart grid communications, inventory management, access control, mobile payments, and fleet management. I also review how secondary markets in spectrum have fared and evaluate both the failures and successes of different approaches to open wireless policy.

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, 70% of smart grid communications, over 90% of tablet mobile data, and 40–70% of mobile broadband data to all devices use open wireless strategies to get the capacity they require.[8] 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.[9] Fleet management is the one area where licensed technologies are predominant. However, UPS — owner of the largest commercial fleet in the United States — has implemented its fleet management system (of 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 flexibly licensed spectrum have been sluggish. Most of the clear successes of open wireless strategies have come from devices and services that use general purpose open wireless bands, like those that support Wi-Fi. Meanwhile, efforts to provide more narrowly tailored unlicensed allocations, such as for transportation or medicine, have been only ambiguously successful. Some more tightly regulated and balkanized allocations, in particular unlicensed personal communications services ("U-PCS"), have been outright failures. Policy is important, then, both to the choice between open wireless and licensed spectrum and among different approaches to open wireless allocations.

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7. Middle Class Tax Relief and Job Creation Act of 2012, Pub. L. 112-96, §§ 6001–6703, 126 Stat. 156, 201–255 (2012) (codified in scattered sections of 47 U.S.C.), *available at* http://www.gpo.gov/fdsys/pkg/PLAW-112publ96/pdf/PLAW-112publ96.pdf. *See also infra* Part V.B.1.

8. *See infra* Part IV.

9. *See infra* Part IV.A.4.C.

Ever since 1922, when then-Secretary of Commerce Herbert Hoover first seized the power to manage spectrum (illegally, as it turned out),[10] policy has been a critical determinant of the rate and direction of innovation in wireless communications. The same will be true in the coming decades. A discussion draft circulated by House of Representatives staff on July 13, 2011 provides a clear example of how government decisions driven by ideology can cut off crucial innovation paths and destroy markets.[11] The bill would have prohibited the FCC from permitting unlicensed devices to operate in any new band unless the FCC conducted an auction in which a coalition of device manufacturers had bid at auction to keep those bands a "commons."[12] The collective action problems associated with getting a group of actors to bid on making it legal for anyone to innovate in a band are overwhelming. It is the equivalent of saying that cities may only dedicate a block for a public park or a street if the public at large outbids any developer who would want to build an office building or a mall over that land. Overcoming the collective action problems associated with creating these kinds of classic public spaces and infrastructures, which are then open to all on equal terms, is the paradigmatic case of public use that even the most ardent critics of takings accept as the proper province of eminent domain.[13] As a practical matter, these collective action problems would cut off future innovation on the Wi-Fi model in any bands other than those where such innovation and markets are already permitted to operate. Had the discussion draft been the law of the land in 1985, there would have been no Wi-Fi. None of the predominant pathways for data transmission today used for handhelds and tablets, smart grid communications

10. There are varied histories of radio from technological, business, and regulatory perspectives. Among the best is the classic by Erik Barnouw. *See* A TOWER IN BABEL: A HISTORY OF BROADCASTING IN THE UNITED STATES TO 1933 (1966). For the centrality of politics to the shape of media markets, broadcast technology, and market structure, see PAUL STARR, THE CREATION OF THE MEDIA: POLITICAL ORIGINS OF MODERN COMMUNICATIONS 327–383 (2004); and ROBERT MCCHESNEY, TELECOMMUNICATIONS, MASS MEDIA, AND DEMOCRACY: THE BATTLE FOR THE CONTROL OF U.S. BROADCASTING, 1928–1935 (1993). For an outline of the various historiographies of radio, and how they feed into the regulatory debate, see Yochai Benkler, *Overcoming Agoraphobia: Building the Commons of the Digitally Networked Environment*, 11 HARV. J.L. & TECH. 287, 298–314 (1998) [hereinafter Benkler, *Overcoming Agoraphobia*]. The illegality of Hoover's power grab was established in *United States v. Zenith Radio Corp.*, 12 F.2d 614, 617–618 (N.D. Ill. 1926).

11. *See* Spectrum Innovation Act of 2011, H.R. __, 112th Cong. § 104(a) (Discussion Draft 2011), *available at* http://www.publicknowledge.org/files/docs/DraftHouseRepublicanSpectrumBill.pdf.

12. *Id.*

13. RICHARD EPSTEIN, TAKINGS 168–169 (1985). What is more, eminent domain applies to already existing expectations, whereas allocating spectrum to unlicensed use in the first instance defeats no expectation.

and healthcare, inventory management, or security would have been legal.[14]

The core question in wireless policy, broadly recognized for at least the last decade,[15] has been how much of the future of wireless innovation will depend on exclusively-licensed spectrum — whether allocated under (1) a command and control system or (2) auction and secondary markets — and how much will be developed in bands where it is permissible to deploy (3) open wireless systems. Some frequencies will almost certainly remain under a command and control system.[16] This will likely be the case for the TV bands (although the incentives auction and TV White Spaces[17] suggest that a mixed-model with auctions and open wireless is preferable). The same can probably be said for military or public safety uses (although again, dynamic frequency sharing in the 5 GHz band[18] and the strong emphasis on spectrum sharing in the PCAST Report[19] suggest that even in those bands there is significant drive to incorporate aspects of both auctions and open wireless). Some will remain under auction and secondary markets, such as the already-auctioned bands dedicated to cellular providers. And some will remain under open wireless systems, as in current Wi-Fi. The question is what policy to adopt for future allocations and how to regulate current allocations.

A particularly crisp example of wireless policy's importance is the difference between U.S. and European regulation of industrial, scientific, and medical bands ("ISM band") and that regulation's effect on markets for smart grid communications. Comparing these two jurisdictions suggests that providing substantial space for open wireless experimentation can result in a significantly different innovation path. Europe uses very little wireless smart grid communication, al-

14. Worse, this proposal had a real chance of passing because it was tacked onto a major piece of budget legislation at a time of the debt ceiling crisis, apparently reflecting the beliefs of a sole influential staffer who simply got it wrong. This perspective on the process was repeated by four interviewees who were involved at various stages, and from various positions, in the legislative process; in separate face-to-face or phone conversations, in the fall of 2011 and early 2012.

15. While the regulatory practice and the academic debate underlying the choice have been going on for longer, *see infra* Parts II–III, the public recognition that the choice among the three approaches is the core policy question dates back to 2002*, see* FCC, SPECTRUM POLICY TASK FORCE REPORT 35 (2002) [hereinafter SPECTRUM POLICY TASK FORCE REPORT], *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-228542A1.pdf.

16. By "command-and-control," I mean a system in which the FCC oversees every allocation of spectrum, unlike auction-and-markets, where the FCC is only involved in the beginning. I use "open wireless systems" to refer to unlicensed, dynamic frequency sharing, license-by-rule, and various other approaches.

17. *See infra* Part V.B.1.

18. Revision of Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, 21 FCC Rcd. 7672, 7673 (June 29, 2006) [hereinafter Revision of Parts 2 and 15].

19. *See infra* notes 368–69 and accompanying text.

most all of it licensed-cellular. U.S. smart grid communications systems, by contrast, overwhelmingly rely on wireless, and three-quarters of these systems use open wireless mesh networks. One obvious difference between the two systems is that Europe has very little open wireless spectrum allocations below 1 GHz.[20] What little remains is balkanized and subject to highly restrictive power limits.[21] Europe also imposes severe power constraints on devices using its 2.4G Hz bands.[22] The United States, by contrast, has a contiguous 26 MHz band, 901–928 MHz, with less restrictive power limits, which plays a central role in U.S. smart grid communications markets.[23]

The past decade has seen a gradual emergence of what was, fifteen years ago, literally unbelievable: spectrum commons are becoming the basic model for wireless communications, while various exclusive models — both property-like and command-and-control — are becoming a valuable complement for special cases that require high mobility and accept little latency. Consider wireless patient monitoring, once thought the epitome of critical applications that could never be allowed to fail and therefore require dedicated spectrum. In the actual market for remote monitoring, open wireless technologies, either general purpose like Wi-Fi, or specific purpose like wireless medical telemetry, cover almost the entire market. How can this be? After all, to quote the most vocal critique of open wireless policy, with open wireless, as with the Internet, "[c]lassically, the brain surgeon cannot read the life-or-death CT-scan because the Internet backbone is clogged with junk e-mail."[24] *Eppur si muove*. Hospitals rely on Wi-Fi extensively, or for some applications on license-by-rule Wireless Medical Telemetry Service ("WMTS") sharing. Cellular machine-to-machine ("M2M") appears to be receding as a viable competitor to these diverse open wireless approaches. It turns out that the rate of innovation in open wireless, the growing capacity of each node, the improvements in shared access over diverse infrastructures, and the design of data flows to be less latency-sensitive have all contributed to making yesterday's unthinkable into tomorrow's inevitable.

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20. Tim Cutler, *Unlicensed Wireless Data Communications, Part I: Defining Requirements*, COMPLIANCE ENGINEERING MAG., http://www.ce-mag.com/archive/02/Spring/cutler1.html (last visited Dec. 22, 2012).

21. *Performance of Different Frequency Bands: 2.4 GHz vs 900/869 MHz*, COOPER CROUSE-HINDS, http://www1.crouse-hinds.com/wirelessio/PDF/White%20Paper/white_paper_frequencies.pdf (last visited Dec. 22, 2012) ("In Europe, 2.4 GHz devices are regulated to 100 mW . . . .").

22. *Id.*

23. *See infra* notes 225–29 and accompanying text.

24. 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, 491 (2001).

In the 1990s, we spoke of the "Negroponte Switch" as the move of personal services like voice from fixed wire to wireless, making them pervasive, and of single-location services like video to wire.[25] The evidence we see in many markets now suggests a very different kind of epochal "switch" in the coming decade. This switch will see most applications moving from generally integrated, proprietary, sparse-infrastructure, latency-indifferent architectures, like mobile cellular networks, to open networks built on "Shared Access Nomadic Gateway" architectures. Shared access architectures exploit the lumpiness of the communications needs of any given application to deliver the kind of connection needed, when it is needed (as opposed to continuously, whether continuity is needed or not). They run on dense infrastructures that share not only open wireless spectrum allocations but also access to high-capacity nodes from diverse wired platforms offered by diverse organizations and individuals, using cross-organizational sharing to make the hops as short as feasible. Sparse architectures will continue to have value, but only as complements to a baseline that will be implemented over the shared access architectures.

After Part I's general introduction, Part II offers a background primer on the policy debate, and Part III focuses on the academic discourse. If you know the landscape of the discussion, you are encouraged to skip those Parts. Part IV describes the new evidence offered in this Article. It surveys seven markets, the performance of secondary markets, and various cases of failure or ambiguous success of special-purpose open wireless allocations. Part V outlines policy implications and offers observations on the political economy of spectrum auctions and the risk it poses to reasoned policy. The market evidence requires a shift in policy toward supporting dense-infrastructure, nomadic gateway architectures but is hampered by a skewed political economy that treats auction revenues as paramount. I also identify some implications for how open wireless allocations should be designed in those bands designated for open wireless use. Part VI concludes.

II. POLICY APPROACHES

A century has passed since August 13, 1912, when Congress enacted An Act To Regulate Radio Communication.[26] The dominant problem that spectrum regulation has sought to address ever since then is interference: the risk that if more than one radiator transmits at a given frequency, no one will be heard properly.[27] In 1912, licensing

25. *See* George Gilder, *The New Rule of Wireless*, FORBES, Mar. 29, 1993, at 96, *available at* http://www.seas.upenn.edu/~gaj1/wireless.html.
26. An Act to Regulate Radio Communication, 47 U.S.C. §§ 51–60 (repealed 1927).
27. *See infra* notes 82–85.

and regulation were introduced as a condition of operating a radio, but the licensing was non-exclusive.[28] From 1912–1922, driven primarily by war production and later by massive amateur and commercial experimentation, radio innovation exploded, focusing from November of 1920 on broadcast.[29] As the number of broadcast stations exploded in 1922, then-Secretary of Commerce Herbert Hoover tried to graft more extensive control over licenses onto the 1912 Act.[30] His core effort was to provide preferred channel access to well-capitalized commercial stations, while concentrating amateur and smaller-scale nonprofit broadcasters in less desirable frequencies.[31] This approach ultimately collapsed with the *United States v. Zenith* decision in 1926.[32] It took Congress a mere two months after it returned to session to pass the Radio Act of 1927,[33] which laid the foundation for our present model.

A large chunk of the available spectrum is reserved for government use; this is the part that the NTIA manages.[34] Other parts of the spectrum are regulated by a federal commission. This commission regulates radio communications by (a) dividing the spectrum into distinct channels, each defined over a range of frequencies, (b) allocating specific communications uses to stated sets of channels, (c) determining which private party will control transmissions over each channel in a given geographic region, and (d) determining at what power that party can radiate on that channel, using what kind of antenna.[35] The 1934 Act did not alter that model, but replaced the Federal Radio Commission with the Federal Communications Commission and consolidated in the FCC's hands power over both radio and wireline communications.[36] The 1996 Telecommunications Act also did not change the basic model.[37]

This basic command-and-control model of wireless communications regulation continues to be the dominant approach governing the majority of bands available for use.[38] Throughout the twentieth century, however, there were precursors of what are now seen as the two

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28. Krystilyn Corbett, Note, *The Rise of Private Property Rights in the Broadcast Spectrum*, 46 DUKE L.J. 611, 617 ("While [the Radio Act of 1912] gave the Secretary of Commerce authority to license broadcasters, it had not given him authority to provide for the exclusive assignment of frequencies or to deny a right to use the electromagnetic spectrum." (internal citations omitted)).

29. *See supra* sources cited in note 10.

30. Benkler, *Overcoming Agoraphobia*, *supra* note 10, at 308–310 and sources cited therein.

31. *See id.*

32. *See* 12 F.2d 614, 617 (N.D. Ill. 1926) (holding that the 1912 Act gave the Secretary the power to grant licenses but not to deny them or impose specific operating channels).

33. Barnouw, *supra* note 10, at 199.

34. Benkler, *Overcoming Agoraphobia*, *supra* note 10, at 298.

35. *Id.*

36. *Id.*

37. *Id.*

38. SPECTRUM POLICY TASK FORCE REPORT, *supra* note 15, at 35.

primary alternatives to command-and-control: markets in licenses and in unlicensed devices. Secondary markets in spectrum have existed since the Radio Act of 1927 permitted transfers but conditioned them on "the consent in writing of the licensing authority."[39] FCC approval shifted in its form and intensity,[40] but over time the agency came to view license transfers as more or less routine and imposed fewer constraints, preferring to rely on markets to determine the best use of spectrum.[41] In effect, secondary markets in spectrum *assignments* (i.e. to determine who gets the license) have existed since the creation of radio, and to some extent — in the limited sense that format regulation is a matter of *allocation* fine-tuning (i.e. determining the use of a particular band) — even allocation was subject to such markets.[42] Similarly, the roots of the unlicensed wireless regime are located in the FCC's 1938 decision to allow the operation of low-power devices without an individual license.[43]

The 1995 personal communications services auctions marked two important advances in the use of a market-based approach to wireless regulation, which has become the FCC's primary means of allocating spectrum. First, and most importantly from the perspective of efficiency, the licenses were defined in broad and loose terms. This meant that as uses and technology changed, licensees could reallocate their spectrum to the new approaches.[44] This basic flexibility and fluidity

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39. Radio Act of 1927, Pub. L. No. 632, § 12, 44 Stat. 1162, 1167 (repealed 1934).

40. *See, e.g.*, Note, *Radio and Television Station Transfers: Adequacy of Supervision Under the Federal Communications Act*, 30 IND. L.J. 351 (1955) (describing the state of the law in the mid-1950s).

41. FCC v. WNCN Listeners Guild, 450 U.S. 582, 584–603 (1981) (affirming the FCC's policy statement preferring to rely on market forces rather than format regulation to decide whether a license transfer was in the public interest).

42. "Allocation" refers to deciding what kind of service will run on what frequencies. "Assignment" refers to which particular individual or organization will be permitted to run that service on those frequencies in a given location and time. "Format regulation" involved the FCC resisting transfer of a radio license from, say, the only classical music station in a metropolitan area to an owner who wanted to create a third country music station in that town. The FCC in the past would resist such a transfer on the grounds that it left classical music lovers without an outlet. If we consider "formats" as different kinds of uses, then we can think of format regulation as an allocation decision rather than an assignment decision.

43. *See* Revision of Part 15 of the Rules Regarding the Operation of Radio Frequency Devices Without an Individual License, 4 FCC Rcd. 3493, 3493 (Apr. 18, 1989) [hereinafter Revision of Part 15]. The best digest of this history is UNLICENSED DEVICES & EXPERIMENTAL LICENSES WORKING GROUP, FCC, REPORT OF THE UNLICENSED DEVICES AND EXPERIMENTAL LICENSES WORKING GROUP (2002), *available at* http://www.fcc.gov/sptf/files/E&UWGFinalReport.pdf. *See also* Kenneth R. Carter et al., *Unlicensed and Unshackled: A Joint OSP-OET White Paper on Unlicensed Devices and Their Regulatory Issues* 6–9 (FCC Office of Strategic Planning & Policy Analysis' Working Paper No. 39, 2003), *available at* http://www.fcc.gov/working-papers/unlicensed-and-unshackled-joint-osp-oet-white-paper-unlicensed-devices-and-their-regu.

44. This is why U.S. firms were able to shift their spectrum to digital 3G data services without need for a new auction, whereas European and Japanese regulators needed to conduct a new auction of 3G licenses. *See* BENKLER ET AL., NEXT GENERATION CONNECTIVITY, *supra* note 1, at 219–229.

for users received a substantial regulatory boost when the FCC created the framework for secondary markets in 2003.[45] Second, and more widely discussed but less critical to efficiency, these were the first licenses to be auctioned using the then-new authority Congress had given the FCC to auction licenses rather than assign them through competitive bidding.[46] Auctions can improve efficiency to some extent if they avoid transaction costs or are designed to assure the creation of a competitive market, but flexible licenses play the more important long-term role. And whatever gains they offer, auctions have enormous costs in terms of political economy. Because they are treated as a politically easy source of revenue, they are dealt with as part of budget processes rather than as part of planning for infrastructure development. Efforts to make reasonable long-term policy decisions with regard to wireless communications and innovation can get swamped by the effort to receive a slightly more favorable score from the Congressional Budget Office ("CBO"). In 2012, Congress, for the first time, empowered the FCC to share some of the auction revenue with incumbents who are cleared from the spectrum designated for auction. This was done in order to entice broadcasters to clear some of their spectrum.[47]

The most important advances in unlicensed policy were achieved early and without real expectation of their significance. In 1985, the FCC expanded Part 15[48] to authorize the operation of unlicensed spread spectrum devices in the 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz bands.[49] The FCC also substantially increased the permissible power level of spread spectrum systems to one watt.[50] These bands were wide enough and their frequency high enough to support high data rate transmissions.[51] The FCC later updated and revised these rules in 1989.[52] In 1993, the FCC tried to build on this

45. Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets, 68 Fed. Reg. 66,252, 66,252 (Nov. 25, 2003) (to be codified at 47 C.F.R. pts. 1 and 27). *See also* Promoting Efficient Use of Spectrum through Elimination of Barriers to the Development of Secondary Markets, 69 Fed. Reg. 77,522, 77,522 (Dec. 27, 2004) (to be codified at 47 C.F.R. pts. 1, 24, and 90) (updating the 2003 framework).

46. Omnibus Budget Reconciliation Act of 1993, Pub. L. No. 103-66, § 6002, 107 Stat. 312, 387–97 (codified in scattered sections of 47 U.S.C.).

47. *See* Middle Class Tax Relief and Job Creation Act of 2012, Pub. L. No. 112-96, § 6402, 126 Stat. 156, 224–25 (codified at 47 U.S.C. § 309), *available at* http://www.gpo.gov/fdsys/pkg/PLAW-112publ96/pdf/PLAW-112publ96.pdf.

48. Part 15 is the part of Title 47 of the Code of Federal Regulations that governs the deployment of all equipment that radiates radio energy, whether intentional or unintentional. It sets the general requirement for a license, as well as a range of exemptions from licensing. *See* 47 C.F.R. § 15.1 *et seq.* (2012).

49. Authorization of Spread Spectrum Systems under Parts 15 and 90, 50 Fed. Reg. 25,234, 25,239–40 (June 18, 1985) (to be codified at 47 C.F.R. pts. 2, 15, and 90).

50. *Id.* at 25,237.

51. *Id.* at 25,237–38.

52. Revision of Part 15, *supra* note 43, at 3502.

experience by dedicating 20 MHz for unlicensed PCS services, a service that failed; from that failure, we need to learn lessons about the design of unlicensed services.[53] In 1997, the FCC passed the Unlicensed National Information Infrastructure ("U-NII") Band Rules, opening up for unlicensed use the bands in 5.15–5.35 GHz and 5.725–5.825 GHz.[54] In 1999, the Institute of Electrical and Electronics Engineers ("IEEE") defined the first Wi-Fi standard, an event followed by explosive growth in the number of unlicensed devices that the FCC approved.[55] By 2002, a spectrum task force appointed by then-Chairman Michael Powell issued the first comprehensive report from the regulatory agency that described unlicensed spectrum as one of the two major alternatives to command-and-control, albeit in a secondary role to auctions and flexible licenses.[56] Following this report, the FCC has sought to enhance permission for unlicensed operation of various forms, including the approval of extremely low power, wide bandwidth devices in the Ultrawideband ("UWB") Order,[57] assignment of the 3.65–3.7 GHz range for license-by-rule operation for wireless Internet service providers ("WISPs"),[58] and coordination with the NTIA to permit unlicensed devices to share spectrum with federal radar systems in the 5 GHz band.[59] Most recently, the FCC has moved over the past four years to permit operation of "white spaces" devices in the band allocated to television stations but not used for that purpose.[60] Now, as the NTIA seeks to open up more federal bands to civilian uses, the cost and complexity of clearing federal users and auctioning off the spectrum increasingly suggests that the net revenue of such clearances would be minimal and their lead times may be as long as a decade.[61] Thus, the 2012 PCAST Report suggests a fundamental reorientation of policy to one that sees various forms of shared access as the baseline, while auctions of more-or-less perpetual property-like rights will be rare: "The essential element of this new Federal spectrum architecture is that the norm for spectrum use should be sharing, not exclusivity."[62]

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53. *See infra* notes 316–27 and accompanying text.

54. Amendment of the Commission's Rules to Provide for Operation of Unlicensed NII Devices in the 5 GHz Frequency Range, 12 FCC Rcd. 1576, 1577 (Jan. 9, 1997).

55. *See* UNLICENSED DEVICES & EXPERIMENTAL LICENSES WORKING GROUP, *supra* note 43, at 9.

56. *See* SPECTRUM POLICY TASK FORCE REPORT, *supra* note 15, at 35–42.

57. Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems, 17 FCC Rcd. 7435, 7436 (Apr. 22, 2002).

58. *See* Wireless Operations in the 3650–3700 MHz Band, 20 FCC Rcd. 6502, 6523 (Mar. 16, 2005).

59. Revision of Parts 2 and 15, *supra* note 18, at 7672.

60. *See* Unlicensed Operation in the TV Broadcast Bands, 23 FCC Rcd. 16,807, 16,808 (Nov. 4, 2008); Unlicensed Operation in the TV Broadcast Bands, 25 FCC Rcd. 18,661, 18,662 (Sept. 23, 2010).

61. *See* PCAST REPORT, *supra* note 1, at vi; *see also* NTIA REPORT, *supra* note 4, at iii.

62. PCAST REPORT, *supra* note 1, at vi.

As a matter of practical policy, this brief overview suggests that the FCC has, over the past two decades, moved to enable markets in both licenses and unlicensed devices. Both markets have flourished and provide us with increasing amounts of evidence to help guide future regulatory decisions about auctions, secondary markets, and open wireless approaches.

III. THE ACADEMIC DEBATE

A. Background

Throughout most of the twentieth century, academic attention, insofar as it deals with the FCC's policy for wireless communications, was dominated by broadcast law.[63] Debates over regulation versus market mechanisms tended to focus on the markets in programming, affiliate relations with networks, or vertical integration with programmers.[64] Most took either a standard economics orientation or a critical stance based on the relationship between economic structure and democratic discourse.[65] The command-and-control approach to spectrum allocation was a background fact in most of this literature, but one extremely influential critique took on spectrum allocation itself.

The market-based approach was anchored in work done in the 1950s by Ronald Coase,[66] which itself built on work by Leo Herzel earlier that decade and was followed up with sporadic work in the 1960s and 1970s.[67] It was only after the broader victory of the Chicago school in antitrust and the broad shift toward market-based mechanisms, however, that work by Evan Kwerel, Gregory Rosston and others who advocated spectrum property approaches really made in-

63. On the early political battles around the time of the FCC's creation, see MCCHESNEY, *supra* note 10, at 210–251. On the policy choices and the battles between considerations of media as markets that should be allowed to operate on their own — the core set of questions considered paramount in the mid-1990s — one can peruse the contents of a standard casebook at the time. *See, e.g.*, THOMAS G. KRATTENMAKER, TELECOMMUNICATIONS LAW AND POLICY (1995).

64. *Compare* BRUCE M. OWEN & STEVEN S. WILDMAN, VIDEO ECONOMICS (1992) (taking the standard economics approach), *with* C. EDWIN BAKER, MEDIA, MARKETS, AND DEMOCRACY (2001) (arguing from the perspective of democratic discourse).

65. *See supra* note 64 and sources cited therein.

66. R.H. Coase, *The Federal Communications Commission*, 2 J.L. & ECON. 1 (1959).

67. *See, e.g.*, HARVEY J. LEVIN, THE INVISIBLE RESOURCE: USE AND REGULATION OF THE RADIO SPECTRUM (1971); Arthur S. De Vany et al., *A Property System for Market Allocation of the Electromagnetic Spectrum: A Legal-Economic-Engineering Study*, 21 STAN. L. REV. 1499 (1969); Leo Herzel, *"Public Interest" and the Market in Color Television Regulation*, 18 U. CHI. L. REV. 802 (1951); William K. Jones, *Use and Regulation of the Radio Spectrum: Report on a Conference*, 1968 WASH. U. L. Q. 71 (1968); Jora R. Minasian, *Property Rights in Radiation: An Alternative Approach to Radio Frequency Allocation*, 18 J.L. & ECON. 221 (1975).

roads in the policy debate.[68] The broader intellectual and political sentiments of the Reagan era were translated into spectrum allocation policy as well and, just as in areas as diverse as banking regulation and welfare reform, were implemented as part of the Clinton Administration's embrace of this market-based approach — in this case the PCS auctions conducted by the FCC under then-Chairman Reed Hundt.[69]

Just as the introduction of auctions moved spectrum property from the "yesterday's heresy" to "today's orthodoxy," as Eli Noam called it at the time,[70] technological developments in digital processing and wireless communications gave birth to a new critique. One version of the critique belonged to Noam's: the new technologies made spectrum property obsolete because they allowed use-rights defined in frequency, power, and geography to be cleared through a dynamic spot market rather than through a market in long-term property holdings.[71] Noam's argument is a clear precursor to both the secondary markets efforts of Spectrum Bridge and Cantor Fitzgerald,[72] as well as the proposals advanced in the PCAST report to permit intermediate-term rental of federal spectrum.[73]

The more fundamental critique, however, posited that technological developments made obsolete the whole idea of defining discrete channels for exclusive control and then allocating and assigning them, whether by regulation or prices. "The central question . . . is no longer *how to allocate spectrum channels* — how to decide who makes unilateral decisions about who may communicate using a frequency band and for what types of communications — but *whether to coordinate by defining channel allocations*."[74] *Markets in equipment*, not in spectrum clearances, were to become primary. The argument was that as

68. *See* Gregory L. Rosston & Jeffrey S. Steinberg, *Using Market-Based Spectrum Policy to Promote the Public Interest,* 50 FED. COMM. L. J. 87 (1997); Evan R. Kwerel & Alex D. Felker, *Using Auctions to Determine FCC Licensees* (FCC, Office of Plans & Policy Working Paper No. 16, 1985); Evan R. Kwerel & John R. Williams, *Changing Channels: Voluntary Reallocation of UHF Television Spectrum* (FCC, Office of Plans & Policy Working Paper No. 27, 1992).

