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CASTLE IN THE AIR: A DOMAIN NAME SYSTEM FOR SPECTRUM

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INTRODUCTION

In the early 1980s, the Internet faced a problem. The network of networks was growing rapidly . . . too rapidly. The increasing number of connected systems was overwhelming the simple system that tracked Internet host addresses. A single, static list couldn't keep up with the growing complexity and fluidity of the Internet. The solution, defined in 1983, was an elegant mechanism called the domain name system (DNS).[1] The DNS established a separate, distributed system for dynamic management of Internet addresses. Every time you type the uniform resource locator (URL) of a website or send an email message, you invoke the DNS. More than twenty-

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[1] *See generally* P. Mockapetris, *Domain Names—Concepts and Facilities* (Network Working Group, RFC 882, Nov. 1983), *available at* http://tools.ietf.org/html/rfc882 (describing the conceptual framework of the domain system and some of its uses); P. Mockapetris, *Domain Names—Implementation and Specification* (Network Working Group, RFC 883, Nov. 1983), *available at* http://tools.ietf.org/html/rfc883 (discussing the specifics of domain name systems and resolvers).

five years later, through massive growth and development of the Internet, the DNS continues to function effectively.

Today, wireless communication faces a similar problem. The rapidly increasing volume of traffic, as well as the growing number and sophistication of devices, threatens to overwhelm the simple, static spectrum allocation system managed by the Federal Communications Commission (FCC) and other government agencies.[2] The current system of command-and-control allocation of frequencies is wildly inefficient. As wireless data connections become increasingly common, the absence of a dynamic spectrum allocation mechanism becomes an increasingly severe restraint on the evolution of the Internet into a ubiquitous mobile platform.

The answer is a solution similar to the DNS: a hierarchical distributed database that brokers among those seeking and providing access to spectrum. The foundations for such a system are being laid today, without policymakers realizing it. The FCC voted in late 2008 to authorize unlicensed wireless "white space devices," (WSD) subject to the creation of a database of available transmission slots throughout the country. The white space database was added as a technical fix for interference concerns, but its potential is more significant than the FCC realized. This database could be the foundation for a spectrum networking database (SND) that plays a DNS-like role in wireless communication. To achieve its potential, however, such a system would need to address both technical and policy requirements. Successful deployment of an SND would facilitate the continued development of a ubiquitous wireless Internet.

I. SCALING: WIRELESS AND THE INTERNET

A. The Spectrum Challenge

As billions of mobile phones gain increasingly sophisticated data capabilities, and trillions of wireless sensors are integrated with physical spaces and objects, conventional approaches to spectrum management will crumble. Current spectrum policy debates focus on initial allocations, such as the rules and auction in 2008 for licenses in the 700 MHz band reclaimed from UHF television stations.[3] The real challenge, however, comes with implementation. The only way to meet growing wireless capacity demands will be to view the spectrum as an ocean of potential capacity, theoretically

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[2] The FCC traditionally allocates specific frequencies to specific companies for specific services. Thus, television broadcasters have licenses to operate TV transmitters in designated frequencies. Devices are tied to services, which are tied to frequencies. The FCC, not private actors or devices themselves, decides who can transmit where. *See* KEVIN WERBACH, NEW AM. FOUND., RADIO REVOLUTION: THE COMING AGE OF UNLICENSED WIRELESS, 11–12 (2003), *available at* http://www.newamerica.net/files/archive/Pub_File_1427_1.pdf.

[3] *See, e.g.*, *In re* Serv. Rules for the 698–746, 747–762 & 777–792 MHz Bands, Second Report and Order, 22 F.C.C.R. 15,289 (Aug. 10, 2007).

available to any local device at any time. No centralized mechanisms, whether publicly or privately determined, can be sufficiently dynamic and localized for such a roiling sea of wireless communication.