69. *Biography of Reed Hundt*, FCC, http://transition.fcc.gov/commissioners/previous/hundt/biography.html (last updated Mar. 8, 2005).

70. *See* Eli Noam, *Spectrum Auctions: Yesterday's Heresy, Today's Orthodoxy, Tomorrow's Anachronism. Taking the Next Step to Open Spectrum Access*, 41 J.L. & ECON. 765 (1998).

71. *See* Eli M. Noam, *Taking the Next Step Beyond Spectrum Auctions: Open Spectrum Access*, 33 IEEE COMM. MAG., Dec. 1995, at 66, 69–70. Noam later elaborated this position in Noam, *supra* note 70, at 769. *See also* Jon M. Peha & Sooksan Panichpapiboon, *Real-Time Secondary Markets for Spectrum*, 28 TELECOMM. POL'Y 603, 606 (2004). Spectrum Bridge's SpecEx is an attempt to implement a primitive and relatively static version of Noam's proposal. *See SpecEx*, SPECTRUM BRIDGE, http://spectrumbridge.com/ProductsServices/search.aspx (last visited Dec. 22, 2012).

72. *See infra* Part IV.B.

73. *See supra* note 62 and accompanying text.

74. Benkler, *Overcoming Agoraphobia*, *supra* note 10, at 292.

computation becomes very cheap, the wireless equipment market can provide solutions that will allow devices to negotiate clearance of their communications without anyone asserting exclusivity over a defined channel, whether that exclusivity is long-term or dynamically leased. The choice becomes one between (1) the Internet model of markets built on smart devices and the services that can be built from networking them and (2) the telecommunications services model of markets built on exclusive proprietary claims to frequencies.[75]

Over the course of the past fifteen years, substantial literature has developed addressing the basic choice between a "spectrum property" model of exclusive licenses defined primarily in terms of frequency and power, and a model based on equipment and services that do not depend on exclusive access to any frequency but rather share a given range of frequencies under a set of generally-applicable coordination rules.[76] The unlicensed/open commons approach to wireless policy has drawn its fair share of critique,[77] but experience, rather than better modeling, will show which of these two approaches should be the

75. I wrote in 1997, and still believe today, that:

> [I]t is at least indeterminate whether an equipment market based on unlicensed spectrum, or a spectrum market based on privatization will be a more efficient means of assuring development and deployment of wireless communications technology. [Analysis] offers some indications that a market in equipment for individual use — like the personal computer or automobile markets — will be better than a market in infrastructure.

Id. at 296.

76. *See, e.g.*, LAWRENCE LESSIG, THE FUTURE OF IDEAS: THE FATE OF THE COMMONS IN A CONNECTED WORLD (2001); Yochai Benkler, *Some Economics of Wireless Communications,* 16 HARV. J.L. & TECH. 25 (2002) [hereinafter Benkler, *Some Economics of Wireless*]; Stuart Buck, *Replacing Spectrum Auctions with a Spectrum Commons*, 2002 STAN. TECH. L. REV. 2 (2002); Martin Cave, *New Spectrum-Using Technologies and the Future of Spectrum Management: A European Policy Perspective*, *in* COMMUNICATIONS: THE NEXT DECADE 220 (Ed Richards et al. eds., 2006), *available at* http://www.cullen-international.com/cullen/cipublic/presentations/martin_cave_communications_next_decade.pdf; 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); Kevin Werbach, *Supercommons: Toward a Unified Theory of Wireless Communication*, 82 TEX. L. REV. 863 (2004); John M. Chapin & William H. Lehr, *The Path to Market Success for Dynamic Spectrum Access Technology*, IEEE COMM. MAG., May 2007, at 96; David P. Reed, *Why Spectrum is Not Property — The Case for an Entirely New Regime of Wireless Communications Policy* (Feb. 27, 2001), http://www.reed.com/dpr/locus/OpenSpectrum/OpenSpec.html [hereinafter Reed, *Why Spectrum is Not Property*]; David P. Reed, Comment on ET Docket 02-135: Comments for FCC Spectrum Policy Task Force on Spectrum Policy (2002) [hereinafter Reed, Comments for FCC Spectrum Policy Task Force on Spectrum Policy], *available at* http://www.newamerica.net/files/archive/Doc_File_142_1.pdf.

77. *See, e.g.*, GERALD R. FAULHABER & DAVID FARBER, SPECTRUM MANAGEMENT: PROPERTY RIGHTS, MARKETS, AND THE COMMONS (2002), *available at* http://assets.wharton.upenn.edu/~faulhabe/SPECTRUM_MANAGEMENTv51.pdf; Stuart Minor Benjamin, *Spectrum Abundance and the Choice Between Private and Public Control*, 78 N.Y.U. L. REV. 2007 (2003); Hazlett, *supra* note 24.

baseline and which should be a useful modifier to that baseline where appropriate.

Before reviewing the new evidence in Part IV, I offer a quick overview of the major elements of the argument for open wireless and a response to some of the past decade's more persistent lines of critique.

B. The Arguments in Favor of Open Wireless Models

1. The Core Scarcities are Computation and Electric Power, Not "Spectrum"

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.[78] *Someone* has to control who "uses" that spectrum, or else no one can "use" it. As a study published in March of 2011 by the National Research Council's Computer Science and Telecommunications Board explained, however, this view is not a correct description of what happens when multiple transmitters transmit at the same frequency.[79] 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.[80] The limitation, or the real economic scarcity, is computation and the (battery) power to transmit and run calculations.[81] 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, in order to enable 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. In that era, thinking about "spectrum" as the relevant scarce input made sense as shorthand for the policy problem.

The core claim of the scholarship developing the open wireless approach has been that, as computation becomes dirt cheap, the assumption that spectrum is a stable, scarce resource is no longer the

78. *See, e.g.*, Jerry Brito, *The Spectrum Commons in Theory and Practice*, 2007 STAN. TECH. L. REV. 1, ¶ 1 ("The radio spectrum is a scarce resource that has been historically allocated through command-and-control regulation.").

79. COMPUTER SCI. & TELECOMMS. BD., NAT'L RESEARCH COUNCIL, WIRELESS TECHNOLOGY PROSPECTS AND POLICY OPTIONS 53–55 (2011) [hereinafter COMPUTER SCI. & TELECOMMS. BD.], *available at* http://www.nap.edu/catalog.php?record_id=13051.

80. *Id.* at 54.

81. *Id.*

most useful way of looking at optimizing wireless communications systems.[82] Rather, the question is: which configuration of smart equipment, wired and wireless infrastructure, network algorithms, and data processing will allow the largest number of people and machines to communicate? 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 as and where you please equipment and networks made of devices capable of identifying the communications they are seeking in the din of a large crowd — will do so more effectively.

The most recent effort to rebut the above is an article by spectrum property advocates Tom Hazlett and Evan Leo. Hazlett and Leo write:

> In fact, radios dispatch streams of energy from their antennas, and that energy propagates through the surroundings at the speed of light. These fluxes are not legal constructs, but physical things. In a microwave oven, they heat soup . . . . Thus, for example, microwave ovens cause 'noticeable' interference with Bluetooth devices operating nearby.[83]

In response to the claim that computation, rather than "spectrum," is the scarce input, Hazlett and Leo state unequivocally: "No amount of additional intelligence embedded in the receiver can reverse the process when interference transforms information into chaos."[84] They conclude:

> The most common form of interference arises when an emission from a single transmitter interferes with itself. This can occur when part of a signal travels directly from the tower to the television, and part travels indirectly, reflecting off (say) a nearby skyscraper. Two different electromagnetic signals of the same frequency cannot in fact coexist at exactly the same place and time.[85]

Hazlett and Leo's argument is simple and deceptively attractive. Radio waves are physical. They can interact with each other to such

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82. *See* Benkler, *Overcoming Agoraphobia*, *supra* note 10; Benkler, *Some Economics of Wireless*, *supra* note 76; Reed, *Why Spectrum is Not Property*, *supra* note 76; Werbach, *supra* note 76.

83. Thomas W. Hazlett & Evan T. Leo, *The Case for Liberal Spectrum Licenses: A Technical and Economic Perspective*, 26 BERKELEY TECH. L.J. 1037, 1083 (2011).

84. *Id.*

85. *Id.* at 1083–84.

an extent that they heat food or cut through steel (lasers). And when they interact, they "interfere" with each other, creating "chaos." But their example of "the most common form of interference" is actually a beautiful instance of exactly the mistake their argument exhibits. They describe the well-known phenomenon of multi-path, the "ghost" image that bedeviled television in the era of rabbit ears antennae. Radio signals would be emitted by a transmitter antenna. They would then travel through space; some would reach the rabbit ears directly, while others would "reflect[] off (say) a nearby skyscraper."[86] The result was that the receiver antenna would get two or more "signals" and would interpret this as "noise," the ghostly figure or the grains on the screen.

The mistake in their argument is that with new technologies multi-path has become a *desirable* feature in radio signals, actively used to enhance the quality of the signal or the capacity of a band, rather than a challenge to be avoided. First explored theoretically in the mid-1990s,[87] equipment and network architectures that use multiple input, multiple output ("MIMO") have become some of the most widely used means of increasing capacity, speed, or both.[88] Wi-Fi 802.11n, WiMax, and LTE or 4G cellular systems all incorporate MIMO.[89] By having multiple antennae on the transmitter and the receiver, and building better computation on both ends, the receiver now treats multi-path as additional information rather than as noise. When receivers were stupid, the additional flows of radiation bouncing off walls or objects were *necessarily* confusing. Now, smart receivers know that there will be several streams with slight variations in their arrival times and angles, and they use that diversity of flows of energy as additional bits of information from which to calculate the original. The same exact physical phenomenon that used to increase noise and

86. *See id.* at 1084.

87. *See, e.g.*, SERGIO VERDÚ, MULTIUSER DETECTION (1998); Gerard J. Foschini, *Layered Space-Time Architecture for Wireless Communication in a Fading Environment When Using Multi-Element Antennas*, 1 BELL LABS TECHNICAL J. 41 (1996); G.J. Foschini & M.J. Gans, *On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas*, 6 WIRELESS PERS. COMM. 311 (1998); Piyush Gupta & P. R. Kumar, *The Capacity of Wireless Networks*, 46 IEEE TRANSACTIONS ON INFO. THEORY 388 (2000); S.V. Hanly & P. Whiting, *Information-Theoretic Capacity of Multi-Receiver Networks*, 1 TELECOMM. SYST. 1 (1993); Michael Honig et al., *Blind Adaptive Multiuser Detection*, 41 IEEE TRANSACTIONS ON INFO. THEORY 944 (1995); R. Knopp & P. A. Humblet, *Information Capacity and Power Control in Single-Cell Multiuser Communications*, 1 1995 IEEE INT'L CONF. ON COMM. 331; David Tse & Stephen Hanly, *Effective Bandwidths in Wireless Networks with Multiuser Receivers*, 1 PROC. IEEE INFOCOM 35 (1998); David N.C. Tse & Stephen V. Hanly, *Linear Multiuser Receivers: Effective Interference, Effective Bandwidth, and User Capacity*, 45 IEEE TRANSACTIONS ON INFO. THEORY 641 (1999).

88. *See* David Gesbert & Jabran Akhtar, *Breaking the Barriers of Shannon's Capacity: An Overview of MIMO Wireless Systems*, TELEKTRONIKK, Jan. 1, 2002, at 1.

89. COMPUTER SCI. & TELECOMMS. BD., *supra* note 79, at 51–52.

reduce capacity is now quality and capacity enhancing.[90] "Diversity gain," or "cooperation gain" as David Reed has called it,[91] is a critical feature of open wireless systems.[92] Far from proving that "[n]o amount of additional intelligence embedded in the receiver can reverse the process when interference transforms information into chaos,"[93] Hazlett and Leo illustrate the opposite.

The physical nature of radio waves is not questioned. When they interact, they superimpose and make extracting information out of them more complex. That complexity, however, is amenable to calculation and does not need to be removed by regulatory decisions, whether implemented as command-and-control or as a cap-and-trade regime (the so-called "spectrum property"). The core design problem for wireless policy is not how to avoid the presence of multiple radiators in a given frequency, time, or location. It is how to assure an innovation path that makes that question no longer the primary source of capacity constraint. The argument in support of open wireless innovation has always been that a market in devices and services built on an Internet innovation model will take advantage of Moore's law, growing more rapidly than a market defined in spectrum allocations that take millions or billions of dollars to exchange. Cap-and-trade carbon markets may or may not be the most efficient regulatory approach to achieving sustainable carbon dioxide emissions; they are not the answer for radiofrequency emissions.

2. Transaction Costs and the Dynamic Shape of Demand for Wireless Capacity Make It Unlikely that Markets Defined in Spectrum Allocations Could Achieve Optimality

The wireless communications capacity and demand of any given set of potential communicators is highly local and temporally dynamic.[94] Imagine two pairs of users: A and B, and X and Y. How much spectrum each pair needs to "use" — in the sense that a communication between A and B would prevent X and Y from communicating using that frequency in that geographic location at that time, which would require the comparative value of the two uses be crystallized and cleared — cannot be defined *ex ante*. Instead, whether any X/Y pair will be excluded and therefore whether communication between

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90. Gesbert & Akhtar, *supra* note 88, at 1, 53 ("Perhaps the most striking property of MIMO systems is the ability to turn multipath propagation, usually a pitfall of wireless transmission, into an advantage for increasing the user's data rate.").

91. Reed, Comments for FCC Spectrum Policy Task Force on Spectrum Policy, *supra* note 76, at 2.

92. *See* Benkler, *Some Economics of Wireless*, *supra* note 76, at 44–47.

93. Hazlett & Leo, *supra* note 83.

94. For a full explanation of the following paragraph, see Benkler, *Some Economics of Wireless*, *supra* note 76, at 47–71.

A and B imposes any social cost that needs to be priced depends on the instantiated system that A and B are using, that X and Y are using, and how those systems interact with the found and built environment in which the two pairs operate. If A and B use very sophisticated devices and are embedded in a cooperative network of repeaters and cooperative antennae, and X and Y use reasonably robust antennae or systems themselves, then no "interference" occurs. X and Y will not fail to communicate when they want to simply because A and B have communicated. This can be true one minute and change the next, such as when A and B are in a built environment rich in multi-path that their equipment uses to enhance communication or are driving through a neighborhood with dense repeater networks and then drive to an area that doesn't have these beneficial characteristics.

The complexity of the necessary transactions is even clearer when one considers the most sophisticated effort to define what property rights in spectrum should look like. Improving on the major work done by De Vany et al. in the late 1960s that focused on time, area, and frequencies,[95] Robert Matheson developed what he called the "electrospace" model for defining property rights to improve wireless communications.[96] This seven-dimensional definition of a spectrum right would include: (1) frequency; (2) time; space defined in the dimensions of (3) latitude, (4) longitude, and (5) elevation; and angle of arrival defined in the dimensions of (6) azimuth and (7) elevation angles.[97] This more complex and realistic characterization of the dimensions necessary for more efficient property rights definitions helps to underscore the severe limitations that transaction costs impose on the feasibility of an efficient market.

Transaction costs are prohibitive, requiring negotiation of the allocation and reallocation of capacity on a dynamic basis. They include the entire communications overhead associated with efficient utilization in open wireless systems (in order to figure out whether any cost is incurred at all) plus a market mechanism to map that determination onto a transaction.[98] These transaction costs would be predicted to lead to the state of affairs we in fact observe: larger-scale allocations to sets of users, who are consumers of a service that bought spectrum and does not clear at the margin using prices but queuing (i.e. dropping calls, losing service). The market in spectrum underwrites the existence of the cellular industry in its relatively concentrated form, but it cannot and does not replace managerial decisionmaking with spot pricing of spectrum clearances. Spectrum auctions and secondary

95. De Vany et al., *supra* note 67.

96. Robert J. Matheson, *Principles of Flexible-Use Spectrum Rights*, 8 J. COMM. & NETWORKS 144, 144 (2006).

97. *Id.* at 144–45.

98. Benkler, *Some Economics of Wireless*, *supra* note 76, at 57–58.

markets, rather than the FCC commissioners and staff, decide whether the managers are those of Verizon or AT&T, rather than T-Mobile or Sprint; the engineers then are those of Verizon and AT&T, rather than those of T-Mobile or the Office of Engineering and Technology. The institution of market forces for deciding who will run the hierarchical managerial system that governs marginal allocation decisions — not dynamic pricing that clears the most valued calls at any given time, location, and band — is the major achievement of spectrum property markets.

Open wireless systems mean that the markets for equipment and services incorporate incentives to design robust equipment and networks capable of operating with limited exclusion of others and that are robust to radiation by others. If Linksys can find a way of achieving higher throughput and lower latency without increasing power (say, by adding multiple antennae to its Wi-Fi equipment), it has an incentive to do so to outcompete Netgear. If Silver Springs Networks can avoid interference by deploying a dense proprietary mesh network for its neighborhood smart grid, and can do so in a way that it gains market share and becomes the largest provider of smart grid communications, it will develop and deploy that mesh.[99] If ExxonMobil wants to implement a touchless payment system, it can do so without having to wait for the cellular carriers to negotiate the standard that would allow them to extract the highest rents from their users.[100] In all these cases, and many others, companies operate in markets and drive innovation and investment in devices and services using those devices, without having to negotiate permission from spectrum owners. Ironically, even AT&T, when faced with capacity constraints posed by the introduction of the iPhone, reverted to Wi-Fi as the more flexible response to data capacity constraints, rather than obtaining spectrum on secondary markets.[101] The freedom to innovate around simple, shared standards that do not require permission to deploy makes open wireless innovation Internet-like; spectrum property innovation ends up, in the best case, running on the Bell Labs model.

99. *See infra* Figure 2.
100. *See infra* notes 255–63 and accompanying text.
101. *See infra* notes 149–53 and accompanying text.

C. Rebutting the Primary Arguments Against Open Wireless Systems

1. Open Wireless is Not a Form of Deregulation, but Merely Another Form of Regulation

Stuart Benjamin and others attack the claim that open wireless approaches represent a market-based solution.[102] Instead, Benjamin argues that "spectrum commons" necessarily require regulation such as maximum power limits or spectrum etiquette rules.[103] These, in turn, become the focus of lobbying and agency capture. Unless technology makes any form of regulation unnecessary, spectrum commons is merely a cover-up for continued regulation with all its warts and failures.[104] A less nuanced but nonetheless succinct way of capturing the flow of the argument is to list the subsection titles of Jerry Brito's 2007 article: "Given a Commons, a Controller; Given a Controller, the Government; Given Government, Inefficiency."[105]

None of the scholars or advocates writing in support of open wireless approaches suggests abandoning all regulation of any kind. Cars on highways must follow the rules of the road; visitors to national parks must obey campsite and fire rules; ships using ocean navigation lanes have to comply with minimal safety rules. Kevin Werbach proposed a universal access privilege coupled with a tort law system to constrain harmful devices and uses.[106] Stuart Buck proposed that the FCC's certification authority is the best means of enforcing sharing rules.[107] Phil Weiser and Dale Hatfield provided their own nuanced critique of spectrum commons with a proposal for a mixed model of collaborative regulation.[108] My own proposal, though underdeveloped, sought to minimize direct regulation by combining some utterly unregulated spaces, a dedicated public trust, and a requirement that FCC device certification be coupled with fast track approval for devices that comply with standards set in open standards-setting processes.[109]

The critique that these approaches invite lobbying during the definition of the sharing regime identifies a genuine concern with the

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102. Benjamin, *supra* note 77; Brito, *supra* note 78, ¶ 3 ("[D]espite the rhetoric, the commons model . . . is not an alternative to command-and-control regulation, but in fact shares many of the same inefficiencies of that system."); Hazlett, *supra* note 24, at 485 ("Gilder, Benkler, and Lessig pursue government regulation to police the commons."); Hazlett & Leo, *supra* note 83, at 1072.

103. Benjamin, *supra* note 77, at 2031–32.

104. *Id.* at 2045–50.

105. Brito, *supra* note 78, at ¶¶ 22, 29, 33.

106. Werbach, *supra* note 76, at 938–43.

107. Buck, *supra* note 76, ¶¶ 40–41.

108. Weiser & Hatfield, *supra* note 76.

109. Benkler, *Some Economics of Wireless*, *supra* note 76, at 76–80. This proposal shares many assumptions with Weiser and Hatfield, *supra* note 76.

design of open wireless approaches. The first generations of unlicensed spectrum allocations had the benefit of being passed before any significant market actors knew or predicted that they could use unlicensed strategies to make money. The early rules therefore passed with no serious lobbying, and even some of the later rules (such as the U-NII band), while driven by a coalition of companies,[110] were naïve in retrospect. Since 2002, lobbying around unlicensed spectrum rulemaking has been extensive. As critics have described exhaustively, the designation of 3.65–3.7 GHz for WISP services was rife with lobbying;[111] the White Spaces Order was almost abandoned because of Dolly Parton's microphone;[112] and Cisco, caught flat-footed on TV-band devices because of its major investments in 5 GHz, spent 2011 fighting tooth and nail to deny its competitors open access to the TV white spaces.[113] This experience certainly lends credence to the concerns about lobbying and agency capture associated with open wireless approaches. But it is an argument for vigilance in the design of these systems, not a refutation of the idea that open wireless allocations are instances of deregulation. Certainly, the FCC regulated power levels for Part 15 permissions in the ISM bands for spread spectrum systems,[114] but doing so did not obviate the fact that the orders in the 1980s were major deregulatory successes. They permitted the deployment of millions of devices that form the basic infrastructure over which massive amounts of data now flow in the form of Wi-Fi,[115] and on which the majority of smart grid communications networks are built.[116] They did so by imposing minimal rules of the road when defining standards and certifying equipment, and then by mostly getting out of the way.

The major fallacy of the critique that "spectrum commons means regulation," however, is that it fails to account for the fact that spectrum property is equally susceptible to the same criticism. Commons are no different from property in this regard. Both systems depend on government decisions and rulemaking, and both require resistance to these pressures in the design of the system. For example, Hazlett and Leo write: "When the FCC unlicenses spectrum, carriers and consum-

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110. Benkler, *Overcoming Agoraphobia, supra* note 10, at 293 (listing corporate supporters of U-NII band).

111. *See* Brito, *supra* note 78, ¶¶ 41–91.

112. Matt Richtel, *Airwaves Battle Pits Dolly Parton Against Google,* N.Y. TIMES, Nov. 4, 2008, at B1, *available at* http://www.nytimes.com/2008/11/04/technology/internet/04wireless.html.

113. Harold Feld, *My Insanely Long Field Guide to Cisco's War on the TV White Spaces*, WETMACHINE (Nov. 15, 2011), http://tales-of-the-sausage-factory.wetmachine.com/my-insanely-long-field-guide-to-ciscos-war-on-the-tv-white-spaces.

114. Revision of Part 15, *supra* note 43, at 3502.

115. *A Brief History of WiFi*, ECONOMIST, June 10, 2004, at 24, *available at* http://www.economist.com/node/2724397.

116. *See infra* Part IV.A.2.

ers must choose Intel's Centrino chips over Qualcomm's CDMA chips and Wi-Fi access points over data networks provided by GSM UMTS/HSDPA, CDMA 1xEV-DV, or WiMax optimized for licensed radio spectrum."[117] In other words, when the FCC dedicates a band to unlicensed use, it is picking winners in the market for chips. But Hazlett and Leo ignore the obvious fact that the inverse statement could be written with equal truth (or, rather, equal half-truth): When the FCC licenses spectrum, carriers and consumers must choose Qualcomm's CDMA chips over Intel's Centrino, and data networks provided by GSM UMTS/HSDPA, CDMA 1xEV-DV, or WiMax optimized for licensed radio spectrum over Wi-Fi access points. There is no neutral baseline by which a decision to license does not benefit some market actors at the expense of others. The two statements are mirror images. More generally, when the FCC decides to package and auction allocations in two 5MHz channels separated by other channels, it is optimizing for incumbent cellular providers for whom this configuration makes upstream and downstream communications with cell towers easier to manage with less expensive hand sets. This is a perfectly fine decision for an agency that sees cellular architectures as dominant in the foreseeable future. But it is not neutral. It prefers cellular architectures of this model over models that rely on, and can benefit from, broad contiguous bands, which the allocation model that the FCC has used in most of its recent auctions makes extremely expensive to reassemble.

Defining exclusive rights for spectrum is extremely difficult, and different definitions will benefit different actors. As Phillip Weiser and Dale Hatfield have shown in detail, the best-designed property systems necessarily require ongoing refinement and supervision through zoning-like and nuisance-like regulations,[118] just as they do for property in land. Government power and public policy have pervaded common law property ever since the Domesday Book.[119] It would take a remarkably naïve view of how modern property law functions to imagine that common law courts are not political, not subject to lobbying, politics, distortion, and plain error, when they develop the rule against perpetuities, decide nuisance cases, pick the American rule over the English rule for ground water as opposed to oil, or decide what to do about a cattle feed lot when the city expands next to it. The naïveté is even more pronounced when one considers the ways in which state and local politics enter land use and property law. To imagine a property regime free from lobbying when parties

117. Hazlett & Leo, *supra* note 83, at 1097.

118. Philip J. Weiser & Dale Hatfield, *Spectrum Policy Reform and the Next Frontier of Property Rights*, 15 GEO. MASON L. REV. 549, 588–98 (2008).

119. The Domesday Book is the record of the massive land survey that William the Conqueror conducted to enable his servants to levy taxes. Seth Safier, *Between Big Brother and the Bottom Line: Privacy in Cyberspace*, 5 VA. J.L. & TECH. 6, 25–26 (2000).

have many billions of dollars at stake and sophisticated lobbying machines geared up is either wishful thinking or purposeful obfuscation.

We cannot escape some level of government regulation over wireless communications and therefore must bear the risks of control, corruption, and error. "Spectrum property" tries to address this weakness by advocating property rights defined in frequency bands that are as broad and flexible as possible and hoping that fluid secondary markets in assignments and allocations will allow companies to reassemble transmission rights to a level that is more or less efficient. Open wireless strategies try to address the same problem by proposing minimal device-level rules, symmetrically applied to all devices and applications, with a privileged position for open standards-setting processes as a backstop against agency capture. Neither approach will completely succeed, and both require vigilance by their respective proponents against corrupt and flawed implementations. Imagining that one is systematically more resistant to the failures of government regulation than the other will not advance either approach.

2. "Tragedy of the Commons" and Technology Will Always Drive Demand Faster than Supply

A common major mischaracterization of the spectrum commons argument is that it depends on a false notion of spectrum abundance, while in reality technology will always drive demand to surpass supply, requiring a price-based allocation mechanism to avoid tragedy of the commons. The Spectrum Policy Task Force Report, for example, sought to dedicate commons where demand was low, as though that approach were particularly suited for instances of abundance, but sought to reserve bands where there was higher demand for property-like regimes.[120] As in many other cases, Hazlett and Leo offer a particularly crisp version of this argument:

> The commons advocates insist that when the technology is smart enough, things *never* get crowded. That story is exactly backwards. Setting aside regulatory barriers, it is the lack of technology that has left some bands relatively empty. Bands that were empty a decade ago are crowded today in large measure because affordable new products have arrived to fill them. In our frame of experience, *technology is not the solution to spectrum scarcity, but its cause*.[121]

120. SPECTRUM POLICY TASK FORCE REPORT, *supra* note 15, at 35–42.
121. Hazlett & Leo, *supra* note 83, at 1079 (second emphasis added).

Hazlett and Leo do not explain why they think technological developments that increase the supply of services people then demand will always necessarily lag behind fulfilling that demand. Technology creates supply (of computation power on a chip) that allows new demands to emerge (people can run new programs that could not run on the prior generation of chips); these new demands ultimately crowd the computation capacity of the last generation of chips just in time to make people want to upgrade to the new generation. Moore's Law describes the technological pattern that repeated roughly every eighteen months for the past half-century. Open wireless technology has followed a similar pattern, based on roughly the same rapid increase in the computation capacity of devices. Indeed, if we take theoretical speeds, Wi-Fi equipment increased in capacity from 2 Mbps in 1998 with 802.11 legacy devices to 1.3 Gbps under the current 802.11ac, whose first units were introduced in the spring of 2012, roughly consistent with Moore's Law.[122] However, Hazlett and Leo merely state that "[t]he spectrum always looks uncrowded to pioneers at the very top of the ladder. Then, when costs drop and regulatory barriers fall, crowds follow."[123] They fail to recognize that, in computation-intensive fields, "crowds follow" implies a beneficial cycle of obsolescence and upgrade.