The future of the Internet is wireless. There are already more than twice as many users of mobile phones as landline telephones worldwide.[4] Mobile broadband Internet subscriptions now exceed 225 million worldwide,[5] a number that nearly doubled from 2008 to 2009.[6] In fact, more than two billion people who own a mobile phone today may never have owned a personal computer—and may never do so.[7]

For most of its history, the Internet was primarily delivered to end users through wired network connections. Wireless systems simply did not offer the capacity and stability of their wired cousins, such as the landline telephone network and coaxial cable television connections. Until the past decade, high-speed wireless data systems, and the mobile devices to make use of them, simply were not available.[8]

In recent years, there has been an explosion of growth in wireless data. Unlicensed wireless hotspots using the wireless fidelity (WiFi) and related protocols for short-range connection have rapidly proliferated, as have laptops and other devices with the capability to make use of these networks.[9] Wide-area wireless data services for the commercial market became feasible with a later version of digital mobile phone technology (so-called 2.5G systems), and have taken off with the growth of third generation 3G mobile wireless technologies. In the United States, all the major wireless carriers now offer nationwide wireless data coverage, with downstream speeds of over one megabit per second.[10] New entrants such as Clearwire promise even faster data speeds.[11]

This mobile data growth is causing huge increases in demand for wireless capacity. The change is not merely in the absolute numbers, but also in

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[4] Jose Fermoso, *U.N. World Report Picks Up Massive Growth in Mobile Phone Ownership*, WIRED, Mar. 4, 2009, http://www.wired.com/gadgetlab/2009/03/report-60-of-wo/.

[5] *See* Nick Wood, *Global Mobile Broadband Subscriptions Near Quarter of a Billion*, TOTAL TELECOM, July 22, 2009, http://www.totaltele.com/view.aspx?ID=447509.

[6] *See id.*

[7] *Compare id.* (showing more than four billion mobile phone users at the end of 2008), *with* Press Release, Forrester Research, One Billion PCs In Use by the End of 2008 (June 11, 2007) (projecting only a quarter that number of personal computers in use at the same time), *available at* http://www.forrester.com/ER/Press/Release/0,1769,1151,00.html.

[8] Wireless data networks began to be deployed in the 1980s for special-purpose applications, such as paging and fleet dispatch services. Metricom's Ricochet system provided end user wireless data service beginning in 1994, but it was a proprietary offering with limited speed and coverage area, and it never gained significant traction. WERBACH, *supra* note 2, at 22.

[9] *See* Amey Stone, *Wi-Fi: It's Fast, It's Here—and It Works*, BUS. WK. ONLINE, Apr. 1, 2002, http://www.businessweek.com/technology/content/apr2002/tc2002041_1823.htm.

[10] *See* David Pogue, *Wi-Fi to Go, No Cafe Needed*, N.Y. TIMES, May 7, 2009, at B1.

[11] Cecilia Kang & Kim Hart, *Clearwire, Sprint Nextel Set Course for WiMax*, WASH. POST, May 8, 2008, at D1.

the quality of usage. Apple's phenomenally successful iPhone is the best example.[12] The iPhone connects to the same networks as other mobile phones, but it encourages much more active usage because it provides a "real" Internet experience. Google found that the average iPhone user searched the Web fifty times more frequently than users of less-capable phones.[13] In the first few weeks after Apple introduced the iPhone 3GS, featuring enhanced video recording capabilities, YouTube saw mobile video uploads increase 400%.[14]

The iPhone is not an outlier; it is a harbinger. AT&T Wireless predicts that broadband wireless data capacity demands will increase by a factor of 250 to 600 between 2008 and 2018.[15] More efficient technologies will provide some increase in capacity. For example, fourth generation wireless systems such as Long Term Evolution (LTE) and WiMax promise to deliver greater capacity in the same spectrum as current 3G systems.[16]

These upgrades alone, however, will never match the scope of increased demand that is forecasted.

Adding new capacity by allocating licenses to new spectrum bands is also not a viable long-term solution. There have been no significant usable "empty" frequency bands for some time. The "low-hanging fruit" of incumbent uses that can easily be cleared out to reallocate frequencies for broadband data has already been tapped.[17]

The terrible irony is that spectrum utilization today is wildly inefficient.[18] Spectrum is not actually scarce, at least not to anywhere near the extent it seems.[19] The frequency allocation table shows a dense checker-

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[12] Leslie Cauley, *iPhone Gulps AT&T Network Capacity*, USA TODAY, June 17, 2009, at B1, *available at* http://www.usatoday.com/printedition/money/20090617/iphone17_st.art.htm.

[13] Maija Palmer & Paul Taylor, *Google Homes in on Revenues from Phones*, FT.COM, Feb. 13, 2008, http://www.ft.com/cms/s/0/667f13de-da60-11dc-9bb9-0000779fd2ac.html.