And this, of course, is directly tied to the failure of Hazlett and others of his persuasion to understand that technology does increase the desired resource (wireless capacity), even though it does not create property (spectrum). This is not a new argument for Hazlett, and his

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122. First legacy 802.11 standard was defined in 1997 for 2 Mbps, and the earliest systems were introduced in 1998. Eric A. Hall, *Lucent 802.11 WaveLAN Adapter* (Aug. 3, 1998), http://www.eric-a-hall.com/articles/19980803ir1.html. 802.11b was finalized in September of 1999, and the first systems shipped with 11 Mbps capacity in early 2000. *Standard Technology — Wireless 802.11* Technologies, BUFFALO TECH., http://www.buffalo-technology.com/en/wireless-802-11-technologies.html (last visited Dec. 22, 2012). 802.11a equipment carrying at 54 Mbps was first introduced in the first half of 2002. Yardena Arar, *Wireless Nets Hit 54 Mbps*, PC WORLD (Jan. 3, 2002), http://www.pcworld.com/article/77544/wireless_nets_hit_54_mbps.html. 802.11n started to appear in early 2007 with speeds of about 300 Mbps. Jon Worrel, *IEEE Finally Ratifies 802.11n 300Mbps Wi-Fi Standard*, FUDZILLA (Sept. 14, 2009, 12:25 PM), http://www.fudzilla.com/home/item/6405-ieee-finally-ratifies-80211n-300mbps-wi-fi-standard (noting that deployments began in the second quarter of 2007). Formal 802.11n came out in 2009, adding a MIMO specification, with a peak capacity of 600 Mbps. Jay M. Jacobsmeyer, *Speed Thrills: The Newest Wi-Fi Standard, 802.11n, Boosts Throughput to 600 Mb/s*, URGENT COMM. (Jan. 1, 2010), http://urgentcomm.com/networks-amp-systems-mag/speed-thrills. By mid-2012 devices shipped with 802.11ac with peak capacity of 1.3 GHz. Jon Fingas, *Buffalo Beats Others to the 802.11ac WiFi Punch, Ships 1.3 Gbps Router and Bridge*, ENGADGET (May 14, 2012, 11:18 AM), http://www.engadget.com/2012/05/14/buffalo-beats-others-to-the-802-11ac-wifi-punch; *NetGear R6300 WiFi Router Review*, CNET (June 27, 2012), http://reviews.cnet.com/routers/netgear-r6300-Wi-Fi-router/4505-3319_7-35315201.html. If we measure the rate of increase in capacity for the intermediate points (not the two edge points), the doubling rate is noisier, sometimes much faster than every eighteen months and sometimes as slow as twenty-five months.

123. Hazlett & Leo, *supra* note 83, at 1080.

earlier predictions based on it ought to give one pause. In 2001, he wrote in almost identical words: "When unlicensed entry thrives, the characteristic pattern is that over-crowding ensues."[124] Quoting extensively from a Department of Commerce report, he argued:

> The use of the ISM [unlicensed industrial, scientific, medical] bands for high reliability communications is problematic, mainly because there is no assurance that today's adequate performance will remain free of interference in the future . . . . Eventually there may be too many additional systems to expect interference-free operation in crowded locations.[125]

As an example of the rent seeking and conflicts that will require FCC intervention, Hazlett explained in 2000:

> [I]n the unlicensed 2.4 GHz band, opposing interests recently battled over standards . . . . The "HomeRF" coalition argued that Proxim's RangeLan2 technology be allowed use of up to 5 MHz in the band . . . . Rival companies supporting "Wi-Fi" technology run up to 11 Mbps, and adamantly opposed the HomeRF proposal . . . . Spectrum scarcity leads to a highly contentious "mess" at 2.4 GHz, a "tug-of-war" between mutually incompatible demands.[126]

The actual market experience of the past decade has shown that Hazlett's concerns that spectrum scarcity would lead to a highly contentious mess in 2.4 GHz were misplaced. That he continues to make the same arguments, sometimes almost verbatim — that technology will lead demand to outstrip increases in capacity and that standards-setting requires a band manager who owns the spectrum — and ignores the actual experience of equipment markets in the past decade, should lead to some skepticism in assessing present reiterations of the same argument.

More generally, the argument in favor of open wireless was never that there is a spectrum abundance. It was, rather, that markets in open wireless devices and the services one can build with them will create better incentives to innovate over time so as to create a supply of new applications and uses more rapidly than would a spectrum-property

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124. Hazlett, *supra* note 24, at 498.

125. *Id.* at 499 (quoting ROBERT J. MATHESON, U.S. DEP'T OF COMMERCE, SPECTRUM USAGE FOR THE FIXED SERVICES 6–7 (Nat'l Telecomm. & Info. Admin., Report 00-378, 2000), *available at* http://www.its.bldrdoc.gov/publications/2409.aspx).

126. *Id.* at 503–04.

market. The innovation model was the model of the Internet: open standards together with robust markets in applications and devices connected to an open network foster extensive innovation. Hazlett again recognized this Internet-like model and understood the relevant market analogy. And once more he misdiagnosed its meaning. He wrote in 2001:

> The spectrum commons idea is motivated by analogy to the Internet. Yet, the architecture of the Internet . . . seriously misallocates scarce bandwidth . . . . High value communications are jammed in congested arteries with massive volumes of data of only marginal significance . . . . The problems thus have been described by financial analysts: . . . . Flat-rate pricing and no financial settlement led to inefficient usage and reduced incentive to eliminate bottlenecks . . . . Many customers who were willing to pay for performance couldn't get it where/when they wanted it, whether it was voice IP (latency), e-commerce (reliability) or entertainment (burstable bandwidth).[127]

Quoting Noam, Hazlett suggested that perhaps these failures could be solved by packet pricing, but he then argued that this would undermine the commons analogy.[128] Hazlett's reliance on claims that the absence of packet pricing would prevent the Internet from developing reliable Voice over IP, e-commerce, and entertainment was based on the same assumptions that underlay his prediction that standards battles between competing device manufacturers would prevent Wi-Fi at 2.4 GHz from being useful.

As the National Academic Study emphasized, the core scarcities of wireless communications are processing and battery power.[129] With enough devices, computation, and cooperative network design, a wireless system can scale demand without exclusivity in spectrum bands. In a system that offers both licensed and unlicensed models, as ours does, unlicensed models scale to meet demand more flexibly. That is why when mobile carriers faced a major data crunch with the introduction of smartphones, they were able to scale their capacity through Wi-Fi offloading more rapidly than by increasing cellular network capacity.[130] That is why MasterCard, Mobil, and E-ZPass were able to

127. *Id.* at 491–92 (internal quotation marks omitted).
128. *Id.* at 492–93.
129. *See* COMPUTER SCI. & TELECOMMS. BD., *supra* note 79.
130. *See infra* notes 149–53 and accompanying text.

develop their own mobile payment systems,[131] and why Silver Springs Networks could complete their mesh smart grid solutions,[132] without waiting for cellular carriers to get around to offering the capabilities. This is not an argument from *abundance*, but rather from innovation and flexibility about the comparative agility of two systems to adapt to increasing demand and to develop solutions to that growing demand.

3. Market Adoption and Failures to Thrive

Perhaps the most significant argument that critics present, and the one that ought to guide our analysis most, is based on levels of market adoption and case studies of failures. Hazlett and Leo emphasize the size and economic value of licensed wireless as compared to unlicensed: "[M]ore than 130 million subscribers receive high-speed data service (fixed and mobile) via exclusively owned bandwidth, as compared to just a few hundred thousand subscribers — at most — to WISPs and those accessing the Internet via a 'spectrum commons.'"[133] As we will see in the mobile broadband case study below, this statement ignores the fact that 40% of mobile handheld data traffic and 92% of tablet data are carried over Wi-Fi.[134] Indeed, it was Wi-Fi that in a sense saved AT&T's system from crashing with the introduction of the iPhone.[135] Comparing mobile cellular to WISPs while neglecting the importance of Wi-Fi offloading stacks the deck against unlicensed in a way that severely understates its centrality to how actual markets handle mobile data services.

Hazlett and Leo further write, "[e]quipment sales tell a similar story. In 2006, global sales for WWANs using liberal licenses were about $225 billion (including handsets), while wireless local area networks ('WLANs'), using unlicensed frequencies, totaled about $3.8 billion."[136] In the past few years there have been studies that have attempted to place more sympathetic estimates on the value of Wi-Fi. A Microsoft-funded study suggested that it is in the range of $4.3 to $12.6 billion per year in homes alone.[137] Similarly, a different analysis commissioned by Google placed the value of Wi-Fi at about $12 billion based on an imputed value for speed or $25 billion based

131. *See infra* notes 255–63 and accompanying text.
132. *See infra* Figure 2.
133. Hazlett & Leo, *supra* note 83, at 1057–58.
134. *See infra* notes 158–64 and accompanying text.
135. *See infra* notes 149–53 and accompanying text.
136. Hazlett & Leo, *supra* note 83, at 1057.
137. RICHARD THANKI, PERSPECTIVE ASSOCS., THE ECONOMIC VALUE GENERATED BY CURRENT AND FUTURE ALLOCATIONS OF UNLICENSED SPECTRUM 7 (2009), *available at* http://apps.fcc.gov/ecfs/document/view?id=7020039036.

on the share of cellular carrier traffic carried over Wi-Fi.[138] Mark Cooper of Consumer Federation of America offers a more expansive approach that includes both imputed value of unlicensed bundled as part of cellular service and savings from Wi-Fi offloading on the supply side and arrives at about $50 billion per year.[139] And in light of efforts to quantify specifically the data-carriage side of Verizon and AT&T's business that suggest a revenue more on the order of $50 to $55 billion per year for licensed mobile data in the United States,[140] Hazlett and Leo's claim of a vast disparity in value appears to be inflated.

Independent of the competing valuations, Hazlett's argument incorporates a major fallacy: that it is reasonable to compare the social values of a technology and the disruptive technology that displaces it by comparing the revenue from each. Consider, for example, classified ads. In 2000, the year that Craigslist first expanded from San Francisco to nine other major cities, U.S. newspaper classified ad revenue was $8.7 billion.[141] By 2007, the last full year before the Great Recession, that number was $3.8 billion, and by 2009 it was $787 million.[142] During the same period, Craigslist, the largest and most significant online replacement for newspaper personal ads, had been reported to have revenues ranging from about $10 million dollars in 2004 to a speculated $100 million in 2009.[143] For 2006, the year in which Hazlett compares the $225 billion in licensed-wireless equipment sales to the $3.8 billion in Wi-Fi equipment to the detriment of the latter, Craigslist had $25 million in sales, while the newspaper classified ads business had revenues of $4.75 billion dollars — about 190 times more revenue.[144] Hazlett's logic would have us believe that the revenue advantage of newspapers supports the proposition that newspaper personals are clearly the superior modality and would thus suggest that government policy should aim to optimize the markets in

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138. PAUL MILGROM, JONATHAN LEVIN & ASSAF EILAT, THE CASE FOR UNLICENSED SPECTRUM ¶¶ 48–49 (2011), *available at* http://www.stanford.edu/~jdlevin/Papers/UnlicensedSpectrum.pdf.

139. MARK COOPER, EFFICIENCY GAINS AND CONSUMER BENEFITS OF UNLICENSED ACCESS TO THE PUBLIC AIRWAVES: THE DRAMATIC SUCCESS OF COMBINING MARKET PRINCIPLES WITH SHARED ACCESS 23–24 (2012), *available at* http://www.markcooperresearch.com/SharedSpectrumAnalysis.pdf

140. *Id.* at 19; MILGROM, LEVIN & EILAT, *supra* note 138, at ¶ 48.

141. Marc Cenedella, *How the Newspaper Business Shrank 92% in a Decade*, CENEDELLA (Mar. 14, 2011), http://www.cenedella.com/job-search/how-the-newspaper-business-shrank-92-in-a-decade.

142. *Id.*

143. Brad Stone, *Revenue at Craigslist is Said to Top $100 Million*, N.Y. TIMES, June 10, 2009, at B10, *available at* http://www.nytimes.com/2009/06/10/technology/internet/10craig.html.

144. Brian M. Carney, *Zen and the Art of Classified Advertising*, WALL ST. J. (June 17, 2006), http://online.wsj.com/public/article/SB115049840863382886-9QyN65ef6meo_D2UlLOxAdRmbN0_20070616.html?mod=rss_free; Cenedella, *supra* note 141.

newspaper classifieds. If one industry completely disrupts the way that another makes money and captures revenue by delivering equivalent or better value at a cost that is orders of magnitude lower, then this pattern of revenues would be exactly the one we would observe. That is precisely what innovation is best at. Comparing the revenues of the two approaches to delivering a human desideratum where each is built on completely different cost models and completely different competition models is simply nonsensical. It would be like trying to value Wikipedia by comparing its revenues to those of Encarta or Grolier. Instead, one needs to compare the human desideratum served, the adoption rate by consenting adults, and the organizations or social processes that serve each. That is the approach I pursue in Part IV.

The fallacy becomes clearer when one realizes that customers who buy wireless data service from Verizon or AT&T are not getting their service delivered exclusively over licensed spectrum. If 92% of data to tablets and 42% of data to handsets is delivered over Wi-Fi, and customers pay for carriage of bits, not for "use of spectrum," a more reasonable approach would be to take the money customers pay for mobile data carriage and equipment and apportion it based on the amount of traffic carried.[145] A different way of saying this would be to underscore that if all the payments to wireless carriers, services and equipment, are attributed to carriage of data over licensed cellular networks, then we see that 99% of what people are spending goes to support carriage of between 8% and 58% of their data. Again, this seems like a weak argument in support of the relative efficiency of the modality of carriage that costs so much more per bit carried. In an ideal market one could imagine arguing that the kinds of bits that cellular carries — highly mobile, latency-intolerant — are so much more valuable than the kinds of bits unlicensed carries — more nomadic and delay tolerant — as to account for the difference in payment. But in a concentrated market with high switching costs and high entry barriers, it is much harder to pin down how much of the revenue represents actual value, and how much represents rent extraction and slow responsiveness of customers with sticky habits. After all, by 2007 newspapers still had personal ad revenues of close to $4 billion. It was only in 2009 that habits changed and revenue fell to $787 million.

Although the particular comparisons and conclusions offered by critics of unlicensed wireless are flawed, it is a sound approach to look for the most significant markets where wireless communications capacity is a core component of the service or equipment purchased, and assess the relative success of licensed spectrum and open wireless approaches in these markets. This is what Parts IV and V do. As Part

145. *See* MILGROM, LEVIN & EILAT, *supra* note 138, at ¶ 48.

IV outlines, using these measures, it appears that in these leading-edge markets, units and services that rely on open wireless techniques to deliver the wireless communications capacity component of their product are being more widely adopted than approaches based on licensed spectrum.

Distinct from the "market adoption" argument are the failure stories: in particular, the failures of the U-PCS and 3.65–3.7 GHz unlicensed allocations.[146] In both cases, the FCC allocated a band of spectrum to unlicensed use; in both cases, there were some efforts to implement equipment and services using these allocations; and in both cases these efforts either failed outright, as in the case of U-PCS, or have been largely anemic, in the case of 3.65 GHz.[147] Indeed, these case studies may suggest that efforts to improve on basic minimal rules like those used in the ISM bands may do more harm than good, and that the basic minimal-rules commons are preferable to more detailed efforts to solve some of the tragedy of the commons issues with more detailed rules. As such, I will return to these case studies in Part IV, when I discuss several markets that emerged, or failed to emerge, around special-purpose unlicensed regimes, and consider the implications for the design of open wireless allocations going forward in Part V.

D. Conclusion

To conclude this Part, the core academic argument in favor of open wireless strategies is that they implement the innovation model of the Internet in wireless communications capacity. Spectrum licenses, particularly when cleared through secondary markets, can offer great flexibility and innovation space, but they are limited by transactions costs and strategic interventions in the design and ongoing enforcement of the rights. Open wireless strategies will tend to innovate and deploy more rapidly in techniques that increase the wireless carrying capacity in any given time, location, or system context. They harness the personal computer market and Internet innovation models to the provisioning of wireless communications capacity. Which of these approaches is better as a baseline, and what mix of them we should adopt as policy, has been a longstanding academic debate. I have sought here to respond to the main criticisms of open wireless policy that emerged over the past decade. But the ultimate arbiter should be experience, and it is to experience that I turn for the remainder of the Article.

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146. Hazlett & Leo, *supra* note 83, at 1077–79; *see also* Brito, *supra* note 78, ¶¶ 44–91.
147. *See infra* Part IV.C.1–2.

IV. EVIDENCE FROM MARKETS

A. Open Wireless Strategies in Seven Core Markets

1. Mobile Broadband

The most urgent calls that more spectrum be auctioned to support broadband policy, the so-called "spectrum crunch," cite the Internet's move 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.[148] Actual market practice, however, has seen carriers and consumers rely on the flexibility and the rapidly growing capacity of Wi-Fi, 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, which challenged AT&T's network beyond its capacity.[149] 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.[150] That transaction ultimately closed in December of 2011, providing AT&T some belated relief. Other firms, Clearwire and the major cable companies, also possessed substantial spectrum holdings that AT&T might have acquired to help meet this demand. As described in Part IV.B, however, secondary markets in spectrum have been relatively inflexible and unable to meet the rapid increases in demand that smartphones and tablets have imposed. What AT&T in fact did was shift data traffic to Wi-Fi. In part, the firm bought Wi-Fi hotspots to reduce load on its capacity-constrained licensed-spectrum network.[151] More importantly, however, iPhones connect to Wi-Fi networks wherever these are available.[152] Customers use home and office Wi-Fi networks extensively to replace the cellular mobile data service. From January to December of 2011, AT&T saw a 350% in-

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148. NATIONAL BROADBAND PLAN, *supra* note 1, at 10–22.

149. Jenna Wortham, *iPhone Overload: AT&T's Burden Hints at Worse Traffic Ahead*, N.Y. TIMES, Sept. 3, 2009, at B1.

150. *See AT&T Closes $1.9-Billion Purchase of Qualcomm Spectrum*, L.A. TIMES BLOGS: TECH. (Dec. 28, 2011, 04:55 PM), http://latimesblogs.latimes.com/technology/2011/12/att-closes-1-point-9-billion-purchase-of-qualcomm-spectrum.html.

151. By the end of 2011, AT&T owned almost 30,000 hotspots around the country. *AT&T Wi-Fi Reaches 1 Billion Connections*, AT&T, http://www.att.com/Common/about_us/pdf/4q_wifi_connections.pdf (last visited Dec. 22, 2012).

152. Press Release, AT&T, AT&T Wi-Fi Supports Auto-Authentication on New iPhone OS 3.0 for Faster Hot Spot Connections (June 17, 2009), http://www.att.com/gen/press-room?pid=4800&cdvn=news&newsarticleid=26865.

crease in monthly Wi-Fi usage and a 550% increase in monthly Wi-Fi data uploads specifically from mobile devices.[153]

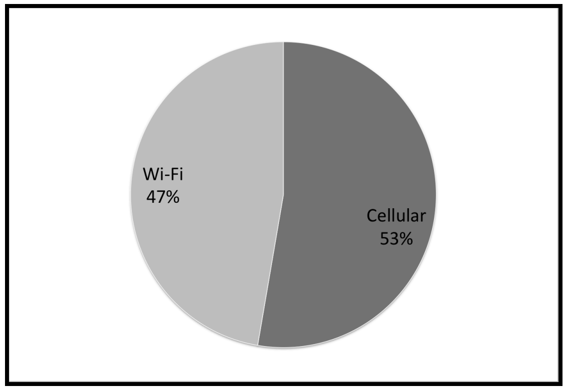

Figure 1a: Share of iPhone Data Traffic[154]

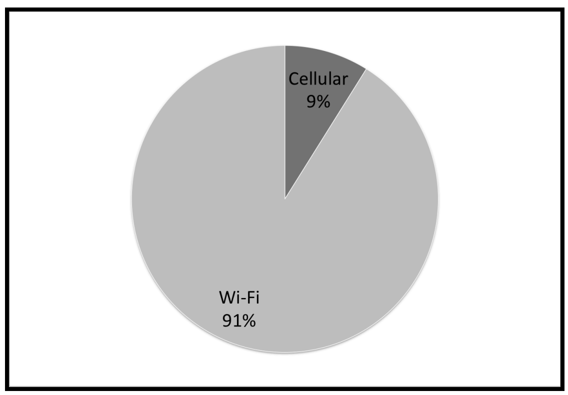

Figure 1b: Share of iPad Data Traffic[155]

Perhaps because the iPhone drove AT&T to early adoption of Wi-Fi offloading, iPhone users rely on Wi-Fi to a greater extent than Android users. An October 2011 study by ComScore reports that users of Android devices, both mobile and tablet, relied on Wi-Fi to a lesser extent, but while also using data less intensively than did iPhone and iPad users.[156] Verizon was more reticent in its Wi-Fi strategy and only announced its plans to offload mobile broadband traffic to Wi-Fi in

153. *AT&T Wi-Fi Reaches 1 Billion Connections*, *supra* note 151.
154. COMSCORE, DIGITAL OMNIVORES: HOW TABLETS, SMARTPHONES AND CONNECTED DEVICES ARE CHANGING U.S. DIGITAL MEDIA CONSUMPTION HABITS 10 (2011) [hereinafter DIGITAL OMNIVORES].
155. *Id.*
156. *See id.* at 3, 11.

May 2011.[157] Verizon's delay in embracing Wi-Fi offloading may have contributed to the relatively lower rates of Wi-Fi usage by Android owners. If this is indeed the difference, then the gap between the two operating systems is likely to close, and iPhone usage should be seen as a leading indicator rather than a likely persistent outlier.

Various assessments place the combined total use of Wi-Fi by smartphones and tablets in a fairly broad range, but in all events growing very rapidly. Juniper Research suggested that over 60% of traffic from smartphones and tablets will be carried over Wi-Fi networks by 2015.[158] In December of 2011, ComScore reported that slightly over 40% of all mobile device traffic was offloaded,[159] up from 37% in late August of that year and from about 34% in May of 2011.[160] Again, if we take iOS to be the leading edge indicator, then it saw 75% of all traffic, iPhone and iPad combined, carried over Wi-Fi, while Android systems saw the reverse: only 29% over Wi-Fi, and 71% over cellular.[161] It will be important to watch whether this difference will persist,[162] or whether the increasing number of Android tablets in the market and the new adoption of offloading by Verizon will make Android usage look more like iPhone Wi-Fi usage. Given Android's growing market share, if its user patterns remain primarily cellular, then we will see an overall decline in the proportion of data carried to these devices over Wi-Fi. In any event, it is almost certain that so much offloading cannot be accounted for by use of hotspots alone. 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%).[163] In that same study, Cisco found that in 2010, 31% of all mobile data was offloaded to home Wi-Fi networks, not including workplace or hotspot offloading and projected that percentage to grow to 39% by 2015.[164]

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157. Phil Goldstein, *Verizon to Offload EV-DO, LTE Traffic onto Wi-Fi*, FIERCE WIRELESS (May 20, 2011), http://www.fiercewireless.com/story/verizon-offload-ev-do-lte-traffic-wi-fi/2011-05-20.

158. *Relief Ahead for Mobile Data Networks as 63% of Traffic to Move Onto Fixed Networks via WiFi and Femtocells by 2015, Finds Juniper Research*, JUNIPER RESEARCH (Apr. 19, 2011, 03:57 AM), http://www.marketwire.com/press-release/relief-ahead-mobile-data-networks-as-63-traffic-move-onto-fixed-networks-via-wifi-femtocells-1503808.htm.

159. COMSCORE, 2012 MOBILE FUTURE IN FOCUS: KEY INSIGHTS FROM 2011 AND WHAT THEY MEAN FOR THE COMING YEAR 40 (2012) [hereinafter MOBILE FUTURE].

160. DIGITAL OMNIVORES, *supra* note 154, at 10.

161. MOBILE FUTURE, *supra* note 159.

162. As of December 2011, iOS accounted for 90% of tablet traffic, and 92% of tablet traffic was, in turn, served over Wi-Fi. *Id*. at 39–40.

163. CISCO, VISUAL NETWORKING INDEX: GLOBAL MOBILE DATA TRAFFIC FORECAST UPDATE, 2010–2015, at 10 (2011) [hereinafter CISCO], *available at* http://newsroom.cisco.com/ekits/Cisco_VNI_Global_Mobile_Data_Traffic_Forecast_2010_2015.pdf.

164. *Id.* at 11. The Cisco paper lumps home Wi-Fi and femtocells into the 39% category, but adjusting for the Juniper study's finding that femtocell offloading accounted for only 2%

Deploying Wi-Fi 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 Wi-Fi to allow any of its mobile customers to use a separate, public portion of their home-broadband customers' Wi-Fi gateways when they are within range.[165] Essentially, SFR has made every one of its home broadband subscribers a tiny-cell tower serving open Wi-Fi to its mobile broadband subscribers when they pass by.[166] SFR was following in the footsteps of another French firm, Free, which began to offer densely nomadic access to all of its subscribers by using all of its subscribers' home connections when it failed to get a fourth mobile license in France's spectrum auctions.[167] BT in the United Kingdom has now followed a similar strategy with its customers, inviting its subscribers to become members of the FON network, which allows any one of its members to connect to the home broadband connection of any other members while on the go.[168] In the United States, Cablevision pioneered a similar strategy, and several of the major cable providers are deploying Wi-Fi throughout their systems, which will be bundled with their home broadband service throughout the service areas of the allied cable providers.[169] For the time being, however, these providers are essentially attaching hotspots to their carriage networks, rather than making the home gateways of customers into gateways shared among all subscribers.

A December 2009 report by Morgan Stanley predicted the growth of Wi-Fi offloading.[170] It reasoned that Wi-Fi is ten times faster than 3G, and the already-existing 802.11n version of Wi-Fi was twice as fast as the not-yet-deployed LTE networks.[171] Arguing that mobile video — which requires high-speed delivery and is largely a stationary activity — is the primary driver of future demand for mobile data, the report emphasized that mobile carriers need to develop a Wi-Fi strategy.[172] A report by HSBC from the same period reached a similar

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of the combined offloading capacity, attributing the entire offloading effect to Wi-Fi is appropriate. *See* JUNIPER RESEARCH, *supra* note 158.

165. BENKLER ET AL., NEXT GENERATION CONNECTIVITY, *supra* note 1, at 154.

166. *Id.*

167. *Id.* at 153.

168. *See What is Fon?*, FON WIRELESS LTD., http://www.btfon.com (last visited Dec. 22, 2012).

169. *See* Josh Long, *Comcast, Other Cablecos Unite In Wi-Fi Initiative*, BILLING & OSS WORLD (May 21, 2012), http://www.billingworld.com/news/2012/05/comcast-other-cablecos-unite-in-wifi-initiative.aspx; Chenda Ngak, *Time Warner, Comcast, Cablevision to Offer Free Wi-Fi Hotspots,* CBS NEWS (May 22, 2012), http://www.cbsnews.com/8301-501465_162-57439268-501465/time-warner-comcast-cablevision-to-offer-free-wi-fi-hotspots.

170. MORGAN STANLEY RESEARCH, THE MOBILE INTERNET REPORT 299–304 (2009).

171. *Id.* at 300.