[14] Dwipal Desai & Mia Quagliarello, *Mobile Uploads to YouTube Increase Exponentially*, BROADCASTING OURSELVES;) THE OFFICIAL YOUTUBE BLOG, http://www.youtube.com/blog?entry=kbaLH7fmm-g (June 25, 2009).

[15] RYSAVY RESEARCH, MOBILE BROADBAND SPECTRUM DEMAND 12 (Dec. 2008), *available at* http://www.rysavy.com/Articles/2008_12_Rysavy_Spectrum_Demand_.pdf.

[16] *See* Peter Rysavy, *Spectrum Crisis?*, INFO. WK., Oct. 26, 2009, at 23, *available at* http://www.rysavy.com/Articles/2009_10_Spectrum_Crisis.pdf.

[17] *See* Susan P. Crawford, *The Radio and the Internet*, 23 BERKELEY TECH. L.J. 933, 934 (2008) (describing the January 2008 auction of 700 MHz frequencies as "probably the last competitive auction for a substantial amount of spectrum for the next few decades").

[18] *See* Kevin Werbach, *Supercommons: Toward a Unified Theory of Wireless Communication*, 82 TEX. L. REV. 863, 863 (2004); Victor W. Pickard & Sascha D. Meinrath, *Revitalizing the Public Airwaves: Opportunistic Reuse of Government Spectrum* 7 (New Am. Found., Working Paper No. 24, 2009), *available at* http://www.newamerica.net/files/Pickard_Meinrath_WorkingPaper24_RevitalizingPublicAirwaves.pdf; PHILIP J. WEISER, THE HAMILTON PROJECT, THE UNTAPPED PROMISE OF WIRELESS SPECTRUM 6–7 (2008), *available at* http://www.brookings.edu/~/media/Files/rc/papers/2008/07_wireless_weiser/07_wireless_weiser.pdf.

[19] *See* Werbach, *supra* note 18, at 909, 913.

board. However, measurements of actual wireless activity show a radically different picture: most frequency bands are not actually used for transmission most of the time, in most places. In fact, a study of wireless utilization in the frequencies below 3 GHz showed that on average only about five percent of bands were in use.[20] Even in New York City, the most densely populated metropolitan area in the United States, the number was only thirteen percent.[21]

The reality is that most spectrum licensees do not, or cannot, use their frequencies in anywhere near the most efficient manner possible.[22] In some cases this is due to the inflexibility of FCC licenses and the legacy characteristics of old systems. For example, broadcast television allocations, which were made in the 1940s, required "guard bands" of dark (unused) frequencies to enable the less sophisticated receivers of that era to distinguish signals.[23] As a result, huge swaths of spectrum were designated as buffer space between allocated frequencies.

Both the demand and the supply of spectrum are inherently local, short-term phenomena.[24] Whether one system can transmit without inhibiting the ability of other systems to do so depends on a multitude of factors, including the technical characteristics of the transmitters and receivers, the nature of the services involved, and the physical geography of the area.[25] And the situation will change over time. The wireless capacity that is "wasted" is bounded by time, geography, and technical characteristics. It cannot be specified globally for all time. Only a system with up-to-date local information can identify the full opportunity space for wireless communication.

The existing spectrum allocation structure is inefficient because it is inherently static and centralized. The FCC makes decisions regarding frequency usage by issuing licenses that authorize certain transmitters and for-

[20] *See* Spectrum Occupancy Measurements, http://www.sharedspectrum.com/measurements (last visited Feb. 20, 2010) (summarizing research and data by Mark McHenry); *see also* MAX VILIMPOC & MARK MCHENRY, NEW AM. FOUND., DUPONT CIRCLE SPECTRUM UTILIZATION DURING PEAK HOURS (June 20, 2003), *available at* http://www.newamerica.net/files/archive/Doc_File_183_1.pdf ("[O]ur tally of spectrum utilization [from one experiment] indicated that *roughly two-thirds of the spectrum is immediately available for shared, license-exempt use*.").

[21] *See* Spectrum Occupancy Measurements, *supra* note 20. This measurement was taken during the Republican National Convention in New York City, a time of extremely high wireless use. *Id.*

[22] The FCC itself acknowledges that we face not a spectrum capacity problem, but a spectrum access problem. *See* FCC, SPECTRUM POLICY TASK FORCE REPORT, ET Docket No. 02-135, at 3 (Nov. 2002), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-228542A1.pdf.

[23] Sascha D. Meinrath & Michael Calabrese, "*White Space Devices" & the Myths of Harmful Interference*, 11 N.Y.U. J. LEGIS. & PUB. POL'Y 495, 497 (2008); *see also* Randy Hoffner, *White Space Devices: Threat to Broadcast TV?*, TV TECH., Dec. 5, 2007, http://www.tvtechnology.com/article/18850 (explaining that the reason for unoccupied television channels in one city is to avoid interference with channels in another city where viewers can receive both signals).

[24] *See* Werbach, *supra* note 18, at 903–04.

[25] *See id.* at 947 (noting factors affecting wireless transmissions).

bid all others.[26] Whether a device in Omaha, Nebraska, can transmit 10 watts of power at 488 MHz (UHF television channel 17) at 2:00 p.m. this Thursday is determined by a decades-old table of frequency allocations issued by the FCC.[27] The frequency table answers the question of who is legally permitted to transmit in a designated frequency band across a large geographic area. It does not address two more important questions—who is actually transmitting in those frequencies, and who else could transmit without disturbing the licensee.

This "command and control" spectrum allocation process was workable when wireless communications systems were limited, but it breaks down in today's environment. When wireless networks were predominantly one-way, large-area, fixed radio and television systems or point-to-point relays, and overall wireless demand was low compared to the present, the inefficiencies were relatively inconsequential. However, increases in demand and more dynamic systems reduce the efficiency of the command-and-control approach. In a world of ubiquitous wireless broadband, the viability of the existing spectrum allocation process is increasingly called into question.[28]

Reforms that leave static allocation in place will not solve the problem. Clearing currently-used frequency bands for auction involves significant time, expense, and conflict among competing groups. Even if more bands can be made available, this does nothing to improve the utilization of existing bands. Another issue is that the FCC's ability to forecast wireless demand patterns into the future is inherently limited. Any decisions it makes to optimize bands for certain uses could prove inefficient as usage changes. Ultimately, the supply and demand for spectrum are local, temporally-bound quantities. Each individual device knows what it needs at that moment, and what is available is a function of local conditions and other users.

The only solution for the wireless capacity crunch is therefore a distributed one, through which spectrum allocation decisions are made locally and for limited durations. Cellular phone systems already do something

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[26] The FCC enforces this regime in several ways. It reviews applications by licensees to construct or modify transmission towers. FCC, CONNECTING THE GLOBE § 3 (June 16, 1999), *available at* http://www.fcc.gov/connectglobe (explaining components of the regulatory process). It oversees an approval process for all wireless equipment that goes on the market. *Id.* And it can issue penalties for "harmful interference" if licensees or others exceed the boundaries of the license. *See* 47 C.F.R. § 15.5(c) (2009); FCC, *supra*, § 7 (noting the FCC's various remedies in cases of repeated harmful interference).

[27] 47 C.F.R. § 2.106 (2009). Moreover, spectrum allocations until recently were specific as to service as well. A television broadcaster cannot decide its license would be more efficiently or profitably used to offer mobile data services; it must operate a broadcast system or nothing at all.

[28] *See* JONATHAN E. NUECHTERLEIN & PHILIP J. WEISER, DIGITAL CROSSROADS: AMERICAN TELECOMMUNICATIONS POLICY IN THE INTERNET AGE 239 (2005) (arguing the existing "command and control" regulation of the spectrum has resulted in "under-utilized spectrum, business plans restricted by excessive regulatory control, and depressed incentives to innovate" and that "among neutral observers, there is little dispute that . . . the current spectrum regime requires a comprehensive overhaul").

like this in their licensed spectrum, dynamically allocating capacity to handsets within range of cellular towers. Because the operator cannot anticipate all possible usage scenarios ahead of time, it allocates some decision-making to software in each base station. However, the cellular example only goes so far because cellular networks operate in defined licensed spectrum bands for the purpose of supporting a particular uniform service, with the ability to control handset technology directly.

The two main proposals for significant reform of spectrum allocation both employ dynamic, local decisionmaking.[29] Under the "property" approach, spectrum licensees would be granted property rights to use or sell their spectrum as they pleased.[30] This approach traces its intellectual history to a famous 1959 article by Nobel Laureate Ronald Coase, urging the FCC to assign property rights rather than more limited licenses.[31] In a property system, decisions about what to do with frequency blocks devolve from a central government regulator to a collection of private owners. These owners can make local decisions about use and access to their spectrum, including whether to sell that spectrum to another owner who values it more.