172. *Id.* at 304.

conclusion, and was skeptical that 4G capacity could scale rapidly enough to meet the growing demand for data from smartphones.[173]

Looking today, and comparing measured — rather than theoretical — capacities of market-deployed networks and products, these predictions seem reasonable. We see that recent product reviews of 4G systems measure maximum speeds of 56 Mbps, with average speeds between 3 and 14 Mbps.[174] By contrast, a roughly contemporaneous product review of one of the first 802.11ac systems marketed in mid-2012 found speeds of 331 Mbps at fifteen feet, and 208 Mbps at 100 feet.[175] Obviously, 4G networks deliver their speeds at longer distances and to higher-mobility units. The point is not, therefore, that Wi-Fi is "better" because it is faster. The point is that the continuing speed difference suggests that for most of the heaviest data consumption that also involves stationary activities, like video or real-time gaming, Wi-Fi connected to a fixed network will continue to be a critical wireless link, and the rise in 4G capacity will not likely replace it. And history suggests that Wi-Fi capacity will continue to increase. As noted earlier, looking at theoretical peak speeds, Wi-Fi has doubled its capacity roughly every 22 months for the past 12 years, a rate remarkably close to Moore's Law.[176]

Following this model, a new sector is emerging aimed specifically at offering Wi-Fi offloading solutions to carriers, dealing with, among other issues, handoff between cellular and Wi-Fi components of the network.[177] Ruckus Wireless has been a particularly active player in this arena. In July, 2011, it signed a deal with KDDI, Japan's second-largest mobile broadband provider, to build out 100,000 Wi-Fi

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173. HSBC GLOBAL RESEARCH, THE CAPACITY CRUNCH: WHAT CAN MOBILE TELECOMS OPERATORS DO AS "MOORE'S LAW MOBILE" BREAKS DOWN? 4 (2009), *available at* http://www.research.hsbc.com/midas/Res/RDV?p=pdf&key=9es25f62mb&n=256089.PDF. The report suggested that either Wi-Fi offloading or major capital expenditures on cell towers to make cells smaller would be necessary. *Id.*

174. *See* Sascha Segan, *Fastest Mobile Networks 2012*, PC MAG. (June 18, 2012), http://www.pcmag.com/article2/0,2817,2405596,00.asp (evaluating speeds of 4G systems from around the country). *But cf.* Mark Sullivan, *3G and 4G Wireless Speed Showdown: Which Networks Are Fastest?*, PC WORLD (Apr. 16, 2012), http://www.pcworld.com/article/253808/3g_and_4g_wireless_speed_showdown_which_networks_are_fastest.html (showing substantially slower speeds, topping at 9.12 Mbps).

175. *NetGear R6300 WiFi Router Review*, *supra* note 122.

176. *See supra* note 122 and accompanying text.

177. *See* Stacey Higginbotham, *Wi-Fi's Coming Identity Crisis*, GIGAOM (July 5, 2011), http://gigaom.com/2011/07/05/wi-fis-coming-identity-crisis; Stacey Higginbotham, *The Mobile Tsunami Is Near: Blame Netflix & Apple*, GIGAOM (Jan. 31, 2011), http://gigaom.com/2011/01/31/the-mobile-tsunami-is-near-blame; Elizabeth Woyke, *U.S. Service Providers Preparing Wi-Fi Offload Rollouts*, FORBES (July 5, 2011), http://www.forbes.com/sites/elizabethwoyke/2011/07/05/u-s-service-providers-preparing-wi-fi-offload-rollouts. Not all agree, needless to say. For a view that Wi-Fi will remain marginal to the core of next generation mobile broadband see HSBC, THE CELL SIDE: TELECOMS OPERATORS' CELLULAR NETWORKS WON'T BE DISPLACED BY WI-FI, BUT CAPEX MUST RISE 1 (2010), *available at* http://www.research.hsbc.com/midas/Res/RDV?p=pdf&key=58mjpry3f7&n=265174.PDF.

spots as a central part of KDDI's next generation network for serving high-bandwidth mobile broadband offerings to more than 30 million subscribers.[178] In July of 2012, Ruckus signed a similar deal with O2, which was the United Kingdom's largest mobile provider prior to the Orange and T-Mobile merger in 2011,[179] to move that company to small-cell architecture using Wi-Fi and a 5 GHz unlicensed mesh network for backhaul.[180] The Ruckus architecture installs Wi-Fi hotspots on lamp or utility poles, directly integrates Wi-Fi into the 3G/4G network, and uses 5 GHz mesh networks where other, wired forms of backhaul are unavailable.[181]

On the consumer side, Republic Wireless, launched in November of 2011, represents an effort to leverage the new, unlicensed-first architecture for a consumer service that offers unlimited data, voice, and text for nineteen dollars a month.[182] The business model has handsets default to Wi-Fi, but, if no open Wi-Fi gateway is available, they fall back on Sprint's wholesale network.[183] The actual business rollout of the project was less than stellar; the operator did not properly gauge the demand for its product, and the capacity limit was not spectrum or interference, but simply a lack of properly equipped handsets.[184] In July 2012 the company announced both a second wave of adoptions and a partnership with Devicescape intended to increase the availability of Wi-Fi spots.[185] Devicescape is a company that develops applications intended to manage and smooth out the process of logging on to

178. *See* Press Release, KDDI & Ruckus Wireless, 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.

179. *See UK Mobile Network Operator Subscriber Data 2007–2011*, TELECOMS MARKET RESEARCH, http://www.telecomsmarketresearch.com/resources/UK_Mobile_Operator_Subscriber_Statistics_2.shtml (last visited Dec. 22, 2012).

180. *See* Press Release, Ruckus Wireless & O2, Telefonica UK (O2) Makes First Big Move to Small Cells with Ruckus Wireless (July 30, 2012), http://www.redorbit.com/news/entertainment/1112665643/telefonica_uk_o2_makes_first_big_move_to_small_cells.

181. *Id.*

182. *See* Zach Epstein, *Republic Wireless Launches with $19 Unlimited Plan*, BGR (Nov. 8, 2011), http://www.bgr.com/2011/11/08/republic-wireless-launches-with-19-unlimited-plan (noting that while the plan is "unlimited," users may have their service terminated if they exceed usage limits on the cellular network).

183. *Id.*

184. Casey Johnson, *Review: Republic Wireless and its $19/Month Cell Service*, ARS TECHNICA (Feb. 1, 2012, 08:00 AM), http://arstechnica.com/gadgets/2012/02/review-republic-wireless-and-its-19month-cell-service (noting that Republic "has only one phone available" and that [t]he selection and quality of handsets will be a hard problem to solve").

185. *See* Matt Burns, *Republic Wireless Outs The Defy XT, Reopens Beta For $19/Month Unlimited Wireless Service*, TECHCRUNCH (July 31, 2012), http://techcrunch.com/2012/07/31/republic-wireless-outs-the-defy-xt-reopens-beta-for-19month-unlimited-wireless-service; Sascha Segan, *Republic Wireless, DeviceScape Pair Up for Free Wi-Fi*, PC MAG. (July 13, 2012), http://www.pcmag.com/article2/0,2817,2407054,00.asp.

Wi-Fi hotspots and make the experience more seamless.[186] It is much too soon to tell whether this pair of companies will win in the marketplace, but they represent precisely the inverted model that relies on unlicensed wireless as a baseline, and uses licensed-exclusive as a backup.

The past two years have seen Wi-Fi's rapid development into a basic fact of network planning. For example, a November 2010 Gartner report 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.[187]

In other words, the "crunch" is not a spectrum crunch, but a lack of agreement about Wi-Fi-enabled devices using their neighbors' Wi-Fi network. This is the problem that Free, SFR, and BT began to solve by making all their subscribers members of the same Wi-Fi roaming network. It is also the problem that Devicescape has set out to solve. The authors of a 2010 academic paper encountered a similar problem while attempting to measure the effects of offloading on 3G use. Using only unsecured Wi-Fi connections, they tested Internet connectivity in an automobile driving through a town. Even though only 11% of the geography was covered by unsecured Wi-Fi, the authors were able to reduce loads on the 3G network by 45% because many applications can tolerate delay between sending or receiving data and having it actually loaded on to the network.[188] Needless to say, a model where all Wi-Fi spots are open under a secure sharing protocol — like the ones SFR, Free, and BT use — would result in higher coverage and the ability to use much more delay-intolerant applications.

The growing role of Wi-Fi in the mobile broadband market, which carries half or more of the data, is important for two reasons. First, mobile broadband is the market whose needs are most often cited in support of repurposing massive amounts of spectrum through

186. Segan, *supra* note 185; *see also* Peter Burrows, *Devicescape: Profiting from Other People's Wi-Fi*, BUSINESSWEEK (July 19, 2012), http://www.businessweek.com/articles/2012-07-19/devicescape-profiting-from-other-peoples-wi-fi.

187. KEN DULANEY ET AL., GARTNER, PREDICTS 2011: NETWORK CAPACITY AND CONSUMERS IMPACT MOBILE AND WIRELESS TECHNOLOGIES 6 (2010).

188. Aruna Balasubramanian et al., *Augmenting Mobile 3G Using Wi-Fi*, *in* PROCEEDINGS OF THE 8TH INTERNATIONAL CONFERENCE ON MOBILE SYSTEMS, APPLICATIONS, AND SERVICES (MOBISYS) 209 (2010).

auctions.[189] Second, because mobile broadband carriers and providers are committed to a licensed-carrier model, they are more resistant to relying on open wireless techniques here than in any other markets we survey. Wi-Fi offloading has not yet solved the billing problem; offloaded connections, where applicable, are not billed as part of the subscriber's usage cap.[190] Using Wi-Fi, therefore, presents real business challenges to the licensed-spectrum carriers, because their primary goal is not to carry data but to bill for data carriage.[191] 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 Wi-Fi offloading is itself a function of inadequate availability of licensed spectrum for mobile data. Once the auctions are concluded, the argument goes, the companies will be fully able to provide for their customers' needs. But the argument entirely misses the lesson from Wi-Fi offloading about the flexibility and innovation feasible in an open wireless environment. We have to expect more devices and applications to come down the road that, like the iPhone, will dramatically increase the demand for wireless capacity. New large allocations of spectrum will undoubtedly allow carriers to serve yesterday's, today's, and perhaps even tomorrow's needs with their existing models. 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. And open wireless, whether Wi-Fi or future generations, will be as flexible and dynamic as it was this time, for exactly the same reasons. Any company can develop a solution, deploy it, and — if it offers significant improvements — have it adopted by others, without requiring either permission from incumbents who hold exclusive licenses or a special allocation from the FCC.

2. 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 United States enjoying far greater and faster deployment of wireless smart

189. *See* NATIONAL BROADBAND PLAN, *supra* note 1, at 81–83.

190. *See Estimate Data Usage*, AT&T, http://www.att.com/esupport/article.jsp?sid=KB109365&cv=820#fbid=ptGtNLqe2sH (last visited Dec. 22, 2012) ("Wi-Fi usage does not count against the data included in your plan.").

191. *See* Michal Lev-Ram, *Is Wi-Fi the Answer to Mobile Operators' Woes?*, CNN MONEY (July 18, 2012), http://tech.fortune.cnn.com/2012/07/18/wi-fi-mobile.

grid communications systems, and Europe largely remaining with power line communications solutions. In part, this may be because Europe's higher voltage electric grid requires fewer transformers per neighborhood, making data over power line more cost-effective than it is in North America.[192] But power line communication systems have limitations, most important among them that if the network goes down, so do the communications necessary to understand the nature of the failure. The difference in the availability of wireless solutions is not that Europe's cellular carriers are not interested in serving smart grid markets; they are, and they do. Indeed, almost all of Europe's wireless smart grid communications happen over cellular M2M systems.[193] The difference is that Europe has no usable open wireless spectrum below 1 GHz, and only constrained availability in the 2.4 GHz bands, and — as a consequence — no significant open wireless solutions were deployed until recently.[194]

In 2009 cellular broadband, licensed wireless, and open wireless networks were seen as significant alternatives for smart grid development.[195] At the time, Gartner had listed automated meter reading in smart grids as one of the most significant application areas for cellular M2M uses,[196] although other observers already saw that the actual companies landing actual contracts with utilities in the United States were overwhelmingly relying on open wireless mesh technologies.[197] The only significant company in this sector that relies on cellular M2M in the North American market is SmartSynch, using AT&T's network. According to a 2012 analysis of the smart grid communications market by Pike Research, SmartSynch accounted for 3% of the North American smart grid communications market.[198] By contrast, the company with the largest market share, Silver Springs Networks,

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192. *North American Versus European Distribution Systems*, ELECTRICAL ENGINEERING PORTAL (Nov. 17, 2011), http://electrical-engineering-portal.com/north-american-versus-european-distribution-systems ("Relative to North American designs, European systems have . . . more customers per trans-former. Most European transformers are three-phase and on the order of 300 to 1000 kVA, much larger than typical North American 25- or 50-kVA single-phase units.").

193. *See infra* notes 202–13 and accompanying text.

194. *See infra* notes 214–17 and accompanying text.

195. Katie Fehrenbacher, *What You Need to Know About Network Options for the Smart Grid*, GIGAOM (Sept. 14 2009, 12:00 AM), http://www.gigaom.com/cleantech/what-you-need-to-know-about-network-options-for-the-smart-grid.

196. NICK JONES & LEIF-OLOF WALLIN, GARTNER, THE SHIFTING SANDS OF THE CELLULAR MACHINE-TO-MACHINE MARKET 2 (2009).

197. DAVID J. LEEDS, GTM RESEARCH, THE SMART GRID MARKET IN 2010: MARKET SEGMENTS, APPLICATIONS AND INDUSTRY PLAYERS 52 (2009), *available at* http://www.greentechmedia.com/research/report/smart-grid-in-2010.

198. PIKE RESEARCH, SMART GRID DEPLOYMENT TRACKER 1Q12, at 11 (2012). Itron purchased SmartSynch in Q12012 and now offers both types; I characterize each here based on its model as of Q12012. Katie Fehrenbacher, *Itron to Acquire SmartSynch for $100M for Smart Grid Tech*, GIGAOM (Feb. 15, 2012, 02:18 PM), http://gigaom.com/cleantech/itron-to-acquire-smartsynch-for-100m-for-smart-grid-tech.

uses a mesh architecture for its neighborhood network, using the 900MHz ISM band.[199] Indeed, all but one of the major companies serving smart grid communications devices deploy open wireless systems — mostly mesh networks — combining 900 MHz, 2.4 GHz, and in some cases amateur band transmission to deliver robust, mission critical, secure services to the nation's electric utilities.[200] A single major provider in this market, Sensus, uses its own licensed spectrum.[201] It serves 20% of the market.[202]

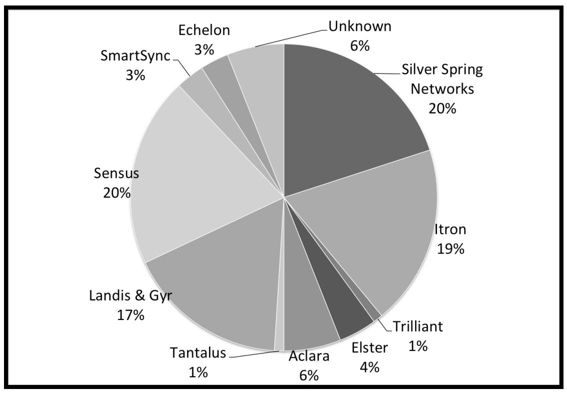

Figure 2: Smart Grid Communications U.S. Market Shares by Firm[203]

Analyzing advanced metering infrastructure ("AMI") node shipments (shipments of nodes that make up the metering infrastructure) provides another point of comparison. In Europe, wireless smart grid communications play a much smaller role than they do in the United States. Only 15% of the European market is wireless; the remainder uses communications over power lines. This wireless market is served solely by cellular carriers. In the United States, by contrast, 87% of AMI nodes shipped in the first quarter of 2012 were wireless.[204] Of the AMI nodes, 75% were for RF mesh open wireless solutions, while

199. SILVERSPRING NETWORKS, WHY UNLICENSED SPECTRUM DOMINATES THE SMART GRID 7–8 (2012), *available at* http://www.silverspringnet.com/pdfs/whitepapers/SilverSpring-Whitepaper-WhyUnlicensedSpectrum.pdf.

200. Conclusion based on author's analysis of the market. Notes on file with author. Analysis involved desk research into each of the companies' offered technologies, white papers, and marketing materials, conducted from August to October of 2011.

201. *See* Jeff St. John, *Arcadian's Smart Grid: Licensed Spectrum Network to Own or Rent*, GREENTECHMEDIA (Sept. 25, 2009), http://www.greentechmedia.com/articles/read/arcadians-utility-offering-licensed-spectrum-to-own-or-rent.

202. PIKE RESEARCH, *supra* note 198.

203. *Id*. I use light grey to denote open wireless and dark grey to indicate licensed, with the characterizations of various technologies my own. Also note that Itron purchased SmartSynch in the first quarter of 2012 and now offers both types; this graph depicts strategies prior to that purchase.

204. *See id.* at 22.

1% were for cellular 2G/3G/4G solutions.[205] The market share of nodes shipped for use in licensed, non-cellular deployments is slightly more than half the market share of Sensus, the primary firm currently using that approach.[206] The disparity between open and licensed non-cellular was evident last year as well, and preceded a decline in Sensus's market share.[207] The difference is easily observable in Figure 3.

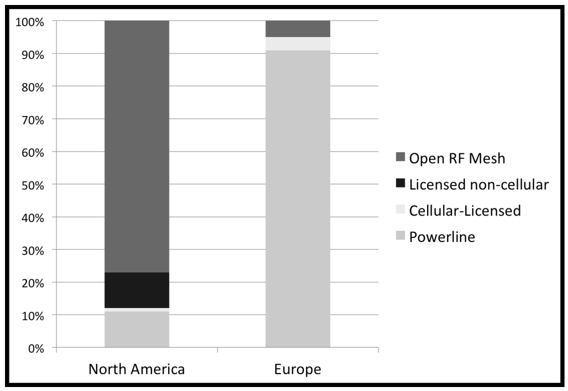

Figure 3: AMI node shipments, Q1 2012[208]

Moreover, the North American markets are more rapidly deploying advanced metering infrastructures capable of interfacing with a home area network. Of nodes shipped, 70% in North America were advanced, compared to only 24% in Europe.[209]

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

205. *See id.*
206. *Id.*
207. KEITH KIRKPATRICK & BOB GOHN, PIKE RESEARCH, PUBLIC CARRIER NETWORKS FOR SMART GRIDS 19 (2011).
208. PIKE RESEARCH, *supra* note 198, at 22, 24.
209. *Id.* at 23–24.

> aggregate and backhaul data from smart meters to the utility.[210]

A senior vice president of Trilliant, one of the companies deploying open wireless mesh architecture in the United States and cellular-based models in Europe, made similar observations in a recent article.[211] Additionally, Landis and Gyr, one of the largest global providers, is using licensed-cellular models in European deployments and open wireless mesh networks in North America.[212] Furthermore, in the first quarter of 2011, cellular wireless accounted for all wireless node shipments in Europe, making up 15% of all nodes shipped.[213] The past year has seen a decline in cellular node shipments and an increase in RF mesh units. In Europe, it appears that cellular models are being used in deployments begun five or six years ago, whereas RF mesh units have been used in deployments since 2009.[214]

It is possible to imagine "cultural" reasons for the difference between the U.S. and European markets, such as the relative strength of mobile use in Europe and the power of the mobile companies there to move early or the relatively more robust culture of unlicensed wireless in the United States. A more likely explanation, however, is the existence of very real and pertinent unlicensed wireless policy differences. Europe takes a vastly different approach to regulating the ISM bands below 1 GHz than does North America. The United States has a contiguous 26 MHz band, between 902–928 MHz, in which anyone capable of operating in the presence of others is allowed to do so, regardless of application type.[215] Devices transmitting in this band play a major part in North American smart grid wireless communications deployments. By contrast, Europe offers only 3 MHz for non-specific applications, broken into two 1.5 MHz bands: one at 868 MHz chopped up into tiny subslivers with various different limitations, and

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210. KIRKPATRICK & GOHN, *supra* note 207, at 16.

211. *See* Rob Conant, *Toward a Global Smart Grid — The U.S. vs. Europe*, ELECTRIC LIGHT & POWER, http://www.elp.com/articles/powergrid_international/print/volume-15/issue-5/Features/toward-a-global-smart-grid---the-us-vs-europe.html (last visited Dec. 22, 2012).

212. *See Gridstream RF*, LANDIS & GYR, http://www.landisgyr.com/na/en/pub/solutions_na/advanced_metering/rf_technology.cfm (last visited Dec. 22, 2012) (describing a North American mesh deployment); *Landis+Gyr E55C Modems and Gateways*, LANDIS & GYR, http://www.landisgyr.eu/en/pub/products_solutions/products_and_solutions.cfm?eventProducts=products.ProductDetails&ID=378&catID=9 (last visited Dec. 22, 2012) (describing a family of nodes built on 2G and 3G).

213. *See* PIKE RESEARCH, SMART GRID DEPLOYMENT TRACKER 1Q11, at 21 tbl.4.9 (2011).

214. *See* PIKE RESEARCH, *supra* note 198, at tbl.3.2.

215. TEXAS INSTRUMENTS, ISM-BAND AND SHORT RANGE DEVICE REGULATORY COMPLIANCE OVERVIEW 7 (Matthew Loy, Raju Karingattil & Louis Williams eds., 2005), *available at* http://www.ti.com/lit/an/swra048/swra048.pdf.

the other at 433 MHz.[216] This tiny bit of spectrum is subject to much lower power limits than those imposed in the United States.[217] Europe also imposes substantially lower power limits on its 2.4 GHz ISM band.[218] It is revealing that the two major deployments of RF mesh in Europe — Gothenburg, Sweden, and British Gas — have chosen AMI communications node companies — the Norwegian Nuri (complemented by Zigbee) and Trilliant (complemented by a proprietary mesh architecture), respectively — that use 802.15.4 at the 2.4 GHz band, rather than the 900 MHz Band used in North America.[219] It appears that European utilities are recognizing the major advantages of mesh networks using unlicensed spectrum and are turning toward open wireless, but they are forced to do so in the teeth of regulations that restrict the use of approaches that have been successful in the United States.

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 1 GHz and even in the 2.4 GHz range, has led to slower adoption of wireless communications in its smart grid infrastructures. The United States' 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.

3. Healthcare

The size and social significance of the U.S. healthcare sector make it an extremely important market for wireless technologies. The promise of telemedicine, remote 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 a market where these choices reflect decisions about systems that buyers believe are mission-critical and, in the extreme case, matters of life and death. Perhaps because of this feature, Hazlett, one of the most vocal critics of open wireless approaches, used a medical example when he mocked

216. *Id.* at 11 tbl.9.
217. *Id.* at 8, 11 tbl.9.
218. *Id.*
219. *See* PIKE RESEARCH, *supra* note 198 (describing the companies chosen); PIKE RESEARCH, SMART GRID NETWORKING AND COMMUNICATIONS 80–81 (2012) (describing the technologies used).

the potential of open wireless spectrum: "Classically, the brain surgeon cannot read the life-or-death CT-scan because the Internet backbone is clogged with junk e-mail."[220] And yet, Wi-Fi transmitting dig-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, in particular Wi-Fi, as the core wireless technology for in-hospital *medical grade, mission-critical wireless networks*.[221]

A September 2011 analysis finds that about 80% of the healthcare wireless market is served by a range of open wireless technologies; only 17% is served by licensed, cellular technologies, primarily for phones and smartphones.[222]

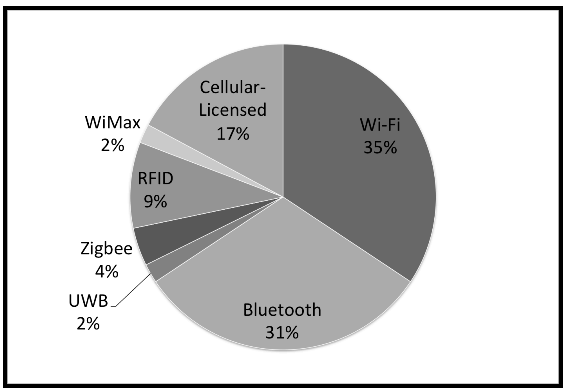

Figure 4: 2010 Market Share of Wireless in Healthcare[223]

A pair of reports from ABI Research from mid-2011 allows us to break down the components of this market dominance of open wireless devices and project that the role of licensed cellular will, if anything, shrink. A major part of the market in wireless healthcare is inside professional healthcare facilities: hospitals and clinics. Because of concerns over cost and cellular reception within buildings intended to shield equipment from interference, the ABI Research report on wireless in professional healthcare facilities emphasized that "[c]ellular and [m]achine-[t]o-[m]achine (M2M) technologies have a role to play in healthcare devices, but ABI Research sees the primary potential in the remote healthcare and assisted living markets rather

220. Hazlett, *supra* note 24, at 491.
221. *See* Steven D. Baker & David H. Hoglund, *Medical-Grade, Mission-Critical Wireless Networks*, IEEE ENGINEERING MED. & BIOLOGY MAG., Mar./Apr. 2008, at 86, 86.
222. MELISSA ELDER, KALORAMA INFO., WIRELESS OPPORTUNITIES IN HEALTHCARE 4–5 (2011).
223. *Id.* at 161.

than in the on-site professional healthcare market."[224] In the home and consumer markets, in turn, ABI Research nonetheless concluded:

> [T]he overwhelming driver for the growth in device shipments within the Home Wellbeing and Healthcare market over the forecast period will be the introduction of broadly supported open wireless protocol standards within the short-range wireless space. The technology lends itself to enabling connectivity to wearable devices more so than M2M cellular does through a range of advantages but primarily through cost and size of the ICs and radios.[225]

In breaking down this market, ABI Research projected no significant role for M2M in the sport, fitness, and wellness market because of its high cost and larger-sized modules.[226] In the home monitoring market, ABI Research reported that M2M accounts for about 2% of the North American market in terms of modules shipped in 2010, and projected that share to grow to 6% in 2011, 12% in 2011, and 25% by 2016.[227] Nonetheless, this was the smallest market of the three covered in the report, and both the sport, fitness, and wellness market and remote patient monitoring market were larger and growing larger yet.[228] The report observed that in 2010, M2M modules accounted for two-thirds of a total of 340,000 modules shipped, but anticipated that almost all the growth would come from non-cellular technologies using short range open wireless approaches — both proprietary and open standards — in unlicensed bands.[229] By 2012 ABI Research anticipated M2M to account for only 17% of remote monitoring modules shipped, and by 2016 M2M modules would be down to 2.5% of the modules shipped, although still accounting for 44% of North America revenues.[230]

As these detailed reports suggest, the market in healthcare applications is a large and complex one, beyond what can be described here. It includes everything from patient monitoring systems using wearable sensors — mostly deploying Radio-Frequency ID ("RFID"), Bluetooth, or ZigBee technologies — through information systems for

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224. JONATHAN COLLINS & SAM LUCERO, ABI RESEARCH, WIRELESS TECHNOLOGIES IN PROFESSIONAL HEALTHCARE 24 (2011).

225. JONATHAN COLLINS & SAM LUCERO, ABI RESEARCH, WIRELESS HEALTH AND FITNESS 2–3 (2011).

226. *Id.* at 40.

227. *See id.* at 48, 51 (calculated from Tables 22 and 32).

228. *Id.* at 45.

229. *See* COLLINS & LUCERO, *supra* note 225, at 55–56 (calculated from Tables 42 and 46).

230. *See id.* at 55–57 (calculated from Tables 42, 43, 46, and 47).

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 Wi-Fi. Body Area Networks, sensors emembedded in the body or worn closely on it, are all open wireless, largely using mesh-capable ZigBee, although some applications include the possibility of communicating their findings through a cellular network.[231] Because these reports are focused on assessing the relative weight of cellular M2M and the various standards-based, ISM-band approaches, they do not focus on the relative weight of devices that rely on the license-by-rule approach — which is a species of open wireless — in the WMTS band. As this Article describes, WMTS devices, which are a registration-based and application-specific form of open wireless, dominate at least one sector of wireless healthcare: in-hospital patient monitoring.[232] Within the home and the hospital, the personal wearable devices, as well as the recording devices that receive information from them, all use open wireless. The Wi-Fi base stations then use wired connections to access the Internet, and the communications occur over that network rather than the cellular provider's network.[233] 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 her home.[234]

Certain companies that focus specifically on highly mobile, continuous monitoring that must be failsafe, like cardiac patient monitoring outside the home, use licensed spectrum. CardioNet, for example, uses open spectrum at 900 MHz to communicate from a patient's pacemaker to her mobile device and then a licensed-spectrum cellular network to communicate irregularities to a monitoring center.[235] Designs based on this model are common in cardiac monitoring: Open wireless does the monitoring work, with Wi-Fi the preferred offloading pathway where available, but cellular networks offer the critical pathway of last resort where Wi-Fi is unavailable to communicate the

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231. Min Chen et al., *Body Area Networks: A Survey*, 16 MOBILE NETWORKS & APPLICATIONS 171, 171–72, 182 (2011).