The major alternative to the property approach, the so-called "commons" model, is even more distributed and dynamic.[32] Under a commons approach, anyone can transmit, subject to technical standards. Devices must negotiate themselves to avoid interference. The best example of this model in practice is the WiFi technology operating in the 2.5 GHz and 5 GHz unlicensed bands. Millions of WiFi base stations offer short-range connections in homes and businesses, coexisting despite the absence of exclusive rights.[33] The WiFi protocol allows individual devices to mitigate interference locally, and individual device owners can also coordinate transmission channels for more efficient operation.[34] As with the property approach, these decisions are superior to those of command -and-control allocation because they are made "on the ground" in response to local conditions, rather than being specified, indefinitely and ahead of time, by a central regulator.

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[29] For a comparison of property and commons models for spectrum, see Yochai Benkler, *Overcoming Agoraphobia: Building the Commons of the Digitally Networked Environment*, 11 HARV. J.L. & TECH. 287, 319–21 (1998); Werbach, *supra* note 18, at 951–69; Eli M. Noam, *The Fourth Way for Spectrum*, FT.COM, May 29, 2003, http://www.citi.columbia.edu/elinoam/FT/5-29-03/4thway.htm; Gerald R. Faulhaber & David Farber, Spectrum Management: Property Rights, Markets, and the Commons 12 (2002) (unpublished manuscript), *available at* http://rider.wharton.upenn.edu/~faulhabe/SPECTRUM_MANAGEMENTv51.pdf.

[30] *See* Werbach, *supra* note 18, at 902.

[31] *See* R. H. Coase, *The Federal Communications Commission*, 2 J.L. & ECON. 1, 1 (1959).

[32] *See* Werbach, *supra* note 18, at 866–67.

[33] *See* Stone, *supra* note 9.

[34] *See* Philip J. Weiser & Dale N. Hatfield, *Policing the Spectrum Commons*, 74 FORDHAM L. REV. 663, 678–79 (2005).

Technology is making such a dynamic spectrum allocation model feasible. Historically, wireless devices could only operate on a limited range of frequencies and transmit in very specific ways.[35] These characteristics had to be defined when the device was created, and built into the physical hardware. Moreover, devices had little or no ability to understand the local spectral environment. Today, numerous technical advances are changing radios into something entirely different: adaptable connected digital platforms.[36] Wireless devices today can be "tuned" to different frequencies and waveforms through software,[37] and can manage interference through power limits or technical protocols. These developments allow for a grand shift of spectrum utilization from static to dynamic.[38]

Dynamic spectrum access (DSA) would enable wireless devices to transmit based on actual availability of capacity rather than preset rules of exclusive frequency allocation.[39] DSA techniques are the subject of extensive technical research today.[40] The Defense Advanced Research Projects Agency (DARPA), the research and development arm of the U.S. Department of Defense, has funded significant development work on adaptive radio technologies, which could be employed for DSA. In addition, academics have suggested technical rules and pricing mechanisms for "secondary"[41] users to access licensed spectrum on an as-needed and as-

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[35] *See* Werbach, *supra* note 18, at 964; WERBACH, *supra* note 2, at 10 ("Wireless networks have historically used integrated, special purpose devices.").

[36] *See* Crawford, *supra* note 17, at 977 n.189; Werbach, *supra* note 18, at 897; Preston F. Marshall, New Am. Found., A Potential Alliance for World-Wide Dynamic Spectrum Access, Issue Brief No. 25, at 1–2 (June 2009), *available at* http://www.newamerica.net/files/Marshall_IssueBrief25_DSA.pdf; WERBACH, *supra* note 2, at 15 ("What were once single purpose, hardwired systems dominated by proprietary radio components increasingly become general-purpose, adaptive platforms dominated by commodity computing components.").

[37] *See* Authorization and Use of Software Defined Radios, First Report and Order, 16 F.C.C.R. 17,373 (Sept. 14, 2001); Comments of Vanu, Inc. at 1-2 (Feb. 28, 2003), Commission Seeks Public Comment on Spectrum Policy Task Force Report, 17 F.C.C.R. 24,316 (Nov. 25, 2002); William Lehr et al., *Software Radio: Implications for Wireless Services, Industry Structure, and Public Policy* 3–4 (Center for eBusiness@MIT, Paper 167, Aug. 2002), *available at* http://digital.mit.edu/research/papers/167_Software_Radio_Lehr_Fuencis.pdf.