232. *See infra* Part IV.C.3.B.

233. *See* Dale Wiggins, Chief Tech. Officer, Philips, Current State of Wireless Health and Lessons Learned: Advancing Patient Care with Innovation in Wireless Connectivity, Address Before the FDA/FCC Joint Forum 5 (July 26, 2010), *available at* http://reboot.fcc.gov/c/document_library/get_file?uuid=8ee839cb-b9d2-409c-8112-67e117fdf238&groupId=19001.

234. Hande Alemdar & Cem Ersoy, *Wireless Sensor Networks for Healthcare: A Survey*, 54 COMPUTER NETWORKS 2688, 2696–2704 (2010).

235. Philip E. Ross, *Managing Care Through the Air*, IEEE SPECTRUM, Dec. 2004, at 26, 29; *Fact Sheet: Mobile Cardiac Outpatient Telemetry*, CARDIONET, https://www.cardionet.com/media/pdf/Fact%20Sheet%20-%20CardioNet%20Product%20and%20Arrhythmias.doc (last visited Dec. 22, 2012).

results to healthcare professionals.[236] The continuous coverage offered by cellular networks appears to be insufficiently significant to justify its costs in the home or at the hospital, as well as for monitoring conditions with a less acute profile, which can tolerate periodic transmission. As the ABI Research report suggests, there will remain a highly valuable niche market in remote monitoring for cellular-based technologies, but it will be just that — a niche market for patients that fall into the relatively small category of both highly mobile, and therefore not susceptible to coverage within the hospital or home where open wireless strategies dominate, and highly acute, so that periodic check-in over nomadic connectivity is insufficient to provide the monitoring necessary. Remote monitoring of cardiac patients in a non-acute phase seems to be the primary use that fits that profile, and is in fact where we have seen that model used successfully. But for the overwhelming majority of healthcare uses, the lower cost, lower power, and greater compatibility and interoperability of systems based on open wireless models in hospitals, homes, and workplaces makes open wireless the most important development path for wireless healthcare. In some fields the more special-purpose designated open wireless for medical applications, WMTS and the new MBAN allocation,[237] play a significant role, although it remains difficult to tell whether their advantage comes from the benefits of limited-application allocations or from the fact that it allows Phillips and GE Healthcare, the primary users, to lock customers into their proprietary solutions.[238]

4. 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 system 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 machine-to-machine ("M2M"). M2M is the cellular carriers' term for the service. In 2010

236. *See* Alemdar & Ersoy, *supra* note 234, at 2703.

237. *See generally* Amendment of the Commission's Rules to Provide Spectrum for the Operation of Medical Body Area Networks, 27 FCC Rcd. 6422 (2012) [hereinafter MBAN Report and Order] (describing the new MBAN allocation).

238. *See infra* Part IV.C.3.B.

the global market for M2M modules was valued at $841 million,[239] and the Yankee Group assessed the M2M connectivity revenue at $3.1 billion.[240] By comparison, the RFID global market for that same year was about $5.3 billion.[241] Cellular M2M nonetheless is projected to grow substantially, with ABI Research projecting that it will reach $35 billion in global sales by 2016.[242]

A. Asset Management: Open Wireless RFID is Predominant in the Market, with Important Exceptions

RFID 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 and pallet tracking, asset management, contactless payment, and ticketing.[243] Most people encounter RFID technologies through item tracking and asset management systems like the one implemented by Wal-Mart, which made a major effort to implement RFID tags throughout its stores and supplier network.[244] 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.[245] In the absence of more recent data, the RFID market appeared fairly competitive in 2007, with the top six holding

239. Press Release, ABI Research, M2M Module Market Declines 16% from 2009 to 2010 Due to Price Erosion; Volume to Spur Market to $2.5 Billion by 2016 (Sept. 19, 2011), http://www.abiresearch.com/press/m2m-module-market-declines-16-from-2009-to-2010-du. This was down from $996 million in 2009. *Id.*

240. *Global Enterprise Cellular M2M Connections Will Nearly Triple by 2015*, YANKEE GROUP (Apr. 5, 2011), http://www.yankeegroup.com/about_us/press_releases/2011-04-05.html

241. *RFID Growth Potential Remains Strong Despite Current Apparel Rollout Slowdown*, ABI RESEARCH (July 8, 2011), http://www.abiresearch.com/press/rfid-growth-potential-remains-strong-despite-curre.

242. *Global Cellular M2M Connectivity Services Market to Rise to $35 Billion by 2016, Led by Automotive Telematics and Smart Energy*, ABI RESEARCH (Jan. 17, 2012), http://www.abiresearch.com/press/3837-Global+Cellular+M2M+Connectivity+Services+Market+to+Rise+to+%2435+Billion+by+2016%2C+Led+by+Automotive+Telematics+and+Smart+Energy [hereinafter *Global Cellular M2M Connectivity Services Market*]. This study should be treated with some caution, though, given that it projects smart grid communications as the second largest contributor to that growth, and our analysis of the smart grid market suggests that this is unlikely to be the case, at least in the United States.

243. MICHAEL LIARD & STUART CARLAW, ABI RESEARCH, RFID ANNUAL MARKET OVERVIEW 10 (2009).

244. *Wal-Mart to Buy 15k RFID Readers; Albertsons 5k*, RFID J. (Apr. 18, 2006), http://www.rfidjournal.com/article/view/6473.

245. *See RFID Industry Solutions*, MOTOROLA, http://www.motorola.com/Business/US-EN/Business+Product+and+Services/RFID/RFID+Industry+Solutions (last visited Dec. 22, 2012); *Setting the Standard*, SAVI, http://www.savi.com/products/active-rfid-hardware (last visited Dec. 22, 2012); *Products*, ALIEN TECH., http://www.alientechnology.com/products/index.php (last visited Dec. 22, 2012).

about 40% of the market.[246] Because of the lower costs associated with implementing asset management solutions that use short range, open wireless Part 15 frequencies and because of 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, licensed-spectrum carriers are trying to enter the RFID asset management market.[247] 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 is express 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, licensed models are dominant. FedEx's SenseAware, which in 2012 graduated from being an in-house system to a general cellular-only solution for monitoring packages and rolling stock, relies on licensed-spectrum cellular networks to offer almost continuous connection to packages.[248] The same is true for UPS' DIAD system.[249] 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. The limit is, however, regulatory, not technical. The UK-based company, Neul, is developing White Space devices that offer M2M functionality, including long-range communications over large cells, using the propagation characteristics of TV bands but without an exclusive license.[250]

246. *See* John Rommel, Senior Manager, Motorola Solutions, Top Ten Reasons to Team Up With . . . Motorola the Leader in RFID 2 (2008), *available at* http://www.scsconnect.com/pdf/RFID/Top_10_Reasons_Moto.pdf.

247. Stephanie Neil, *Verizon Adds Asset Management to M2M Wireless Network*, TECHMATCH PRO (Mar. 23, 2011, 10:49 AM), http://www.techmatchpro.com/article/2011/3/verizon-adds-asset-management-to-m2m-wireless-network.

248. *See* Press Release, FedEx, FedEx Expands Sensor-Based SenseAware Service for General Use (Jan. 23, 2012), http://news.van.fedex.com/fedex-expands-sensor-based-senseaware-service-general-use; *Add Some Peace of Mind to Your Shipments*, SENSEAWARE, http://www.senseaware.com/wp-content/uploads/SA2000_Sales_Slick.pdf (last visited Dec. 22, 2012) (product fact sheet for SenseAware 2000); *Slip Some Peace of Mind into Your Shipments*, SENSEAWARE, http://www.senseaware.com/wp-content/uploads/SA1000_Sales_Slick.pdf (last visited Dec. 22, 2012) (product fact sheet for SenseAware 1000).

249. *See The Evolution of the UPS Delivery Information Acquisition Device (DIAD)*, UPS, http://pressroom.ups.com/Fact+Sheets/The+Evolution+of+the+UPS+Delivery+Information+Acquisition+Device+(DIAD) (last visited Dec. 22, 2012) (listing GPRS or CDMA as the communications technologies).

250. *See Product Brief*, NEUL, http://www.neul.com/downloads/NeulNET_Data_Sheet_130611.pdf (last visited Dec. 22, 2012). While a product brief is by no stretch of the imagination a market share, what this document does offer is a sketch of what a White Space device-based M2M system could look like, with cell footprint roughly similar in size to those of cellular networks.

B. 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.[251] A wide variety of technologies are employed as well, from smart cards, to biometrics, to keypads. Of these technologies, low, open wireless frequency-based smart cards represent "the largest revenue contributor to the card-based electronic access control market."[252] For example, Honeywell — a major producer of access control systems — produces smart card, biometric, proximity, Wiegand, keypad, 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.[253] ASSA ABLOY, another major producer of access control systems identified technologies that operate over open wireless spectrum (RFID, near field communication, and ZigBee) as important components to the company's success.[254] 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.

C. 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 appear poised to compete directly in the near future. Early implementations in the United States have relied on open wireless RFID. These include toll collection systems, like E-ZPass; keychain contactless payment, like ExxonMobil's Speedpass; and MasterCard's PayPass. Contactless payment is seen as an area of

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251. PHILLIP M. PARKER, ICON GROUP INT'L, THE 2009–2014 OUTLOOK FOR ELECTRONIC ACCESS CONTROL SYSTEMS IN THE AMERICAS & THE CARIBBEAN 48–49 (2009).

252. Heather Klotz-Young, *State of the Market: Access Control*, SDM (Apr. 11, 2011), http://www.sdmmag.com/articles/86430---state---of---the---market---access---control (quoting GLOBAL INDUSTRY ANALYSTS, INC., ELECTRONIC ACCESS CONTROL SYSTEMS — A GLOBAL STRATEGIC BUSINESS REPORT (2011)).

253. *See generally Readers*, HONEYWELL, http://www.honeywellaccess.com/products/readers (last visited Dec. 22, 2012) (listing product technical specifications for each type of Honeywell reader by specific models under the desired class of reader).

254. ASSA ABLOY GROUP, ANNUAL REPORT 2010, at 46 (2010), *available at* http://www.assaabloy.com/Global/Investors/Annual-Report/2010/Annual-Report-2010-EN-ASSA-ABLOY.pdf.

significant growth among RFID implementations.[255] 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 13.5 MHz, combined with a high-speed wired connection to the point of sale.[256] 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 United States 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 efforts by an alliance of mobile carriers ("Isis"),[257] as well as a Google Wallet Android application by Google, Citibank, and MasterCard.[258] The Google implementation does not require a cellular connection; a user's credit card information is stored and encrypted locally, and the accounting and payment is done by near-field communication, using a dedicated chip on the device and on the merchant's terminal, without need for a licensed-cellular connection.[259] Isis is not yet deployed,[260] and it is unclear whether it will be designed to rely on a real-time cellular connection to its sponsors' networks, or whether it too will rely on NFC and the vendor's network, while the primary role of the cellular carrier will be in its capacity as handset distributor. The closest precursor, Starbucks' tap and pay, uses barcode technology that, like NFC, is designed not to require verification over a wireless connection.[261] A recent white paper found that 70% of smartphone owners

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255. *See* LIARD & CARLAW, *supra* note 243 (predicting the most revenue growth for RFID in the contactless payment vertical).

256. Chris Foresman, *Near Field Communications: A Technology Primer*, ARS TECHNICA (Feb. 9, 2011), http://arstechnica.com/gadgets/2011/02/near-field-communications-a-technology-primer.

257. Shane McGlaun, *AT&T, T-Mobile, Verizon Wireless Showcase Isis Mobile Payment System*, DAILYTECH (Nov. 16, 2010, 10:25 AM), http://www.dailytech.com/ATT+TMobile+Verizon+Wireless+Showcase+Isis+Mobile+Payment+System/article20152.htm.

258. Ryan Kim, *Google Launches its Wallet Platform to Jumpstart NFC Payments*, GIGAOM (May 26, 2011, 11:14 AM), http://gigaom.com/2011/05/26/google-tries-to-jumpstart-nfc-payments-with-wallet-platform. In mid-2012, the application added other major credit cards. Dino Londis, *Google Wallet Accepts All Cards, But Will Retailers Come?*, BYTE (Aug. 6, 2012, 11:27 AM), http://www.informationweek.com/byte/news/personal-tech/240004981.

259. *See FAQ*, GOOGLE WALLET, http://www.google.com/wallet/faq.html (last visited Dec. 22, 2012) (describing Google Wallet's use of a secure Near Field Communication connection).

260. McGlaun, *supra* note 257.

261. The technology does not appear to be likely to change with the newly announced alliance between Starbucks and Square. *See* Thomas Claburn, *Starbucks, Square Partner for Mobile Payments*, INFO. WEEK (Aug. 8, 2012), http://www.informationweek.com/internet/ebusiness/starbucks-square-partner-for-mobile-paym/240005198.

who use tap and pay do so through an app, not a web browser or SMS.[262] The Starbucks app, in turn, stores limited credit locally for communication over barcode (which could be implemented with NFC when this technology is widely adopted) 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.[263]

The point is not that any particular current technology, like NFC, is clearly the future of touchless payment. It is not. The point is that current implementations — MasterCard's PayPass, the Starbucks app, and Google Wallet — all indicate that there is neither a technical nor an 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. Of course, an alliance led by cellular carriers may choose to build dependence on cellular communications, either for vendor terminals or for end-user payment verification, in order to assure that these payment systems in fact depend on the carriers' core asset and billing pathway.

The open-innovation model fostered by open wireless meant that the first mobile payment systems in the United States 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 future 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.

D. 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.[264] Transportation currently accounts for about $1 billion of the M2M market, including revenue from wireless and wireline technologies.[265] ABI Research projects that fleet management will account for almost half

262. COMPETE FINANCIAL SERVICES, MOBILE MONEY 4 (2011) (using second quarter data).

263. *See Customer Service*, STARBUCKS, http://www.starbucks.com/customer-service/faqs/coffeehouse (last visited Dec. 22, 2012).

264. Tammy Parker, *Dots on the Map Provide a Foundation for New Apps*, *in* THE M2M OPPORTUNITY 15, 16 (Sue Marek ed., 2010).

265. HARBOR RESEARCH, SMART DEVICES AND SERVICES CONNECTED BY CDMA2000, at 4 (2010).

of their projected revenue from global M2M markets.[266] The best-known cellular, licensed-spectrum-based implementation of automobile telemetry is General Motors' OnStar. Major players in truck fleet management, Qualcomm and Transics, have used GPS and satellite-based systems.[267] 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 most valuable. All four major cellular carriers offer fleet management services as part of their M2M strategy.[268] 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 Positive Train Control ("PTC") fleet management system.[269]

One significant exception is UPS's in-house fleet management solution. As of 2012, UPS operates the largest commercial fleet in the United States.[270] Rather than turning to a cellular- or satellite-based solution, the company developed its own system, relying on 900 MHz open wireless spectrum.[271] UPS's implementation highlights the importance of indifference to delay, or latency, in making licensed-spectrum cellular architectures valuable. UPS continuously gathers information about the usage and maintenance level of its trucks with on-board short-range connections that do not require licensed spectrum.[272] The truck then uploads the data over the 900 MHz range when each truck returns to the garage.[273] UPS's system emphasizes that innovations in the way data uploading and management are done can permit open wireless services to substitute for licensed-spectrum services. The exceptions are those applications that really are intoler-

266. *Global Cellular M2M Connectivity Services Market*, *supra* note 242.

267. *Transportation*, QUALCOMM, http://transportation.qualcomm.com (last visited Dec. 22, 2012); *What is Meant by Tracking Systems*, TRANSICS, http://www.transics.com/en/resources/glossary/tracking-system.html (last visited Dec. 22, 2012).

268. JOHN KEOUGH, YANKEE GROUP, A CLOSER LOOK AT M2M CARRIER STRATEGY 3–7 (2010).

269. *Recent SpecEx Transactions*, SPECTRUM BRIDGE, http://www.spectrumbridge.com/specex/transactions.aspx (last visited Dec. 22, 2012); Robert J. Derocher, *PTC Push, Narrowband Nudge Present Opportunities for Radio Technology Suppliers*, PROGRESSIVE RAILROADING (Sept. 2009), http://www.progressiverailroading.com/ptc/article/PTC-Push-Narrowband-Nudge-Present-Opportunities-for-Radio-Technology-Suppliers--21416.

270. *Top 300 Commercial 2012*, FLEET-CENTRAL, http://www.fleet-central.com/TopFleets/pdf/FLT500top300.pdf (last visited Dec. 22, 2012).

271. Shelley Mika, *Telematics Sensor-Equipped Trucks Help UPS Control Costs*, GREEN FLEET (July 19, 2010), http://www.greenfleetmagazine.com/article/2520/telematics-sensor-equipped-trucks-help-ups-control-costs.

272. *Id.*; Maisie Ramsay, *M2M Moves to the Car*, WIRELESS WEEK (July 2010), http://www.wirelessweek.com/Articles/2010/07/Technology-Moves-to-Car-M2M.

273. Mika, *supra* note 271; Ramsay, *supra* note 272.

ant of latency, whose information flow 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. A core value of dedicated open wireless availability in the TV bands would be to permit innovation and experimentation with wider coverage. This open wireless band could provide an alternative to licensed-spectrum approaches even in very wide area applications that have moderate tolerance for latency, like fleet management.

E. Interim Note on Leveraging Lumpy Demand

One broad thematic lesson from these market studies is that the older view of the critical role of cellular exclusive-licensed services failed to recognize the lumpiness of demand for wireless connectivity along the dimensions of both space and time. Take mobile health applications. When these were thought to require continuous coverage of patients everywhere, licensed cellular networks seemed the inevitable model for supporting such applications. However, actual wireless healthcare market deployments suggest that a relatively small number of applications have that demand shape.[274] Open wireless strategies succeeded in capturing most of the healthcare market because the overwhelming majority of patient demands are in fact lumpy in space, time, or both.

One dimension of lumpiness is space. Patients with low mobility tend to be in the home or in a professional care facility. They may require continuous monitoring in the time dimension, but only in limited spaces. For these, it turns out that some combination of ZigBee and Bluetooth for continuous monitoring on the body, connecting with Wi-Fi to send information 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. This combination is more cost-effective, more secure, and more reliable than cellular M2M, given the architecture of hospitals and the penetration of cell coverage. We see a similar dynamic in mobile video, the largest contributor to mobile data capacity demand, where most of the demand is episodic and stationary.

274. *See supra* Part IV.A.3.

The other dimension of lumpiness is time. The other dimension of lumpiness is time. Consider fleet management. Fleets of trucks and cars are highly mobile and are located throughout the highway system. Nomadic access over Wi-Fi or similar open wireless models was thought insufficient. And, indeed, that is how most of the market is structured. But the in-house fleet management system UPS developed shows that timeliness is not absolute, but instead 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; its data management requirements were designed to make periodic updating of that data sufficient. With the right data management design, nomadic access (access sometimes, when you are near a connection) is enough as long as it is available sufficiently often to meet your needs. Continuous connectivity is unnecessary and inefficient when you only need to update your information infrequently. For UPS, it might be once a day, so the infrastructure for communicating from the car to the data management center can be very sparse. For patients who need vital signs checked every hour or two, you need a denser infrastructure that can support shorter delays between uploads. But you still do not need a continuous connection.

Licensed-spectrum services can offer sparse-infrastructure, low latency 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 unless and until the FCC permits unlicensed operation in lower bands that will permit development of large or mid-size cell deployments, or until we develop sharing models that could support a truly dense small cell infrastructure.

Open wireless services can offer nomadic gateways when and where you need them. They exploit the lumpiness (along either or both dimensions) of the communications needs of any given application to deliver the kind of connection needed, when it is needed. The more dense the available infrastructure, the larger the range of latency-sensitive applications that can still be served using a nomadic gateway architecture. In a growing range of applications, a critical enabling factor is using standards-based communication (mostly Wi-Fi) to connect over gateways owned by diverse owners and operated by diverse providers, who all allow nodes to hop on and off their connections with sufficient regularity to deliver the desired service. Increasing the ease of access to diversely owned gateways that are already deployed and have excess capacity will be a critical policy intervention that can significantly increase the wireless capacity available throughout the United States in the years to come.

B. The Anemic Performance of 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 to reassign their rights fluidly to others who have higher-value uses for the spectrum.[275] Without fluid secondary markets, there is no reason to believe that any given current allocation of spectrum rights 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 secondary markets in 2003.[276] That regulatory permission for secondary markets in exclusive spectrum licenses led to the creation of public-facing markets, like Spectrum Bridge's SpecEx.com and Cantor Fitzgerald's Cantor Spectrum Exchange.[277] Information about the performance of these markets is largely absent.

Secondary markets in spectrum have not exactly failed, but it is difficult to see them as a success story. In August of 2009, Spectrum Bridge had announced that it had reached a total of $8 million in transactions for spectrum.[278] By July of 2010, its CTO, Peter Stanforth, made a presentation entitled "Why Haven't Secondary Markets Been Successful?"[279] There, Stanforth identified lack of education,

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275. *See* De Vany et al., *supra* note 67, at 1500; *cf.* Kwerel and Williams, *supra* note 68, at viii.

276. Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets, 68 Fed. Reg. 66,252, 66,252 (Nov. 25, 2003). *See also* Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets, 19 FCC Rcd. 17,503, 17,505 (Dec. 27, 2004) (updating the 2003 framework).

277. Press Release, Spectrum Bridge, Spectrum Bridge Announces SpecEx™, the World's First Online Market Place for Wireless Spectrum (Sept. 8, 2008), http://www.businesswire.com/news/home/20080908005823/en/Spectrum-Bridge-Announces-SpecEx-TM-Worlds-Online; Press Release, Cantor Fitzgerald Telcom Services, Cantor Telcom Revolutionizes Trading of Radio Frequencies with Launch of Cantor Spectrum & Tower Exchange (Dec. 20, 2004), http://www.cantor.co.uk/assets/pdf/article20041220.pdf.

278. Press Release, Spectrum Bridge, Spectrum Bridge Surpasses $8 Million in Spectrum Transactions, Forecasts Robust Growth (Aug. 10, 2009), http://spectrumbridge.blogspot.com/2009/08/spectrum-bridge-surpasses-8-million-in.html. The announcement did not mention the number of transactions, any information about the transacting parties, or the frequencies sold. *See id.*

279. Peter Stanforth, Chief Tech. Officer, Spectrum Bridge, Why Haven't Secondary Markets Been Successful?, Address at the International Symposium on Advanced Radio Technologies (July 30, 2010), *available at* http://www.its.bldrdoc.gov/isart/art10/slides_and_videos10/SBI-ISART.pdf.

fear of interference, lack of incentives against hoarding, and high transactions costs as the primary reasons for the disappointing performance of secondary markets.[280] The Australian regulator expressed similar concerns in its ten-year review process of secondary markets.[281] 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.[282] 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 the information and transaction costs associated with the larger-scale, infrastructure-like spectrum markets would be their Achilles' heel.[283]

The most glaring secondary market failure is the mobile broadband "spectrum crunch." Clearwire owns, or holds long-term leases on, about 150 MHz of spectrum that covers most major markets.[284] Its holdings are nearly as large as those of Verizon and AT&T put together, but the company actively uses only a small fraction of its capacity (by one plausible assessment about 10%).[285] At the same time, Comcast, Time Warner, and Cox held substantial holdings in both the AWS bands (bands that mobile carriers also hold or use for mobile data) and, to a lesser extent, 700 MHz blocks — entirely unused, for years.[286] Only in 2012 did they negotiate a deal with Verizon to sell their spectrum, and the regulatory hurdles that the deal had to pass offer insight into the difficulty associated with transactions in large-scale infrastructure investments.[287]

Given factors like (1) the known crunch that AT&T faced after the introduction of the iPhone, (2) the continued claims of major capacity crunch driving an extensive search for more spectrum to auction, and (3) 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 frequen-

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280. *Id.* at 5.

281. *See* AUSTL. COMMC'NS & MEDIA AUTH., SPECTRUM TRADING: CONSULTATION ON TRADING AND THIRD PARTY AUTHORISATIONS OF SPECTRUM AND APPARATUS LICENCES 15–19 (2008), *available at* http://www.acma.gov.au/webwr/_assets/main/lib310771/spectrum_trading.doc.

282. *Id.*

283. *See* Benkler, *Overcoming Agoraphobia*, *supra* note 10, at 390; Benkler, *Some Economics of Wireless*, *supra* note 76, at 57 ("[T]he transaction costs associated with market clearance of property rights will be systematically higher than the transaction costs associated with open wireless network communications.").

284. Kevin Fitchard, *Meet the Spectrum Bosses*, GIGAOM (Jan. 3, 2012, 05:00 PM), http://gigaom.com/2012/01/03/meet-the-spectrum-bosses.

285. *See* DEUTSCHE BANK, COPING WITH THE SPECTRUM CRUNCH 24 (2011).

286. Maisie Ramsay, *Verizon's AWS Trump Card*, WIRELESS WEEK (July 31, 2012), http://www.wirelessweek.com/Articles/2012/07/business-Verizon-AWS-Trump-Card.

287. *Id.*

cies to improve the capacity of the major mobile broadband carriers. Certainly a large part of the barrier is regulatory, but as we will see below, the size and nature of the transactions invite regulatory scrutiny and political lobbying; large infrastructure transactions are never as simple as buying tomatoes at the supermarket. But the Clearwire story suggests that the limits of secondary markets are 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.[288] Binding the two systems together would be difficult. Second, Clearwire's holdings are in a contiguous band,[289] while the major carriers built their systems to utilize paired, separated bands.[290] And third, capacity requires towers, backhaul, etc., not just the right to radiate at a given frequency.

The failure to lease Clearwire's bands in the face of the so-called "spectrum crunch" 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 enough to hamper or even prevent a fluid secondary market.[291] The very long period during which no transaction was proposed for the cable companies' spectrum, and the subsequent regulatory scrutiny, emphasize 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, and strategic considerations can intervene, all interfering with efficient market operation.

Another important source of failure, as we have seen with ample clarity in 2011 and 2012, is that the sheer size of the markets and transactions invites regulatory oversight. AT&T's purchase of Qual-

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288. *See* Joan Lappin, *Softbank Must See the Value in Clearwire's 2.5 Ghz Spectrum*, FORBES (Oct. 11, 2012), http://www.forbes.com/sites/joanlappin/2012/10/11/softbank-must-see-the-value-in-clearwires-2-5-ghz-spectrum.

289. Alan Weissberger, *No Surprise: Clearwire to Shift from WiMAX to LTE — But Who Will Fund it?*, COMSOC COMMUNITIES BLOGS (Aug. 4, 2011, 01:49 AM), http://community.comsoc.org/blogs/alanweissberger/no-surprise-clearwire-shift-wimax-lte-who-will-fund-it.

290. COLEMAN BAZELON, BRATTLE GROUP, THE ECONOMIC BASIS OF SPECTRUM VALUE: PAIRING AWS-3 WITH THE 1755 MHZ BAND IS MORE VALUABLE THAN PAIRING IT WITH FREQUENCIES FROM THE 1690 MHZ BAND 8–9 (2011), *available at* http://www.brattle.com/_documents/UploadLibrary/Upload938.pdf.

291. This is consistent with early critiques of secondary markets. *See* Benkler, *Overcoming Agoraphobia*, *supra* note 10, at 346 ("Transaction costs also include the costs associated with switching between uses . . . . [T]he equipment that is likely to be deployed for their services will be relatively specialized. A shift in use will entail the purchase of new specialized equipment. This cost will present a barrier to shifting uses of the transmission right.").

comm's 700 MHz holdings for $1.9 billion was delayed because of concerns of market foreclosure. That transaction was held up while the FCC considered AT&T's other effort to expand its holdings — its proposed merger with T-Mobile.[292] The failure of the T-Mobile deal,[293] in turn, is tied with the close review of the Verizon/SpectrumCo deal. Because the markets are so concentrated, and the number of players so sparse, any transaction goes beyond a standard input — it is a market-shaping result. In the AT&T/T-Mobile case, the deal fell through because it would have eliminated one of the four major competitors in the market.[294] In the case of Verizon/SpectrumCo, part of the deal was, effectively, a vertical market-division agreement between Verizon and its major competitors in home broadband delivery.[295] Thus the transaction is as much about dividing the quadruple play market[296] as it is about alleviating a spectrum crunch that Verizon, the company that has the largest spectrum inventory available for LTE upgrade,[297] may have. All these limitations, both regulatory and technical, seem to arise out of the same basic problem. These markets at their most important are not in fact fluid markets that efficiently price and clear competing spectrum uses. They are markets in large, complex, and long-term infrastructure, underwriting highly concentrated service markets, rife with imperfections and regulatory oversight.

The most enthusiastic proponents of spectrum secondary markets identify three major domains that they see as success stories: Mobile Virtual Network Operator ("MVNO") markets, M2M markets, and

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292. Brendan Sasso, *AT&T and Qualcomm Urge FCC to not Delay Deal Approval*, THE HILL (Dec. 6, 2011, 11:36 AM), http://thehill.com/blogs/hillicon-valley/technology/197441-atat-and-qualcomm-urge-fcc-to-not-delay-deal-approval.

293. Chris Velazco, *The AT&T/T-Mobile Deal is Dead*, TECHCRUNCH (Dec. 19, 2011), http://techcrunch.com/2011/12/19/att-tmobile-merger-dead.

294. *See* Complaint at 3, United States v. AT&T, No. 1:11-cv-01560 (D.D.C. Aug. 31, 2011).

295. Verizon mostly gives up on being an active competitor in home broadband, marketing the cable companies' services together with its wireless service; the cable companies, in turn, abandon the option of entering as mobile carriers offering integrated service with home broadband. Alex Sherman, *Verizon Wireless Allies Itself with Cable in $3.6 Billion Deal*, BLOOMBERG (Dec. 2, 2011, 04:45 PM), http://www.bloomberg.com/news/2011-12-02/verizon-wireless-allies-with-cable-carriers-in-3-6-billion-spectrum-deal.html.

296. Triple-play commonly refers to an offering of voice, video, and data to the home. Quadruple play adds mobile services to that offering, allowing a customer to transact with one company, through one bill, for all these communications needs. *See* Marguerite Reardon, *Cable Goes for the Quadruple Play*, CNET (Nov. 7, 2005, 04:00 AM), http://news.cnet.com/Cable-goes-for-the-quadruple-play/2100-1034_3-5933340.html.

297. *See* Brad Reed, *LTE Spectrum: How Much do the Big Carriers Have?*, NETWORK WORLD (Jan. 23, 2012 06:07 AM), http://www.networkworld.com/news/2012/012312-lte-spectrum-255122.html?page=3 ("Verizon simply blows away AT&T when it comes to spectrum already available for LTE use . . . . Verizon has an average of 62MHz of spectrum available for LTE use today in the top 100 U.S. markets while AT&T has an average of 37MHz . . . .").

the spectrum exchanges themselves.[298] The first of these arguments is misplaced. The second is factually contradicted by actual developments in most M2M sectors. And the third is weakened by the stark evidence from the failure of secondary markets to do anything to alleviate the mobile broadband providers' capacity crunch. MVNOs do not buy spectrum at all. They buy complete minutes at wholesale from incumbent carriers and resell them to customers at retail.[299] 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. This in turn can lead to real innovations: Republic Wireless relies on Sprint's network, and Sprint's own 4G service depends on a partnership with Clearwire.[300] These are welfare enhancing, and they are excellent ideas, but they are a far cry from the kinds of either micro-efficiency[301] or macro dynamic reallocation[302] that secondary markets were supposed to deliver.

M2M markets, as we have already seen, are the cellular carriers' version of wireless communications in a range of vertical markets, 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 1–3% of the market.[303] In healthcare, that number is closer to 15–18%, although it is projected to shrink.[304] While cellular M2M therefore plays an important niche role, like outdoor cardiac monitoring, FedEx package tracking, or most of trucking fleet management

298. *See* JOHN W. MAYO & SCOTT WALLSTEN, SECONDARY SPECTRUM MARKETS AS COMPLEMENTS TO INCENTIVE AUCTIONS 6 (2011), *available at* http://www.gcbpp.org/files/Academic_Papers/AP_Mayo_SecondarySpectrum_062011.pdf [hereinafter MAYO & WALLSTEN, SECONDARY SPECTRUM MARKETS]; John Mayo & Scott Wallsten, *Enabling Wireless Communications: The Role of Secondary Spectrum Markets*, 22 INFO. ECON. & POL'Y 61, 65–70 (2010) [hereinafter Mayo & Wallsten, *Enabling Wireless*].

299. Kevin Fitchard, *Why are MVNOs So Hot Right Now? Thank the Carriers*, GIGAOM (June 25, 2012, 05:00 AM), http://gigaom.com/mobile/why-are-mvnos-so-hot-right-now-thank-the-carriers.

300. *Sprint Partners with Clearwire to Offer 4G WiMAX*, SPRINT, http://developer.sprint.com/site/global/home/4g/sprint_clearwire/sprint_clearwire.jsp (last visited Dec. 22, 2012).

301. For example, A and B bid opposite X and Y to have their packets go through at point P, time T, and frequency F.

302. For example, TV bands become cellular broadband.

303. *See supra* Part IV.A.2.

304. *See supra* Part IV.A.3.

that requires continuous outdoor connectivity, broadly speaking it is consistent with a view of secondary markets as a limited success.[305] The Amazon Kindle, which John Mayo and Scott Wallsten use[306] and Hazlett repeats,[307] provides a nice example. Amazon was strategically committed to its Whispernet cellular-based service, so much so that it had bundled the price of the service into the price of the device, and did not include Wi-Fi connectivity.[308] Over the last two years, however, Amazon began to introduce Wi-Fi capabilities into its Kindles, at first retaining the cellular based functionality.[309] Finally, as Amazon shifted to adding video streaming through its Amazon Prime service, it released its major entry into the tablet market as a Wi-Fi-only device.[310] It is genuinely puzzling to see advocates of market mechanisms insist that a given approach to designing wireless services (licensed, cellular, proprietary, cleared through markets) is superior to an approach that beats it in most actual markets where the two compete, through the choices of customers and sophisticated firms.

The final evidence Mayo and Wallsten offer is the steady flow of secondary market 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.[311] While MHz-pop is a common measure of the value of transactions in spectrum, it is difficult to translate into an assessment of how these transfers promote the efficient allocation of communications capacity.

To see the limitations of this approach to measurement, we can take the two strategies AT&T used when faced with the iPhone-created capacity crunch. The AT&T/Qualcomm deal transferred about 2.25 billion MHz-pop.[312] It offered AT&T some additional capacity, although that number tells us nothing about how much of its network traffic is carried over those frequencies. Additionally, AT&T used Wi-Fi to offload half of its iPhone traffic.[313] Wi-Fi offloading would

305. *See supra* Part IV.A.4.E.

306. Mayo & Wallsten, *Enabling Wireless*, *supra* note 298, at 65–66.

307. Hazlett & Leo, *supra* note 83, at 1054.

308. *See, e.g.*, Adam Frucci, *Amazon Kindle Delivers Free EV-DO 'Whispernet' Service*, GIZMODO (Nov. 19, 2007, 09:56 AM), http://gizmodo.com/324310/amazon-kindle-delivers-free-ev+do-whispernet-service.

309. *See Kindle Keyboard 3G*, AMAZON, http://www.amazon.com/dp/B003FSUDM4 (last visited Dec. 22, 2012).

310. Matt Hamblen, *Why the Kindle Fire and Nook Tablet are Wi-Fi-Only*, COMPUTERWORLD (Nov. 9, 2011), http://www.computerworld.com/s/article/9221642/Why_the_Kindle_Fire_and_Nook_Tablet_are_Wi_Fi_only.

311. MAYO & WALLSTEN, SECONDARY SPECTRUM MARKETS, *supra* note 298, at 6.

312. *See* Alan Rappeport & Paul Taylor, *AT&T to Buy Qualcomm's Spectrum for $1.93bn*, FIN. TIMES (Dec. 20, 2010, 02:52 PM), http://www.ft.com/cms/s/0/0a76b47c-0c42-11e0-b1a3-00144feabdc0.html. The number is derived from reports in the article that AT&T's $1.93 billion bought spectrum at $0.86 per MHz-pop. *See id.*

313. *See supra* notes 148–53 and accompanying text.

count as a transfer of zero MHz-pop, because no license changed hands. But from the perspective that sees "spectrum" as a scarce resource that is "used" for communications, something clearly got reallocated. AT&T handsets were sending traffic over different frequencies that they did not use before. How much? If we take only the 2.4 GHz range (ignoring for a moment the Wi-Fi implementations that also use the 5 GHz range) and treat it as a nationwide license (because AT&T can in fact use these frequencies anywhere), the reallocation would equal about 30 billion MHz-pop.[314]

Moreover, when Verizon started to use Wi-Fi, 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 2.4 GHz range was redeployed to carry data generated by AT&T or Verizon customers using their smartphones. The point is not that this calculation gives us the correct measure of the value of Wi-Fi offloading 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 successfully complete a given number of communications in a stated time and place. For that, assessments of actual markets, like those surveyed above, and the relative role that secondary markets play in serving them, is a better measure.

C. Special-Purpose Open Wireless Models

The successes I describe earlier in this Part have used the ISM bands in 900 MHz and 2.4 GHz and the 5 GHz U-NII band. What typifies these general-purpose bands, by comparison to the special purpose bands I consider here, is that they are unprotected, provide a clear set of rules, and allow device manufacturers to capture economies of scale and scope to produce low-cost, high-quality devices for a wide range of applications. Several other open wireless designations have either failed in the market or have had more ambiguous success. In part, these sound a general cautionary note with regard to open wireless designation, but they also provide insight into how best to design open wireless allocations once one has decided that open wireless is the strategy for a given band.

The clearest failure of an open wireless allocation has been the U-PCS band; its design failures offer important lessons in what not to do. A second likely failure-to-thrive story is 3.65–3.7 GHz band for WISPs, where the effort to pursue a desirable social policy by designing a license-by-rule band to the specifications of rural WISPs may

314. The 30 billion derives from a population of approximately 300 million multiplied by a 100 MHz band.

have made the allocation too constrained to be useful. In particular, it may have prevented the development of a device market independent of a fixed service provider market. In other words, the 3.65 GHz band replicated the carrier model of innovation, not the open wireless model, but made it available only to relatively small and financially weak carriers: rural ISPs. The ITS band at 5.9 GHz provides a case that appears to be a failure to thrive, although there are enough indications that we ought to reserve judgment for another decade given the rate of developments in the past two years and anticipated uses over the next few years. The most successful story among these special-purpose open wireless designations is the medical telemetry band, WMTS. While it has its critics, WMTS has undoubtedly performed its intended task and its users have captured the lion's share of the market for patient monitoring; these, in turn, have now successfully sought designation of a second generation allocation for medical body area networks ("MBAN") just below the 2.4 GHz band.[315]

1. U-PCS

Three characteristics made the U-PCS allocation significantly different from the ISM and U-NII bands. First, while the overall allocation was for 30 MHz, it was balkanized. The allocation consisted of two non-contiguous bands, 1910–1930 MHz and 2390–2400 MHz.[316] The former was again subdivided: the FCC imposed various specific distinct constraints on specific subsets of this lower part of the band. The 1920–1930 MHz portion was to be used for isochronous voice applications, while the 1910–1920 portion (as well as 2390–2400 MHz) was to be used for asynchronous data communications.[317] As a result, the only segment of these that has developed a significant market presence is the cordless phone market, which now uses the 1920–1930 MHz allocation as the core for the now-dominant DECT standard.[318] In the lower band, 1915–1920 MHz was reallocated to Advanced Wireless Services in 2004[319] — not a surprising move given

315. *See* MBAN Report and Order, *supra* note 237.

316. *See* Amendment of Part 2 of the Commission's Rules to Allocate Spectrum Below 3 GHz for Mobile & Fixed Services, 16 FCC Rcd. 16,043, 16,047 (Aug. 9, 2001) [hereinafter Amendment of Part 2].

317. *See id.*; Amendment of the Commission's Rules to Establish New Personal Communications Services, 9 FCC Rcd. 4957, 5037 (June 9, 1994); Allocation of Spectrum Below 5 GHz Transferred from Federal Government Use, 10 FCC Rcd. 4769, 4779–80 (Feb. 7, 1995).

318. *See* Amendment of Part 15 of the Commission's Rules Regarding Unlicensed Personal Communications Service Devices in the 1920–1930 MHz Band, 27 FCC Rcd. 3645, 3645 (Mar. 22, 2012) [hereinafter Amendment of Part 15].

319. Amendment of Part 2 of the Commission's Rules to Allocate Spectrum Below 3 GHz for Mobile and Fixed Services to Support the Introduction of New Advanced Wireless Services, 19 FCC Rcd. 20,720, 20,740, 20745 (Sept. 9, 2004). On history, see Amendment of Part 15, *supra* note 318.

that the Commission had approved no devices for operation in that band throughout the period.[320]

The second distinguishing characteristic of the U-PCS band, and likely a critical component in stifling the development of U-PCS devices, was the requirement that device makers pay to clear incumbent microwave users. In order to do so, the FCC created UTAM, Inc., a collective agency that would act on behalf of device makers and collect device fees to cover the reallocation costs paid to incumbents.[321] Because nomadic devices need to be able to operate anywhere at any time, while incumbents had geographically specific licenses, it was impossible to deploy devices at scale before clearing the whole band.[322] In turn, it was difficult to get potential device makers into UTAM, Inc. when there was so much uncertainty as to when a sufficient number of incumbents would be cleared to allow manufacturers the economies of scale they needed to justify production of devices.[323] As a result, the clearing payment requirements effectively prohibited nomadic devices, with the FCC permitting only devices with known locations.[324] This arrangement permitted the cordless phone manufacturers to use the 1920–1930 MHz band, but made it impossible to use the 1910–1920 MHz and 2390–2400 MHz bands during the long clearance process.[325] In the interim, the demand for nomadic unlicensed wireless access was fulfilled in the ISM and U-NII bands, and the heart of the allocation was already handed over to AWS.[326]

This combination of very narrow and balkanized allocation, coupled with the need to raise funds for clearing devices to operate *on an unlicensed band* before any nomadic devices could be authorized and sold likely would have killed the utility of this band irrespective of the additional factors that were present, including a particular industry-negotiated sensing and interference-avoidance protocol. These factors alone are probably sufficient to explain the failure of U-PCS. It is difficult, therefore, to determine whether the addition of the third distinguishing feature — the requirement of a particular industry-agreed protocol — would have independently stymied the development and deployment of devices because it would limit the economies of scale of device chipsets to only the number of U-PCS devices sold.

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320. Kenneth Carter, *Policy Lessons from Personal Communications Services: Licensed vs. Unlicensed Spectrum Access*, 15 COMMLAW CONSPECTUS 93, 107 n.96 (2006).

321. *Id.* at 107.

322. *See* Henry Goldberg, Grazing on the Commons: The Emergence of Part 15, Address at Information Economy Project Conference: The Genesis of Unlicensed Wireless Policy 3–4 (Apr. 4, 2008), *available at* http://iep.gmu.edu/wp-content/uploads/2012/04/Grazing_on_the_Commons-HenryGoldberg.pdf (describing the process and failures of allocating U-PCS from the first-person account of an attorney who participated in the allocation).

323. *Id.*

324. *See* Carter, *supra* note 320, at 108.

325. *See* Amendment of Part 2, *supra* note 316, at 16,047.

326. *See* Carter, *supra* note 320, at 109–110, 114.

Two important lessons come out of the U-PCS band experiment. The first, similar to what we learned from looking at smart grids and the ISM bands in Europe,[327] is that an allocation that is too narrow, balkanized, and saddled with incumbent protection requirements will fail to thrive. The second lesson is that the collective action problems associated with getting device manufacturers to pay a fee before they can deploy a product are prohibitive. Even though the FCC created the relevant vehicle, UTAM, Inc., deploying only after funds were collected and paid proved too difficult. If a device fee is thought necessary for fiscal reasons, it needs to follow a command-and-control reallocation. In the first instance, the federal government should clear the spectrum for unlicensed use (or otherwise declares certain operating constraints that protect incumbents) and then add a standardized fee on a per-device basis from devices developed for a known allocation. UTAM, Inc. made clear that imposing the clearance costs, but not specifying if or when enough of the country will be cleared to permit nationwide deployment of devices, is almost sure to fail.

2. The Perils of Special-Purpose Sharing Allocations and License-by-Rule: 3.6–3.7 GHz

In 2007, the FCC concluded proceedings that made available a 50 MHz band from 3.65 GHz to 3.7 GHz for non-exclusive, licensed use.[328] Although originally the FCC had considered making the band unlicensed and permitting general nomadic devices on the model of ISM bands alongside higher-powered, fixed-location devices,[329] the FCC ultimately settled on a hybrid model optimized for rural wireless ISPs.[330] WISPs can obtain a site license through a simple, cheap application process, but that license provides them no protection from later applicants in the similar band and location and requires them to cooperate with all licensees in an area to minimize interference.[331]

There are two distinct ways in which this model significantly departs from the rationale for open wireless allocations. First, the argument for open wireless allocations has always depended on the innovation dynamics of device markets. And this dynamic was produced only when innovative and disruptive entrants could develop and deploy devices without need for permission.[332] By predicting and de-

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327. *See supra* Part IV.A.2.

328. Wireless Operations in the 3650–3700 MHz Band, 22 FCC Rcd. 10,421, 10,421 (May 22, 2007) [hereinafter Wireless Operations in the 3650–3700 MHz Band].

329. Unlicensed Operation in the Band of 3650–3700 MHz, 19 FCC Rcd. 7545, 7553 (Apr. 15, 2004).

330. Wireless Operations in the 3650–3700 MHz Band, *supra* note 328, at 10,422.

331. *Id.*

332. *See generally* Benkler, *Overcoming Agoraphobia*, *supra* note 10 (describing the history and growth of radio); Benkler, *Some Economics of Wireless*, *supra* note 76 (discussing how spectrum commons allow help foster innovation).

ciding to optimize the rule for a particular application — rural wireless broadband — and excluding general-purpose unlicensed operation from the bands, the FCC essentially gave up on a core dynamic of open wireless. Second, by designing the rules to cater to rural WISPs,[333] the FCC robbed the market of the economies of scale that urban deployments could have offered, severely limiting the investment potential in developing devices and chipsets for use in this allocation. In combination, the allocation seems to have been optimized as a kind of subsidy to wireless rural broadband rather than as an open wireless allocation. While rural broadband is an important goal, it is not self-evident that this particular form of subsidy was the most productive.

It is too soon to tell whether this allocation is a clear failure. However, the stories of two major players do give some indication that this band is not likely to thrive. First, in 2008 FairPoint Communications gave Nortel a contract for what was believed to be the largest-yet 3.65 GHz deployment.[334] However, following both the Nortel and Fairpoint bankruptcies in 2009,[335] it appears that FairPoint has shifted its focus to high-end copper, along with fiber deployment closer to the home and cell towers for wholesale service to cellular carriers.[336] More tellingly yet, as late as 2009, Towerstream was attempting a ten-market urban deployment of 3.65 GHz wireless ISP service in the 3.65 GHz band.[337] However, by its 2012 annual report, it was clear that the company's strategy had shifted fundamentally to serving Wi-Fi offloading and providing Wi-Fi node leasing to cellular

333. *See* Press Release, Tier One Networks, Nationwide FCC License Granted to TierOne Networks for 3.6 GHz Spectrum (Apr. 8, 2009), http://www.pr.com/press-release/144345 ("The FCC is explicitly opening the [3.6–3.7 GHz] band for WISPs, particularly to stimulate broadband access in rural areas.").

334. *FairPoint 3.65 GHz WiMAX Contract*, TELEGEOGRAPHY (Oct. 30, 2008), http://www.telegeography.com/products/commsupdate/articles/2008/10/30/fairpoint-3-65ghz-wimax-contract.

335. Ian Austen, *Nortel Seeks Bankruptcy Protection*, N.Y. TIMES, Jan. 15, 2009, at B2, *available at* http://www.nytimes.com/2009/01/15/technology/companies/15nortel.html; Clarke Canfield, *FairPoint Bankruptcy Plan Would Cut Debt Sharply*, USA TODAY (Feb. 8, 2010, 02:50 PM), http://usatoday30.usatoday.com/money/industries/telecom/2010-02-08-fairpoint-telecom_N.htm.

336. *See* Bernie Arnason, *FairPoint Cites Progress, 15 Mb/s in New England*, TELECOMPETITOR (June 27, 2011, 12:14 PM), http://www.telecompetitor.com/fairpoint-cites-progress-15-mbs-in-new-england; Joan Engebretson, *FairPoint Accepts Part of Connect America Fund Allotment*, TELECOMPETITOR (July 24, 2012, 11:22 AM), http://www.telecompetitor.com/fairpoint-accepts-part-of-connect-america-fund-allotment. Indeed, as of November 2012, a search for "wireless" on FairPoint's website yields references to the 2008 Nortel deal, references to the annual report that lumps fixed wireless with DSL and cable for home broadband revenues, and mostly reference to wholesale services for cellular carriers.

337. *Towerstream*, WIMAX, http://www.wimaxforum.org/sites/wimaxforum.org/files/document_library/Towerstream_Case_Study_FINAL.pdf (last visited Dec. 22, 2012).

carriers for offloading purposes.[338] In all, a more complete assessment of the success of this band must await an evaluation of the entire market of wireless ISPs and its performance relative to other rural broadband alternatives. But the anecdotal evidence suggests that 3.65 GHz has not given rise to the kind of innovation we have seen in the ISM bands. If this is the case, that would be a clear indication that general purpose unlicensed allocations are superior to the special-purpose-design, license-by-rule approach represented by 3.65 GHz. Certainly, in considering future allocations, the FCC should be extremely cautious about following the approach adopted for 3.65 GHz, rather than the more general purpose approach represented by the ISM bands and originally considered for 3.65 GHz as well.

3. Special-Purpose Dedicated Channels: Automotive ITS, Health WMTS, and MBAN

Another spectrum-sharing approach adopted by the FCC is the dedication of specific bands for specific desirable applications, requiring only standardized registration for nonexclusive use. The two most significant applications have been "intelligent transportation systems" ("ITS") in the 5.9 GHz range and medical telemetry in the WMTS bands and the freshly minted MBAN allocation. The former suggest caution regarding these allocations; the latter offer probably the clearest success story for the approach, although it too involves real tradeoffs by comparison to general purpose unlicensed models of open wireless.

A. Automotive Communications: ITS at 5.9 GHz; Radar at 77 GHz

In October of 1999,

> [T]he FCC decided to use the 5.850–5.925 GHz band for a variety of Dedicated Short Range Communications (DSRC) uses, such as traffic light control, traffic monitoring, travelers' alerts, automatic toll collection, traffic congestion detection, emergency vehicle signal preemption of traffic lights, and electronic inspection of moving trucks through data transmissions with roadside inspection facilities.[339]

338. *See* Towerstream Corp., Annual Report (Form 10-K), at 6 (Mar. 14, 2012), *available at* http://ir.towerstream.com/secfiling.cfm?filingID=1144204-12-14858&CIK=1349437.

339. Press Release, FCC, FCC Allocates Spectrum in 5.9 GHz Range for Intelligent Transportation Systems Uses (Oct. 21, 1999), http://transition.fcc.gov/Bureaus/Engineering_Technology/News_Releases/1999/nret9006.html.

As of 2012, these 5.9 GHz systems have not made major inroads. The most widespread use, toll collection, is largely provided over systems that use the 900 MHz ISM band, including the E-ZPass system, which serves about 60% of toll roads.[340] There continues to be activity in the field, and core standards were defined in 2010 and 2012.[341] Dedicated Short Range Communications ("DSRC") systems, as their name implies, rely on a dense infrastructure of roadside units to communicate to on-board units; the lack of infrastructure, which is largely a public function along roadsides, limits adoption of this model.[342] Public bodies faced with limited budgets will often prefer to invest in another lane or divider, compared to technological infrastructure usable only by not-yet-developed devices.[343] Hence the relative ease of toll collection systems, by comparison to collision avoidance or traffic updates that require roadside units to have coverage over most roads where the system must be used for these purposes. Nonetheless, the ubiquity of 900 MHz devices and the scope of products designed for that range made deployment of simpler, less expensive and versatile devices for toll collection follow a path that utilizes the ISM band rather than the more protected, but less versatile, 5.9 GHz dedicated band. Toyota, for example, has described its future connected vehicle as building on a DSRC system utilizing the ITS infrastructure, but does not anticipate deployment before 2016–2018.[344]

It is impossible to declare the ITS band a failure as of yet. If, as Toyota projects, deployment begins in 2016, there could be near-universal deployment by 2026 through the gradual inclusion of onboard units in all new cars.[345] Similarly, as a recent KPMG study suggested, the National Highway Traffic Safety Administration could issue a mandate for adoption of such systems (modeled on safety-belt

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340. *See* Peter Samuel, *Support for 5.9GHz as Next Electronic Toll Technology Growing, But It's a Way Off*, TOLLROADSNEWS (Oct. 15, 2009), http://www.tollroadsnews.com/node/4404. E-ZPass' RFID transponders are currently supplied by Kapsch TrafficCom, which acquired Mark IV Industries, the prior supplier referenced in the article, in 2010. Press Release, Kapsch Group, Kapsch TrafficCom Acquires MARK IV IVHS Creating Leadership in Intelligent Transportation Systems (ITS) (Dec. 1, 2010), http://www.kapsch.net/en/KapschGroup/press/articles/Pages/ktc_101201_pr.aspx.

341. *See* Kapsch TrafficCom, 5.9 GHz DSRC Overview, Presentation at CommNexus 5, 14 (Apr. 11, 2012), *available at* http://www.commnexus.org/assets/020/11895.pdf.

342. *See The Connected Car*, ECONOMIST, June 4, 2009, at S18, *available at* http://www.economist.com/node/13725743.

343. U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-12-308, INTELLIGENT TRANSPORTATION SYSTEMS: IMPROVED DOT COLLABORATION AND COMMUNICATION COULD ENHANCE THE USE OF TECHNOLOGY TO MANAGE CONGESTION 23 (2012) (stating that transportation officials often view other transportation investment options, such as adding a new lane to a highway, more favorably than ITS when deciding how to spend limited transportation funds).

344. *See* John B. Kenney, Vehicle-to-Vehicle Communications: A Focus on Collision Avoidance, Presentation at CommNexus Meeting 4, 6, 10 (Apr. 10, 2012), *available at* http://www.commnexus.org/assets/020/11894.pdf.

345. *See id.* at 16 (projecting ten years from initial deployment to full adoption).

regulations), which could bring about near-universal deployment by 2025.[346] Both suggest the possibility that ITS will become a ubiquitous infrastructure element with the ability to save hundreds of thousands of lives and be well worth the quarter century between the dedication of the band and its full utilization. But present applications use other, general-purpose unregulated light frequencies or cameras, as well as radar systems that use a different dedicated-to-automotive unlicensed band (the 77 GHz microwave band).[347] Using those bands allows these systems to be deployed by many different firms, developing different systems, without depending on a mandate for universal adoption or on major public infrastructure investments in roadside units. That means that ITS might have been a long-term waste. The KPMG study does suggest that there are advantages to a mixed model of ITS and autonomous systems.[348] In either case, intelligent transportation systems and autonomous vehicles will all build on open wireless, whether ITS or 77 GHz automotive radar (except for GPS, which is more of an old fashioned command-and-control system delivering a public good). How this market develops will provide important insight into future allocations, but we will likely not be able to draw a clear lesson for a decade (77 GHz is also, after all, an application-specific unlicensed allocation, albeit in a very non-scarce band).

B. Medical Applications: WMTS and MBAN

The Wireless Medical Telemetry Service[349] band is largely a success story, with some cause for caution regarding its performance relative to ISM-band devices. In one clear sense WMTS was a resounding success. The FCC first allocated WMTS bands in 2000.[350] The two leading firms in patient monitoring, Philips and GE Healthcare, began to develop devices using these frequencies almost immediately. In fact, Baylor Hospital, where interference with earlier wireless telemetry systems triggered the WMTS allocation, was able to install WMTS telemetry systems in its Cardiac Rehab center by

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346. *See* KPMG & CTR. FOR AUTO. RESEARCH, SELF-DRIVING CARS: THE NEXT REVOLUTION 21–22, 25 (2012), *available at* http://www.kpmg.com/US/en/IssuesAndInsights/ArticlesPublications/Documents/self-driving-cars-next-revolution.pdf.

347. The 76–77 GHz band was opened for unlicensed automotive radar in 1995. *See* Amendment of Sections 15.35 and 15.253 of the Commission's Rules Regarding Operation of Radar Systems in the 76–77 GHz Band, 27 FCC Rcd. 7880, 7881 (July 5, 2012). The Audi A8 is one example of a car that utilizes these bands. *See* Richard Stevenson, *Long-Distance Car Radar*, IEEE SPECTRUM (Oct. 2011), at 52–54, *available at* http://spectrum.ieee.org/green-tech/advanced-cars/longdistance-car-radar.

348. *See* KPMG & CTR. FOR AUTO. RESEARCH, *supra* note 346, at 14–15.

349. FCC Personal Radio Services, 47 C.F.R. § 95.1103(c) (2012) (defining WMTS as "[t]he measurement and recording of physiological parameters and other patient-related information via radiated bi-or unidirectional electromagnetic signals . . . .").

350. *About Wireless Medical Telemetry*, FCC, http://wireless.fcc.gov/services/index.htm?job=about&id=wireless_medical_telemetry (last updated Mar. 10, 2003).

2001.[351] By 2006, the two largest firms in the U.S. patient monitoring market had deployed extensively, but debates over the costs and benefits of WMTS relative to more general-purpose Wi-Fi systems had already begun.[352]

The basic tradeoff that commentators then saw was that WMTS allocations were relatively narrow-band and mostly reflected proprietary technology that imposed very high switching costs for hospitals, thereby locking them into their large and established vendors and requiring separate networks rather than allowing standards-based integrations with the wider range of Wi-Fi-compliant network nodes and devices.[353] Nonetheless, Philips and GE Healthcare increased their market share and by 2008 accounted for about two-thirds of the North American market in patient monitoring.[354] Philips, the market leader with close to 50% of the market, offers both WMTS and Wi-Fi-based systems, stating that "WMTS is reserved for transmission of life-critical data in healthcare facilities . . . . In contrast, the ISM band (in which 802.11 systems operate) is a large, unlicensed spectrum space for a growing variety of devices that can be used to transmit virtually any kind of data."[355] GE Healthcare is the second-largest provider in the market, also invested in WMTS devices.[356] Mindray, the third-largest provider with about 9% of the market, provides both WMTS and Wi-Fi systems.[357] The smaller competitors in the market, however, rely exclusively on Wi-Fi bands, both 2.4 GHz and 5.8 GHz.[358]

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351. *See* Eileen Putman, *Hospitals Face Higher Telemetry EMI Risks in 2006*, BIOMEDICAL INSTRUMENTATION & TECH., Jan./Feb. 2012, at 22, 25.

352. *See id.* at 26; *see also* Steven D. Baker and David H. Hoglund, *Medical-Grade, Mission-Critical Wireless Networks*, IEEE ENGINEERING IN MED. AND BIOLOGY MAG., Mar./Apr. 2008, at 86, 86 (noting that insufficient bandwidth forced many hospitals to add Wi-Fi).

353. *See* Baker & Hoglund, *supra* note 352, at 88.

354. *See* Deborah DiSanzo, Chief Exec. Officer of Healthcare Informatics, Philips Healthcare, Healthcare Informatics and Clinical Decision Support 4 (Apr. 6, 2009), *available at* http://www.philips.com/shared/assets/Downloadablefile/Investor/11_disanzo_070509.pdf (showing 65.1% market share as the sum of Philips' 42.3% and GE's 22.8% market share in 2008).

355. *See Instrument Telemetry: Bedside Monitoring on Phillips 1.4 GHz Common Wireless Infrastructure*, PHILIPS HEALTHCARE, http://www.healthcare.philips.com/us_en/products/patient_monitoring/products/instrument_telemetry (last visited Dec. 22, 2012).

356. *See* DiSanzo, *supra* note 354 (showing GE is second with 22.8% market share); *ApexPro CH Telemetry System*, GE HEALTHCARE, http://www3.gehealthcare.com/en/Products/Categories/Patient_Monitoring/Wireless_Networks/ApexPro_CH_Telemetry_System (last visited Dec. 22, 2012) (showing an example GE WMTS device).

357. *See* DiSanzo, *supra* note 354; *Interoperability*, MINDRAY, http://www.mindray.com/na/products/Interoperability.html (last visited Dec. 22, 2012).

358. *See* DiSanzo, *supra* note 354 (indicating that Dräger had a 7.4% market share in 2008); *Welch Allyn FlexNet™ Wireless Patient Monitoring*, WELCH ALLYN, http://www.welchallyn.com/pressroom/media/FlexNet/flexnet_newsroom.htm (last visited Dec. 22, 2012); *Introducing Welch Allyn FlexNet™ for 802.11a Life-Critical Wireless Networks*, WELCH ALLYN, http://www.welchallyn.com/pressroom/media/FlexNet/flexnet_brochure.pdf (last visited Dec. 22, 2012) (Welch Allyn's patient monitoring system based on Wi-Fi); *Welch Allyn FlexNet® for 802.11a Life-Critical Wireless Networks*,

Observing this success, and in response to a request by Philips and GE Healthcare, the FCC has extended this approach further. On May 24, 2012, the FCC allocated a further 40 MHz, just below the 2.4GHz ISM band, specifically for MBANs.[359] From one perspective, this is a well deserved extended allocation. Of all the unlicensed bands we have discussed, WMTS moved from approval to market most quickly, and its users are playing the leading role in a market of undoubted social value. Furthermore, as the FCC Order makes clear, there were precious few responses to the NPRM, only twenty-four comments and five replies.[360] It remains to be seen whether this new allocation will continue to be important to these firms, and the market generally, or whether this allocation will be looked back on as an instance of an agency handing over spectrum to the largest incumbents and ignoring the possibility of more open, general purpose allocation. Despite the concerns over proprietary standards and lock-in, it appears that the WMTS experience is the strongest piece of evidence in favor of special-purpose allocation of license-by-rule.

D. Observations on Markets, Architecture, and Policy

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.

Because of regulations intended to protect licensed services, open wireless strategies 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 denser infrastructure, open wireless networks often reuse existing infrastructures or construct infrastructures ad hoc from the open wireless devices themselves. Wi-Fi offloading in part reuses physical broadband connections to homes,

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WELCH ALLYN, http://www.welchallyn.com/apps/products/product.jsp?id=16-vo-96-1234190869014 (last visited Dec. 22, 2012); *Dräger Patient Monitoring Deployment in the Cisco Unified Wireless Network Infrastructure*, CISCO, http://www.cisco.com/web/strategy/docs/healthcare/Draeger_dg.pdf (last visited Dec. 22, 2012) (noting that Dräger Infinity patient monitoring systems operate on Wi-Fi); *Our Whole Portfolio at Your Fingertips!*, DRÄGER, http://www.draeger.us/sites/enus_us/Pages/Hospital/ProductSelector.aspx?navID=221 (last visited Dec. 22, 2012); *Move Life-Critical Patient Data on Your Existing Network*, DRÄGER, http://www.gtri.com/assets/files/Healthcare/9066144_OneNet_EN_FIN.PDF (last visited Dec. 22, 2012) (describing the Dräger Infinity Wi-Fi device); *Dräger Infinity M300 Monitor Wi-Fi Certified*, HOSPITALPRODUCTS.COM, http://hospital-products.com/page/4432/ (last visited Dec. 22, 2012) (giving another example of a Dräger Infinity Wi-Fi device).

359. *See* MBAN Report and Order, *supra* note 237, at 6423.

360. *Id.* at 6425.

offices, and hotspot locations to provide nomadic broadband access. Mobile payments reuse connections to vendor points of sale. RF mesh architectures build their infrastructure by making electricity meters dual use. Every electricity meter becomes not only a "user" of the infrastructure by sending 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 cell towers, by providing for the acquisition of more spectrum licenses.

V. IMPLICATIONS FOR POLICY

A. Proposals for Exhaustive Auctioning Should Be Rejected Outright

The period between July of 2011 and July of 2012 saw diametrically opposed views of the future of wireless regulation expressed in two published government documents. The first, distributed on July 13, 2011, was the House Republican staff discussion draft of the Spectrum Innovation Act of 2011.[361] By requiring that any new allocations of bands to open wireless devices be permitted only if these bands had been purchased at auction by potential open wireless equipment and services developers, the draft legislation would have effectively eliminated any future open wireless allocations.[362] The idea is not new,[363] but the obvious counterarguments have never been adequately addressed. Namely, provisioning a band in which anyone is permitted to operate presents a collective action problem: the firms that would contribute would either limit access to their devices, thereby controlling competition and innovation in the market for devices, or would face significant free rider problems.[364]

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361. Spectrum Innovation Act of 2011, H.R. __, 112th Cong. (Discussion Draft 2011), *available at* http://www.publicknowledge.org/files/docs/DraftHouseRepublicanSpectrumBill.pdf.

362. *See infra* Part V.D.

363. An early, less objectionable version included a publicly purchased commons — the possibility of which is limited only by politics, not theory — as well as a privately funded commons. FAULHABER & FARBER, *supra* note 77, at 17–18 (proposing that any of the national government, state or local authorities, foundations, or market actors who build commons-based equipment could buy bands and deploy commons). Another rendition was the FCC's idea of a "private commons" introduced as part of the 2004 Secondary Markets proceeding. Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets, 69 Fed. Reg. 77,522, 77,531–32 (Dec. 27, 2004).

364. Benkler, *Overcoming Agoraphobia*, *supra* note 10, at 362–65.

The argument in favor of this proposition is hard to pin down, but likely reflects a basic ideological commitment to private property and a failure to appreciate that "spectrum property" is more akin to a tradable permit than to a fee simple, while a "spectrum commons" is akin to speed limits and traffic signals.[365] At a minimum, those who claim to support spectrum property in the defense of private enterprise and free markets should look at actual markets and actual companies adopting open wireless strategies. If they did, they would recognize that the system to which they object is neither based on Soviet-style planning[366] nor old-school progressive agency control.[367] Rather, this system provides a technique for dramatically decreasing the role of government in deciding who gets to develop, sell, and deploy services and equipment. But unlike a property-style approach to decentralization, it emphasizes freedom of action rather than power to control, a technique that has had enormous success across practically all market segments that require wireless communications capacity.

The second document, which offered the most extensive embrace in a government publication of spectrum sharing and open wireless techniques, was the PCAST Report of July 2012. That report stated unequivocally:

> PCAST finds that clearing and reallocation of Federal spectrum is not a sustainable basis for spectrum policy due to the high cost, lengthy time to implement, and disruption to the Federal mission. Further, although some have proclaimed that clearing and reallocation will result in significant net revenue to the government, we do not anticipate that will be the case for Federal spectrum . . . . The essential element of this new Federal spectrum architecture is that the norm for spectrum use should be sharing, not exclusivity.[368]

While "sharing" here includes short term leases as well as unlicensed, open wireless use, this is nonetheless the most expansive statement yet of the broad change in policy — from exclusive use and auctions first, complemented by some open wireless, to dense-

365. A recent document with a "tell" of the ideological origins of the "spectrum property" idea, authored by Senators Ron and Rand Paul, marks as one of the terrible liberty-defeating ideas it abhors: "Wireless, the lifeblood of the mobile Internet revolution, must be micromanaged as a government-controlled commons, with limited exclusive property rights." *See* Rand Paul & Ron Paul, *C4L Introduces "The Technology Revolution,"* CAMPAIGN FOR LIBERTY, http://www.campaignforliberty.org/national-blog/c4l-introduces-the-technology-revolution (last visited Dec. 22, 2012).

366. *See* FAULHABER & FARBER, *supra* note 77, at 5.

367. *See* Brito, *supra* note 78, ¶¶ 33–38; Paul & Paul, *supra* note 365.

368. PCAST REPORT, *supra* note 1, at vi.

infrastructure, open wireless as a foundational strategy, complemented by mechanisms to allow purchase of exclusive use where necessary.[369]

Although the PCAST Report has its own limitations, the basic insight is that proposals that would effectively prevent future open wireless allocations should be off the table. That proposition is supported by persistent evidence across diverse, cutting-edge, and broad markets. Considering the value only of remote payment systems — even looking solely at toll collection systems that have saved untold hours and gallons of gas waiting in tollbooths, multiplied by the number of years since toll road operators were able to deploy E-ZPass and similar systems throughout the United States — the value of open wireless becomes clear. The cellular providers have still not standardized a cellular M2M payment system.

The value American consumers and businesses gain from Wi-Fi data carriage is enormous. At least a portion of the savings from smart grid deployments is attributable to communications, and these in North America are dominated by open wireless. Combined, these experiences suggest that the lost revenues from auctions pale in comparison to the business opportunities gained in other contexts. Any argument based on a belief that all this innovative flourishing is somehow struggling under the yoke of Soviet-style economic planning is simply laughable. At a certain point ideology, unless it is to become religion, must give way to facts. And it is difficult to see how spectrum policy is a proper target for religious disputation.

Until the most recent set of legislative clashes, the question of open wireless versus flexible exclusive licenses was not a partisan one. The 900 MHz and 2.4 GHz bands were opened under Presidents Ronald Reagan and George H.W. Bush for the kinds of roles they play today.[370] The U-NII band in 5 GHz and U-PCS bands were opened under President Clinton's FCC Chairman Reed Hundt.[371] The Spectrum Policy Task Force Report was initiated by President George W. Bush's Chairman Michael Powell.[372] The Ultrawideband, 3.65–3.7, and most importantly the initial TV White Spaces Order were initiated and passed under Chairmen Powell and Kevin Martin.[373] The TV Bands Order was pushed and implemented by President Obama's

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369. *See id.* at 18–19, 22–27.

370. *See supra* notes 49–52 and accompanying text.

371. *See* Amendment of the Commission's Rules to Provide for Operation of Unlicensed NII Devices in the 5 GHz Frequency Range, 12 FCC Rcd. 1576, 1577 (Jan. 9, 1997); *supra* notes 316–20 and accompanying text.

372. Michael K. Powell, Chairman, FCC, Broadband Migration III: New Directions in Wireless Policy, Address at the Silicon Flatirons Telecommunications Program, University of Colorado at Boulder (Oct. 30, 2002), *available at* http://transition.fcc.gov/Speeches/Powell/2002/spmkp212.html.

373. *See supra* notes 58–60 and accompanying text.

appointed Chairman, Julius Genachowski.[374] Throughout this period there were some who argued the question in left-right terms, but it was not politically aligned in the way it became in the 2011–2012 legislative battle. Given that open wireless and exclusive flexible licenses are both mechanisms of providing market actors freedom to operate, it is odd that open wireless would draw the ire of Republicans. It is unclear what has marked open wireless policy as a left-right issue: whether it had to do with interest in open wireless from Google, a company which, after the net neutrality debates, was associated with the Democrats' agenda; whether it was related to cellular carriers' lobbying; or whether it was the simple fact that a range of organizations that are, broadly speaking, "left of center" have made open wireless part of their agenda. Whatever the reason, partisanship will likely cloud the facts and undermine reasoned policy.

B. The Basic Architecture and Market Switches Should Be Reflected in a Policy Switch

A clear pattern that emerges from the market studies in Part IV is the inversion of the relationship between open wireless and exclusively-licensed services. Ten years ago the FCC's Spectrum Policy Task Force Report saw licensed, carrier-owned spectrum and the services built upon it as primary, and unlicensed as a valuable complement. The market developments of the past few years, however, indicate that today's reality is the inverse. In some areas, like healthcare and smart grids, the inversion is almost complete, with open wireless strategies thriving and filling every niche, and cellular M2M limited to a narrow range of services (albeit services critical to those who need them). Part IV's market surveys suggest the necessity of more open wireless freedom to operate and interventions aimed at permitting easier flow across and between densely packed gateways. The document that came closest to making this policy recommendation is the PCAST Report. As a broad principle, the policy switch means that relevant federal agencies should assure that new dedications include sufficient open wireless expansion. Mark Cooper recently proposed a fifty-fifty ratio as an easy benchmark.[375] Rather than attempting such a general statement, I will point to certain ongoing proceedings.

1. TV Bands and White Spaces

Legislative activity on wireless policy in 2011–2012 centered on providing the FCC with the authority to use incentives auctions to

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374. *See* Innovation in the Broadcast Television Bands: Allocations, Channel Sharing and Improvements to VHF, 25 FCC Rcd. 16,498, 16,535–36 (Nov. 30, 2010).

375. COOPER, *supra* note 139, at 47.

move some of the bands dedicated to TV signals to mobile broadband.[376] The core innovation was to permit the FCC to share some of its auction proceeds with incumbent TV station license owners, so as to induce these owners to place their licenses in the auction. This new authority has implications for the choice between exclusive licensing and open wireless in two ways. First is the effect on existing white spaces, already allocated under the FCC's orders approving deployment of white spaces devices in TV bands.[377] These devices are permitted to exploit the fact that in any given town or county, bands nominally allocated to TV signals are not in fact assigned to any licensee, so as to make sure that there is no interference among TV stations in adjacent markets. So, for example, in market A TV stations 2, 3, 5, and 7 will be assigned, and in the geographically proximate market B stations 4, 6, 8, and 9 will be assigned. This means that in market A, these latter channels are unused, as are the former channels in market B. TV white space devices can exploit this fact to use the vacant channels without displacing any signals because they are limited to lower power levels than the potential spillovers that nearby TV stations would have generated. Repacking the same number of TV stations into a smaller number of channels following the auctioning of TV bands would potentially crowd out TV white spaces devices.

The second potential implication for open wireless systems is the effect of the proposed "guard bands."[378] The background to these guard bands is that mobile carriers tend to prefer their systems to use paired allocations with some separation between them. Most auctions aimed at mobile cellular carriers therefore offer paired channels, rather than single continuous channels. As a practical matter, that means that — in order to maximize the revenue from the auctions and their utility to mobile broadband — the FCC is likely to package the auctioned bands in two separate bundles, one for upstream and the other for downstream data service. Furthermore, the mobile services need to be separated from the remaining TV services. The bands separating the uplink and downlink bands from the adjacent TV channels could be opened to open wireless. Indeed, Congress explicitly empowered the FCC to permit operation of unlicensed devices in this "guard band," but also decreed that "[s]uch guard bands shall be no larger

376. *See supra* notes 5–7 and accompanying text.

377. *See, e.g.*, Unlicensed Operation in the TV Broadcast Bands, 23 FCC Rcd. 16,807 (Nov. 4, 2008); Unlicensed Operation in the TV Broadcast Bands, 25 FCC Rcd. 18,661 (Sept. 23, 2010); Argos Net, Inc., 27 FCC Rcd. 2786 (Mar. 23, 2012).

378. Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, 2012 WL 4712202 at *4, *35–36 (F.C.C., Oct. 2, 2012) [hereinafter Incentive Auctions Order].

than is technically reasonable to prevent harmful interference between licensed services outside the guard bands."[379]

TV white space devices are in their infancy. The FCC approved the first device in December of 2011, and the first commercial deployment occurred in Wilmington, North Carolina, in January of 2012.[380] The IEEE adopted the first regional wireless area networks standard, 802.22, in July of 2011.[381] The earliest implementations of TV white space devices suggest that these devices can now carry data at 16 Mbps at peak, and at a distance of ten kilometers (though likely at lower-than-peak speeds).[382] Whether this capacity is in fact already available is less important than recognizing that TV band devices could, given proper regulatory freedom, target the exact spot where prior unlicensed allocations were lacking: continuous coverage.

As in all its decisions, the FCC is bound to serve the public interest. Were open wireless not part of the equation, the FCC's decision could reasonably simply seek to maximize the number of bands available for auction consistent with Congress's explicit requirement that the FCC make "all reasonable efforts" to preserve existing TV service.[383] However, open wireless is part of the equation, and Congress expressly preserved the FCC's White Spaces Order.[384] The FCC must therefore seek to optimize on three, not two dimensions. When it clears, repacks (moves station assignments around so that even those retained licenses allow for the new broadband spectrum to be contiguous), and reallocates the spectrum, the FCC must seek to clear as many bands as feasible, subject not only to continued television coverage but also subject to preserving as much space for open wireless operation as possible. This could be done by (1) making the guard bands as large as possible and (2) avoiding TV band clearance or repackaging where the clearance would result in a substantial loss of white spaces availability.

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379. Middle Class Tax Relief and Job Creation Act of 2012, Pub. L. 112-96, § 6407, 126 Stat. 156, 231 (codified in scattered sections of 47 U.S.C.), *available at* http://www.gpo.gov/fdsys/pkg/PLAW-112publ96/pdf/PLAW-112publ96.pdf.

380. *See* Julius Knapp, Chief, Office of Engineering & Tech., Spectrum Management Activities at the FCC's Office of Engineering and Technology, Presentation at the National Spectrum Management Association 3 (May 16, 2012), *available at* http://www.nsma.org/conf2012/Knapp%20NSMA%202012.pdf.

381. Press Release, IEEE, IEEE 802.22™-2011 Standard for Wireless Regional Area Networks in TV Whitespaces Completed (July 27, 2011), http://standards.ieee.org/news/2011/802.22.html.

382. *Product Brief: A Wireless System Designed to Exploit the Full Potential of the TV White Space Spectrum*, NEUL, http://www.neul.com/downloads/NeulNET_Data_Sheet_130611.pdf (last visited Dec. 22, 2012).

383. Middle Class Tax Relief and Job Creation Act § 6403(b)(2) ("In making any reassignments or reallocations . . . the Commission shall make all reasonable efforts to preserve . . . the coverage area and population served of each broadcast television licensee . . . .").

384. *Id.* § 6403(i).

Under the FCC's proposed plan, there would be two guard bands of 6 MHz each, one separating the lower end of the downlink band from the TV bands, and the other separating the lower end of the uplink band from TVs.[385] To this, the FCC has raised the possibility of opening to white space operation channel 37, which is currently used for radio astronomy and WMTS,[386] and the microphone white space channels, the two 6 MHz channels most closely adjacent to channel 37 and not otherwise allocated.[387] These five 6 MHz channels — the two guard bands, channel 37, and the two microphone channels — might be thought of as providing a new baseline freedom to operate set for unlicensed devices in the TV bands. I will refer to them here as the "baseline channels" approach.

As a practical matter, the baseline channels approach has certain advantages, while white spaces have others. The baseline channels approach provides device developers and manufacturers a predictable set of frequencies that offer almost nationwide coverage (except the small number of exclusion zones around radio astronomy sites). National predictable coverage would help services that would build on this equipment, knowing that there will be *some* service everywhere, although the allocations are mostly fragmented. White spaces, on the other hand, are largely unavailable in various major markets like New York and San Francisco, at least under current rules.[388]

In favor of white spaces relative to the baseline bands is the possibility of having many more channels and contiguity, bonded together to create much larger bandwidth for higher speed transmissions.[389] In rural areas in particular, where few TV channels are actually assigned and used, these channels could be bonded to provide very high-speed wireless capabilities, at least for backhaul and middle-mile functions. The greatest limitation on applications such as these is that the number of devices that can be used only in rural applications may be too small to create the economies of scale necessary to develop cheap equipment. These devices will therefore largely remain a carrier

385. Incentive Auctions Order, *supra* note 378, at *36.

386. *Id.* at *56–59.

387. *Id.* at *61–63.

388. *See generally* Kate Harrison, Shridhar Mubaraq Mishra & Anant Sahai, *How Much White-Space Capacity Is There?*, 2011 IEEE SYMPOSIUM ON NEW FRONTIERS IN DYNAMIC SPECTRUM ACCESS NETWORKS (DYSPAN) (describing the geographic distribution of white spaces allocations), *available at* http://www.eecs.berkeley.edu/~sahai/Papers/DySpAN10MeasuringWhitespaceCapacity.pdf.

389. One does not have to accept the clearly exaggerated claims of the WhiteSpace Alliance's launch press release to accept that bonding several channels can produce higher speeds than a single contiguous 12, 24, or even 30 MHz channel. *See* Press Release, WhiteSpace Alliance, WhiteSpace Alliance Formed to Deliver Affordable, High-Speed Broadband Internet Access to 3.5 Billion Households (Dec. 15, 2011), http://www.businesswire.com/news/home/20111215005492/en/WhiteSpace-Alliance-Formed-Deliver-Affordable-High-Speed-Broadband (claiming the ability to bond forty channels sending 29 MHz each to reach gigabit speeds).

solution for rural broadband providers, unless repacking can create significant allocations available in several large urban areas covering a significant portion of U.S. households and small and medium enterprises. The number of channels available to the major urban center with the smallest number of available white spaces channels — likely the New York metropolitan area — will likely limit the bandwidth of devices that developers want to deploy nationwide. Given the proven track record of open wireless strategies, the FCC should assure as much white space capacity as feasible in its repacking process, particularly in urban areas. For example, the FCC might offer television stations added compensation from the relocation fund to double up and share spectrum in markets where doing so would preserve a white space channel that would not otherwise be available. The critical insight here is that the public interest standard and the preservations of white spaces by Congress require the FCC to optimize all three goals — preserving TV audience coverage, optimizing licensed auctions, and optimizing white space availability — not merely the former two.

Furthermore, the FCC should seek to create a coherent approach for near-national access to the baseline bands by combining the guard bands, channel 37, and the wireless microphone bands. To optimize the use of these bands, the FCC should combine three elements. First, the devices permitted to operate should be "white space" devices, capable of the same agility and context awareness, database or otherwise, used by white space devices. This will make sure that the baseline channels are integrated with the white space channels and can expand and contract as local conditions permit and demand.

Second, these devices (and all white space devices) should be permitted to operate at variable power, based on context. It makes no sense to require devices that know whether they are in Montana or Manhattan to operate at the same power in both locations.

Third, the FCC should adopt a general permission to operate in channel 37, subject to the radio astronomy services exclusion zones, and in the wireless microphone channels, perhaps with hyper-local, very brief local exclusion zones.[390] The baseline principle should be that the FCC seeks to permit operation of any device, without picking particularly valuable applications. Three significant incumbent applications in these channels are radio astronomy, WMTS, and wireless microphones. The major radio astronomy services in channel 37 should continue to be protected; these reflect extremely expensive, stable, public investments in very discrete locations that have little impact on the overall market for devices and create little constraint on

390. This idea was suggested to me by Anant Sihai and Kate Harrison in a phone conversation on November 30, 2012.

use of the channel. But white space devices should be permitted to operate in channel 37, subject to exclusion zones around the twelve radio astronomy centers currently using channel 37.[391] As the study of WMTS devices here indicates, WMTS has been a successful allocation,[392] but channel 37 is only one component of that allocation, utilized effectively by two companies: GE Healthcare and Phillips. The same service and companies have just received a major new allocation, in the form of the MBAN allocation.[393] In the future, WMTS devices should be permitted to operate in channel 37, but should receive no special protection in that channel from white space devices. The widespread use of Wi-Fi for similar applications by providers other than GE Healthcare and Philips, as well as the availability of several distinct WMTS channels[394] and the new MBAN allocation suggest that the burden on the two companies that use WMTS is manageable. It would be inadvisable to exclude an entire industry of devices from this desirable allocation in an effort to preserve incumbent systems.

Finally, the FCC should utilize microphone bands. As part of the deal that led to approval of the initial White Space Order, live-entertainment events received a protected white space allocation for wireless microphones on the two channels nearest channel 37 that are not actually occupied by television.[395] For all the political power of Broadway and other live-event producers, it seems unwise to continue to subsidize this one industry at the expense of a full 12 MHz of channels that could be deployed for a wide range of new industries or uses. The benefit of the exclusivity is simply that wireless microphones can be made cheaper than they otherwise would be if they were required to operate in the presence of high overall background radiation from other white space devices. Given the likely minuscule portion of the costs that microphones impose on the broad industries that use microphones in live events, even a doubling of the cost of microphones is unlikely to impose significant constraints. Avoiding that speculative cost by excluding an entire range of industries from a band that would add 12 MHz of white space availability, nationwide — open to any industry to develop — seems unjustified, possibly failing even the most basic standards of administrative discretion given our background experience with the enormous innovative capacity of open wireless allocations. At most, one might imagine these two bands as offering the opportunity to test the new PCAST three-tier approach. On this model, live-performance venue operators could

391. Incentive Auctions Order, *supra* note 378, at *57.
392. *See supra* Part IV.A.3.
393. *See* MBAN Report and Order, *supra* note 237.
394. *See supra* Part IV.A.3.
395. *See* Incentive Auctions Order, *supra* note 378, at *61–63; Richtel, *supra* note 112.

register their location, using a GPS-enabled smartphone app, and for a small per-hour fee could reserve two clear channels in the wireless microphone channels within a radius of two or three city blocks around the venue during the performance. Such an application would require no change in the microphones themselves. It would require merely that the white space devices utilizing those channels be able to query the database periodically and that live venue operators have access to a smartphone app that can update the database.[396]

To conclude, TV bands, and the opportunities created by the repacking process and the new guard bands, offer a unique, and likely last chance to create an open wireless allocation that could fill the coverage gap that present open wireless systems experience. As the evidence collected in this Article suggests, open wireless strategies are thriving in most of the core markets that require wireless capacity. The pattern of deployment, however, suggests that the greatest weakness of open wireless architectures is coverage, and the major constraint is the extent to which those architectures can offer near-mobile-nomadic connectivity, as opposed to more sporadic nomadicity. Certainly, organizational and protocol approaches to sharing existing infrastructure across organizations, such as Devicescape, or even simply extensive deployment of shared infrastructure, like BT FON, SFR, or the new approaches announced by Google Fiber and the cable Wi-Fi initiative can go a substantial way toward resolving this problem.[397] But serious attention to preserving permission to operate in the TV bands is another critical avenue to furthering that goal.

2. NTIA Fast Track and the PCAST Report

In a series of reports, the NTIA has studied the possibility of moving federal spectrum to use by non-federal users.[398] Of particular interest at present is the NTIA's study of the 1755–1850 and 3500–3650 bands. The bottom 25 MHz of the former bands are attractive to cellular carriers because they can be paired with other, existing Advanced Wireless Services spectrum.[399] The NTIA's study concluded, though, that it could not reasonably clear only the bottom 25 MHz without substantially impairing some of the current systems using the

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396. This idea was proposed to me by Anant Sihai and his students in a conversation on November 30, 2012.

397. *See supra* notes 166–69; Marcus Wohlsen, *Google Attacks Cable and Telcos with New TV Service*, WIRED (July 26, 2012, 02:36 PM), http://www.wired.com/business/2012/07/cable-companies-shouldnt-fear-googles-networkyet.

398. NAT'L TELECOMMS. & INFO. ADMIN., AN ASSESSMENT OF THE NEAR-TERM VIABILITY OF ACCOMMODATING WIRELESS BROADBAND SYSTEMS IN THE 1675–1710 MHZ, 1755–1780 MHZ, 3500–3650 MHZ, AND 4200–4220 MHZ, 4380–4400 MHZ BANDS, at iv (2010), *available at* http://www.ntia.doc.gov/reports/2010/FastTrackEvaluation_11152010.pdf.

399. NATIONAL BROADBAND PLAN, *supra* note 1, at 86–87.

spectrum, particularly air combat training systems.[400] In all, the NTIA found that it would take ten years and cost $18 billion to clear existing federal users to accommodate exclusively licensed non-federal users for broadband.[401] The NTIA assessed that it would be easier to permit operation of licensed WiMax-style broadband in the 3550–3650 band, but only with substantial exclusion zones from the coasts, where ship-to-shore radar systems often cause broadband applications to fail.[402]

In both cases, however, the NTIA had assessed the feasibility of accommodating exclusive use models of broadband. The PCAST Report from July 2012 took these conclusions and proposed a radically different model. Noting that "if this band were auctioned for high-power, wide-area use consistent with current commercial wireless business models, non-Federal use of frequencies from 3550 to 3650 MHz would be excluded in an area roughly 200 miles inland around the entire coastline of the United States," the Report instead proposed that "[d]edicating the 3550–3650 MHz band to small cell, low power use could allow for significant reduction or even elimination of the exclusion zones."[403] Indeed, the PCAST Report saw this approach as part of a broader, ambitious effort to identify 950 MHz of contiguous bands between 2700–3650 MHz that could be made available for shared access.[404]

As a practical matter, the most immediate implication is that the NTIA should update its study of the 1755–1850 and the 3500–3650 bands to consider specifically what kinds of open wireless devices it could accommodate in these bands without relocating any of the existing services. Rather than assessing the possibility of clearing or accommodating high-power, sparse infrastructure licenses, the NTIA should conduct a separate analysis of the feasibility of accommodating a lower-power or otherwise more dynamic model. For example, the 3550–3650 band could lend itself to a simplified white space model, where any device that has a GPS device and can find itself outside of the exclusion zone can use high power, and devices that are on the shores can use lower power. Similarly, the database model developed for white spaces could be used for making the exclusion zone more dynamic, based on actual use by naval vessels, rather than static exclusion. If devices are sufficiently agile and aware of changing uses by the federal incumbents, there is no reason why they cannot share the band more generally. Such a band would have propagation charac-

400. NAT'L TELECOMMS & INFO. ADMIN., AN ASSESSMENT OF THE VIABILITY OF ACCOMMODATING WIRELESS BROADBAND IN THE 1755–1850 MHZ BAND 28 (2012), *available at* http://www.ntia.doc.gov/files/ntia/publications/ntia_1755_1850_mhz_report_march2012.pdf.

401. *Id.* at iii.

402. NAT'L TELECOMMS. & INFO. ADMIN., *supra* note 398, at 1–6.

403. PCAST REPORT, *supra* note 1, at 51.

404. *Id.*

teristics already known to work for WiMax service, providing some penetration advantages over the 5 GHz range and some speed advantages over 2.4 GHz.[405] The questions of whether the same is feasible in the 1755–1850 range, and if so, under what constraints, should be the subject of a new, dedicated study.

The evidence collected in this Article does not bear directly on the disposition of any particular band of frequencies. What it does is provide a greater degree of confidence that an allocation to open wireless devices would not be wasted in pursuit of a theoretical dream. It would take federal bands that currently prohibit use by any civilian uses, and make them available to equipment developers serving the markets for non-federal users. The findings in this Article provide some confidence that such a model would provide an open and valuable innovation platform for a diverse range of products and services without displacing existing federal users.

3. Shared Access Gateways

Perhaps the clearest insight from the diverse market studies explored here is that the "spectrum crunch" is not a spectrum crunch, but a network access and architecture crunch. As the FCC's National Broadband Plan explained, "[i]n the absence of sufficient spectrum, network providers must turn to costly alternatives, such as cell splitting, often with diminishing returns."[406] Almost all means of wireless data communications (except for point-to-point walkie-talkie and autonomous mesh networks) involve a combination of wires, gateways, and wireless bridges. Macro-cells such as the ones mobile carriers use include fiber or other specialized line to the tower, and then a long, high-powered wireless hop. The same data, from the same device, using what we have come to call "Wi-Fi offloading" uses more fiber, coaxial cable, or copper, reaching all the way out to the coffee shop, workplace, or home, and then uses a shorter, lower-power wireless hop to the device. Thus, the differences between cellular macro-cells and Wi-Fi offloading are the amount of fiber, the density of gateways, and the length of the wireless hop (and therefore the power of the transceivers). 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 and connecting them with fiber. These spectrum auctions allow cellular carriers to postpone capital expenditures on the fiber and towers necessary to split their cells and increase network capacity without adding a single megahertz to their spectrum holdings.

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405. *Id.* at 52.
406. NATIONAL BROADBAND PLAN, *supra* note 1, at 77.

Understanding this dynamic allows us to understand that there is vast wireless carriage capacity already deployed throughout the United States that is dramatically underutilized under present organizational and technical practices. As I have mentioned in the earlier mar-market analyses, one of the core features of open wireless strategies is that they utilize diverse infrastructures owned by diverse entities and individuals. A mobile video stream can be carried over a fiber, tower, and band owned by a mobile carrier; however, it is more often carried over fiber, copper, or coaxial cable owned by workplaces, cafés and other businesses, and homes. A mobile payment will have a very short wireless hop, and will then travel over wired infrastructure of various merchants. Toll collection systems will similarly use short wireless hops and wired (or possibly point-to-point wireless) infrastructure owned by the various turnpike authorities who accept a given payment system, such as E-ZPass. With all these strategies, widespread nomadic gateways rely on standards-based approaches that allow devices to hop on and off diversely wired networks through gateways owned by many different actors, rather than require that all wireless communications go over infrastructures owned by a single service provider.

Wireless capacity, then, as opposed to "spectrum," is a function not of spectrum bandwidth alone, but of bandwidth plus availability of access to a wired gateway. The more gateways that are available for wireless devices to use, the more capacity the network made of those devices and gateways will have. The United States has millions of households and businesses with wired Internet connections. Each of these households and businesses has, or has the capacity to install, a Wi-Fi gateway connecting to its wired Internet connection. If each such gateway had two distinct wireless ports, one private and one public, the amount of wireless communications capacity that would become available throughout the United States without allocating a single additional megahertz to any new use would be staggering. This model is not science fiction. In France, Free and SFR, two major players in the broadband market, have been using this model for several years.[407] In the United Kingdom, BT has adopted the same approach by implementing a model called FON.[408] The basic idea in all these models is that when customers install a gateway in their home, they make it available to other subscribers of the same service. In exchange, they are permitted to use the gateways of every other subscriber who has joined this network. As a result, each of the subscribers is now able to access wireless Internet at Wi-Fi speeds over a much larger area. In the case of Free, at least, the gateways manage the capacity such that it gives the private network users pri-

407. *See* BENKLER ET AL., NEXT GENERATION CONNECTIVITY, *supra* note 1, at 160.
408. *See supra* note 168 and accompanying text.

ority if demand for the public side of the network conflicts with supplying the needs of the private side.[409] In the United States, it seems likely that Google will adopt a similar approach for its Kansas City fiber-to-the-home experiment.[410]

Given that (1) consumer use of wireless capacity, particularly for video and web access, is responsible for the overwhelming majority of demand for wireless connectivity,[411] and (2) both activities (but particularly video) are mostly nomadic, opening more Wi-Fi networks for use by all consumers is by far the shortest route to meeting the increase in demand. In its pursuit of the national policy of making wireless broadband capacity ubiquitous and plentiful, the FCC should strive to make all existing and newly deployed Wi-Fi gateways into open Wi-Fi networks available to fulfill the wireless carriage needs of any device within their reach whose use does not detract from use by the gateway's owner. As a national strategy, the need for pursuing a path to such a dramatic increase in wireless connectivity capacity throughout the country, without any new spectrum allocations, is particularly critical at a time when the model of clearing large swaths of spectrum for exclusive licensing, central to the National Broadband Plan only two years ago, has come to be seen as clearly unattainable in the near term and unsustainable in the intermediate to long term, when increase in demand will always outpace the clearance for exclusive licensing.[412]

The dramatic capacity increase I have described has strong public goods characteristics, and consequently there is significant risk that it will not be realized by market actors alone. First, home broadband providers can gain some benefits from permitting more Wi-Fi access to their networks, but only for their own subscribers as a competitive advantage. At a minimum, even if competition in home broadband drove carriers to support open wireless architectures such as the one proposed here, we would have a network with two walled gardens for each market segment: cable subscribers over cable and DSL subscribers over telco infrastructure. The total value of wireless connectivity

409. BENKLER ET AL., NEXT GENERATION CONNECTIVITY, *supra* note 1, at 160.

410. John Callaham, *Google Fiber to Offer WiFi Hotspots in Kansas City*, NEOWIN.NET (Aug. 14, 2012, 02:24 PM), http://www.neowin.net/news/google-fiber-to-offer-wifi-hotspots-in-kansas-city.

411. *See* CISCO, *supra* note 163.

412. *See* PCAST REPORT, *supra* note 1, at vi ("PCAST finds that clearing and reallocation of Federal spectrum is not a sustainable basis for spectrum policy due to the high cost, lengthy time to implement, and disruption to the Federal mission."); *see also* Blair Levin, *When an ROI 500 Times Better than Goldman Isn't Enough: Reallocating Our Focus on Reallocating Spectrum*, BROADBAND AND SOCIAL JUSTICE BLOG (Mar. 14, 2012), http://broadbandandsocialjustice.org/2012/03/when-an-roi-500-times-better-than-goldman-isn%E2%80%99t-enough-reallocating-our-focus-on-reallocating-spectrum (lead author of the National Broadband Plan describing the political barriers to successful, sustainable reallocation of spectrum to new exclusive license arrangements, as well as the systematic shortfalls associated with that solution pathway).

would thus be lower than that of a unified network. Second, incentives for the mobile carriers cut both ways. On one hand, they will benefit from the increased offloading capacity; on the other, the more ubiquitous Wi-Fi nodes become, the less secure the carriers' hold on the spectrum-license-limited market for mobile services. Third, even if mobile providers or DSL incumbents would negotiate with cable providers, the two groups are in a bilateral monopoly situation, which could lead to the failure of negotiations.

To capture the opportunity of a dramatic increase in available wireless capacity and avoid the losses due to likely negotiation failures or foregone positive externalities, it is appropriate for the FCC to foster the development of shared access gateway architecture. As an initial matter, the FCC should convene service providers and device manufacturers to consider how to construct gateways and network access such that future Wi-Fi routers have public and private ports, with the public ports available to any device. To the extent that sign-on procedures and standards are lacking, the FCC could facilitate voluntary standard setting for these procedures. In preparation, the FCC should study the state of dual-use Wi-Fi gateways, identify barriers to their deployment, if any (such as lack of interoperability or security), and identify plausible target roll-out dates. The FCC should consider whether to include as part of its device certification procedure the presence of dual-use open networks that are interoperable with other devices and available for mutual carriage. For example, the FCC could declare that by a date certain, a device that is a home or office wireless router must have dual-use networks deployed as a precondition to certification for Part 15 operation as a gateway router. Then, through the normal process of obsolescence and attrition, a nationally available open network architecture would emerge, built entirely of interoperable, open devices capable of serving wireless connectivity to any device in their vicinity. The immediate gains in wireless data carriage capacity from such a policy are likely to exceed those of any other presently considered policy intervention.

C. The Attraction of Auction Revenue Distorts Wireless Policy

One persistent argument against open wireless allocations in general, and in the congressional debates over incentive auctions specifically, stems from the attractiveness of auction revenues. This argument has two distinct arms. The first is that auctions improve efficiency. The second is that they are a source of revenue that is not a tax, but rather sensible husbandry of a national asset. Both claims have elements of truth, but also important limitations.

Most of the efficiency gains from spectrum markets come from secondary markets. The best a well-designed auction can do for efficiency is to provide a snapshot of current competing valuations and deliver the initial allocation to the entity most willing and able to pay for it. Subject to several constraints, a clean auction can deliver exclusive licenses efficiently in the first instance.[413] But thereafter — if that party fails to deliver, or its prediction about what would be a useful future application was wrong, or technology changes — the long-term efficiency of an auction-based system depends on low transaction costs and fluid secondary markets in licenses. In a well-functioning secondary market with an initial allocation by lottery on Day 1, on Day 2 the licenses would be in the hands of the highest bidder, with the seller holding the windfall instead of the government. The marginal contribution of the auction to efficiency would depend on the extent to which the auction itself is a more efficient market than the secondary market, factoring in the transaction costs associated with the secondary license minus the administrative costs of running the auction itself. That after-market flexibility and secondary markets are the more important contributors to efficiency is not a controversial claim; it is accepted by exclusive-allocation property rights advocates as well.[414]

Auctions could certainly improve welfare if the market structure post-auction is more competitive than the market structure pre-auction, but can only do so at the expense of reduced auction revenue. Imagine that pre-auction there is a wireless market with only two providers, who are able to exercise pricing power to keep prices relatively high, with the usual deadweight losses associated with a highly concentrated market. If an auction is structured to exclude the incumbents — so that at its end three or four competitors emerge in the market — then the welfare improvements associated with the more competitive market can be assigned to the auction only if they are coupled with constraints on mergers and takeovers post-auction, to avoid the kinds of losses that led the Department of Justice to oppose the AT&T merger with T-Mobile.[415] Spectrum is more valuable to the incumbent than to the entrant precisely to the extent that a more concentrated market allows an incumbent to extract rents.

The debate over the TV incentive auctions and whether to exclude Verizon and AT&T from them presents the problem cleanly. Verizon and AT&T currently own 78% of the frequencies in the cellu-

413. *See* Peter Cramton, *Spectrum Auctions*, *in* 1 HANDBOOK OF TELECOMMUNICATIONS ECONOMICS 605, 607 (Sumit Majumdar et al. eds., 2002).

414. *See* Thomas W. Hazlett & Roberto E. Muñoz, *A Welfare Analysis of Spectrum Allocation Policies*, 40 RAND J. ECON. 424, 437–38 (2009).

415. *See* Complaint at 3, United States v. AT&T, No. 1:11-cv-01560 (D.D.C. Aug. 31, 2011).

lar and 700 MHz bands.[416] Because of their propagation characteristics, these lower frequency bands allow those companies to use larger cells. To achieve the same coverage, competitors who do not hold these frequencies would need to build or lease space on more cell towers. 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."[417] The question in setting spectrum caps in the TV bands auction was precisely how many national competitors would 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 is considered highly concentrated by the standard antitrust measure[418]) can expect a market foreclosure effect if they acquire enough of the newly available spectrum. Just as AT&T argued in the T-Mobile merger review, 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 700 MHz 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 are necessarily a component of their willingness to pay more in auction. As a result, an auction that is unconstrained in terms of participation and aggregation will systematically yield higher short-term returns in revenue, while at the same time assuring that fewer competitors can enter the mobile broadband market.

The lost efficiencies from the market imperfection in the post-auction market are a policy distortion caused by the political convenience of auctions, whose revenues are not perceived as a "tax." Furthermore, the search for auction revenue systematically biases allocation in favor of licensed relative to unlicensed, because the former will result in certain revenue while the latter spurs innovation but does not produce immediately measurable revenue. Its benefits only become revenue over time as devices and service using the open allocation are sold and taxed. These may or may not be greater than the

416. *See* Annual Report and Analysis of Competitive Market Conditions With Respect to Mobile Wireless, Including Commercial Mobile Services, 26 FCC Rcd. 9664, 9838 (June 24, 2011) [hereinafter Annual Report of Competitive Market Conditions].

417. Answer at 3, United States v. AT&T, No. 1:11-cv-01560 (D.D.C. Sept. 9, 2011).

418. Annual Report of Competitive Market Conditions, *supra* note 416.

auction revenues in a ten-year period. Regardless, they are not scored as revenue by the CBO. The CBO scoring process systematically biases congressional policy toward licensed exclusive wherever incumbent, exclusive-license based businesses are likely to bid at auction, whether or not that allocation is indeed the most conducive to innovation, growth, or welfare over time.

The political dynamic behind the emphasis on auction revenues has particular salience at a period when the Republican Party is committed to levying no new taxes.[419] The desire of House and Senate Republicans to raise money through incentives auctions dominated the provisions of both bills introduced — and the statute as passed — to create the FCC's incentive auctions authority in the TV Bands.[420] Raising revenue was a priority of both the normal congressional committees as well as the Super Committee, which also negotiated a version of the incentive auctions bill.[421] In this context it is important to understand that auctions, in fact, *do* function as a tax. In the best-case scenario, if the market post-auction were perfectly efficient, the cost of the auction would be passed on to consumers in their service bills. Auctions are not capped at the cost of running the auction plus the cost of the FCC enforcement apparatus designed to help prevent interference, nor is the revenue earmarked to serve wireless communications. Instead, auctions are politically attractive precisely because they are available for use in the general treasury. Unlike general income tax, they are levied only on those who buy a given service — in this case, wireless mobile broadband. In this sense, they operate as an excise tax.[422]

Given that the auctions are run not in an ideal market, but in the market we actually have — with its incumbents, their market share and existing spectrum allocations[423] — maximizing auction revenue in effect operates as tax-farming on the model used in Rome, Medie-

419. Following a two-decade campaign centered around the Grover Norquist pledge, it has become all but impossible for Republicans to support the levying of new taxes. *See 60 Minutes: The Pledge: Grover Norquist's Hold on the GOP* (CBS television broadcast Nov. 20, 2011), *available at* http://www.cbsnews.com/8301-18560_162-57327816/the-pledge-grover-norquists-hold-on-the-gop. Lately, though, some Republicans have reneged on the pledge, but it is too soon to tell if the movement will be mainstream enough to affect the party's policies on spectrum auctions or anything else. *See* Tom Cohen, *GOP Resistance to Anti-Tax Pledge Grows*, CNN (Nov. 27, 2012, 09:03 AM), http://www.cnn.com/2012/11/26/politics/fiscal-cliff/index.html.

420. See *supra* Part V.B.1.

421. This observation reflects interviews conducted by the author with congressional staff and individuals from both civil society groups and industry, who lobbied and participated in the process.

422. *See Excise Tax*, IRS, http://www.irs.gov/businesses/small/article/0,,id=99517,00.html (last updated Dec. 7, 2012).

423. See *supra* notes 416–18 and accompanying text (discussing the foreclosure effect of the given market structure).

val England, or the French *ancien regime*.[424] There, a private enterprise bought the right to collect taxes by promising the Crown a certain known return; it was then up to the tax collector to collect at least that amount, along with whatever else the tax collector could get away with. In the act as finally passed, Congress sought to increase the CBO score (the expected revenue) by explicitly prohibiting the FCC from excluding the largest incumbents from bidding.[425] Prohibiting exclusion maximizes revenues because, as explained above, the dominant carriers value the spectrum in part for the capacity to serve their customers at higher speeds and lower cost, just as their competitors do, and in part for the foreclosure effect that owning bands provides by denying the same cost- and performance-enhancement characteristics to their competitors.[426] Given the overwhelming dominance in spectrum holdings by the two largest firms, these firms can internalize the value of the market foreclosure. Their smaller competitors, whose holdings are mostly in higher frequencies, cannot. The incumbents, therefore, can outbid would-be competitors by spending down some of the rents they anticipate charging consumers in a less competitive market. What is auctioned, then, is in part a license to prevent competitors from using particularly cost-attractive frequencies. American consumers, in turn, will pay more for service because the incumbent carriers pass these auction costs on to customers. But, unlike an excise tax that sets precise levy rates, the size of the tax is a function of the pricing power over consumers that the auctions will give the dominant carriers. The carriers will capture that entire gain, transferring to the government only what they contracted to pay at auction.

As a practical matter, then, auctions function as a tax but are not politically perceived as such. This makes the revenue from auctions a siren song that legislators cannot resist, and drives wireless communications policy to benefit a more concentrated, cellular-carrier model. Welfare gains from a more competitive market — or most pertinently to this Article, welfare gains from innovation and growth in open wireless technologies of the type we saw in smart grids, telemedicine, mobile payments and security systems, and, indeed, Wi-Fi offloading — are simply invisible to this revenue-centric approach. Making foundational market-structure policy choices about the core infrastructures of the twenty-first century based on whether the approach will

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424. *See, e.g.*, Eugene N. White, *France's Slow Transition from Privatized to Government-Administered Tax Collection: Tax Farming in the Eighteenth Century* (Rutgers Univ. Dept. of Econ., Working Paper No. 2001-16, 2001), *available at* ftp://snde.rutgers.edu/Rutgers/wp/2001-16.pdf.

425. Middle Class Tax Relief and Job Creation Act of 2012, Pub. L. No. 112-96, § 6404, 126 Stat. 156, 230 (amending 47 U.S.C. § 309(j) (explicitly prohibiting the FCC from excluding any company that meets the technical eligibility criteria from bidding).

426. *See supra* notes 416–18 and accompanying text.

raise $20 billion dollars over ten years, or $15 billion, or nothing, is a profound distortion of public policymaking.

D. The Political Economy Overvalues Licensed Approaches vis-à-vis Open Wireless

Complementing the bias against open wireless auctions, investment in lobbying is generally skewed against open wireless. Because the benefits of open wireless strategies are widely distributed and the "allocation" gives no set of well-defined companies exclusivity they can leverage, the political economy of these debates is lopsided. Companies that expect to bid on and buy spectrum can internalize all the benefits of winning the policy debate and then the auctions. Most companies that would benefit from open wireless networks do not even know that they are affected by spectrum policy. Even if they were aware, such concerns would likely be trumped by other political needs. Better next-generation open wireless communications will likely provide benefits to Wal-Mart in inventory management, to UPS in fleet management, and to major hospitals using wireless healthcare systems. But spectrum policy is not an interest of sufficient weight for any of these organizations such that they would be willing to trade political favors for it — much less actually bid on keeping spectrum free for any company to come up with the next Wi-Fi or ZigBee.

No single firm or group of firms can internalize the positive externalities from open wireless. Even though 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 incentives of companies like Verizon and AT&T to lobby for exclusive control. It will be very difficult to overcome this basic imbalance, which impacts both the political economy of lobbying and the willingness to pay at auction.

E. Design Considerations for Open Wireless Allocations: General-Purpose, Minimal-Rules Open Allocations Versus Special-Purpose Open Allocations

Study of prior open wireless allocations suggests that the greatest degree of creativity has come in bands that have allowed the greatest degree of freedom in design: the ISM bands. What typifies these bands is a relatively broad contiguous band that has both maximum power requirements and general equipment certification procedures. The only clearly successful model that deviates from this approach is the WMTS band, where the major incumbent firms utilize license-by-rule, special-purpose designations to deliver wireless health services. Nonetheless, even in wireless healthcare, most applications rely on

Wi-Fi or other open standards over ISM bands. Wi-Fi has made significant inroads even in remote monitoring. And it is very likely that, had there been no special designation, firms would have developed Wi-Fi-or Zigbee-based solutions where they now use specialized, proprietary standards-based equipment over WMTS.

As the FCC and the NTIA move forward with allocating the TV bands and implementing the mandate to make more federal spectrum available for non-federal use, this lesson is critical. Efforts to provide more fine-grained allocations that are specially tailored to a preconceived purpose or following a preset clearance-and-collision-avoidance model — like the U-PCS band, the 3.65Ghz band, or the European approach to sub-1GHz bands — have been largely unsuccessful. Efforts to assure that devices "pay" for access to the band, as with U-PCS, have led to significant delay and failure because they create a chicken-and-egg problem: Clearance is necessary before any device can be deployed, but devices need to be deployed before there is enough money to clear. The default model, therefore, absent very well-developed arguments and evidence to the contrary, should be a model of wide contiguous bands, access to which is application agnostic, with minimal, clear, globally-available power limits. If there is need for geographic differentiation because of sharing with incumbent uses, the sharing regime should be open to any one of a range of alternative approaches rather than simply picking a winner. As in the case of the IEEE standards for Wi-Fi and other open wireless approaches, equipment certification should be easy and uniform for equipment that meets standards set in an open, public forum. The process should still, of course, provide a backup facility for testing and approval for devices that utilize proprietary approaches.

VI. 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 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 evidence supports the broad approach outlined in the PCAST Report for federal sharing of bands, but the study of the various hybrid models in Part IV.C suggests some caution about the Report's proposals that privilege short-and medium-term leasing approaches to sharing over pure open wireless approaches. There is strong evidence of the success of the latter approaches in many diverse markets; the former are untried approaches that may or may not have any real purchase. The risk, of course, is that in the search for revenues associated with leasing, the complexity of the design will result in the kind of balkanization and suppressed performance seen with the U-PCS devices. The social welfare costs of delaying wireless capacity deployment are likely to outweigh any fiscal gains from licensing revenues down the line.

The primary way in which open wireless policy contributes to the development of wireless infrastructure is to harness an Internet model of innovation in the wireless space, instead of depending exclusively on the 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, they quickly catch up to 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.

Fundamentally, market evidence shows that we are in the midst of an inversion of wireless utilization. If until the past few years it was possible to persist in the belief that exclusive-licensed spectrum was the core approach to provisioning ubiquitous connectivity, while unlicensed was a useful sideshow, it is now increasingly clear that dense infrastructures with unlicensed wireless devices at their ends are the core carriage medium for ubiquitous connectivity. Sparse infrastructure, or macro-cell models that depend on exclusive-licensed allocations, can still provide a highly valuable backup function for high velocity mobile applications that can tolerate little latency. Our policies, however, should adapt to reality and pay increasing attention to supporting these dense-infrastructure, open wireless approaches.