[38] *See* WERBACH, *supra* note 2, at 13–24.

[39] *See* John M. Chapin & William H. Lehr, *The Path to Market Success for Dynamic Spectrum Access Technologies*, IEEE COMM. MAG., May 2007, at 96; Qing Zhao & Brian M. Sadler, *A Survey of Dynamic Spectrum Access*, IEEE SIGNAL PROCESSING MAG., May 2007, at 79, 80; Marshall, *supra* note 36, at 1.

[40] *See* Douglas C. Sicker, *The Technology of Dynamic Spectrum Access and Its Challenges*, IEEE COMM. MAG., June 2007, at 48 ("As radio devices increasingly gain intelligence . . . DSA is becoming one of the most pertinent and complex topics in wireless communications research."). *IEEE Communications Magazine*, a leading technical journal in the field, devoted a special issue to the topic in 2007, and research has only intensified since then. *See id.*

[41] "Secondary" access occurs when one user is assigned "primary" use of a band, and another user or group of users is allowed to transmit there only if not interfering with the primary user. A related development is a "secondary market," in which the primary user transfers authority to the secondary user

available basis.[42] Even Google has entered the fray, proposing continuous real-time auctions for spectrum capacity, analogous to the way it sells advertising on its search engine.[43]

The limitation of all these proposals is the absence of a coordination mechanism. Each envisions a particular DSA mechanism for a particular purpose, even though the DSA concept is potentially applicable to the entire usable spectrum.[44] What is needed is a way to "flip the switch" from the static to the dynamic paradigm. The missing piece for far-reaching spectrum reform is a meta-infrastructure with the capacity to incorporate virtually all forms of dynamic access as well as both the property and commons allocation mechanisms. The criteria for this notional spectrum meta-infrastructure bear a striking parallel to an existing resource: the Internet's domain name system.

B. Lessons from Internet Addressing

Every computer network must have an addressing system. Without unique addresses, data could not flow from one point to another. On a single network, addresses can be assigned and managed centrally, because one authority controls all aspects of the system. The Internet, however, is a network of networks that has no central regulator.[45] Instead, addresses must be assigned by agreement of the network operators or users. Remarkably, the Internet developed an addressing structure that is robust, scalable, and flexible, despite these limitations. That infrastructure is the domain name system (DNS).

The original Internet addressing mechanism was called the host name table. In those days, prior to the mid-1980s, machines were directly connected to the network, generally at universities or other research and government institutions. Addresses were maintained in a single flat text file by a graduate student named Jon Postel.[46] As the Internet grew, this simple mechanism became unworkable. The DNS was developed to replace it in

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through a market transaction. *See In re* Promoting Efficient Use of Spectrum, Report and Order, 18 F.C.C.R. 20,604 (2003).

[42] *See* Jon M. Peha & Sooksan Panichpapiboon, *Real-Time Secondary Markets for Spectrum*, 28 TELECOMM. POL'Y 603, 604 (2004).

[43] John Markoff, *Google Proposes Innovation in Radio Spectrum Auction*, N.Y. TIMES, May 22, 2007, at C10.

[44] One exception is spectrum dedicated for radio astronomy, where any radiated energy interferes with scientific research. *In re* Allocations and Service Rules for the 71–76 GHz, 81–86 GHz and 92–95 GHz Bands, Report and Order, 18 F.C.C.R. 23,318, 23,330 (2003).

[45] Kevin Werbach, *The Centripetal Network: How the Internet Holds Itself Together, and the Forces Tearing It Apart*, 42 U.C. DAVIS L. REV. 343, 400, 406 (2008).

[46] Jay P. Kesan & Rajiv C. Shah, *Fool Us Once Shame on You—Fool Us Twice Shame on Us: What We Can Learn From the Privatizations of the Internet Backbone Network and the Domain Name System*, 79 WASH. U. L.Q. 89, 170 (2001).

1983 by Paul Mockapetris, a researcher who helped develop key technical protocols for email and other Internet services.[47]

The technical requirements and applications of the DNS were spelled out in a series of protocol documents that were revised over time.[48] There are many aspects to the DNS, but at its core the DNS is a special kind of database. Paul Vixie, a longtime technical expert on Internet addressing, has called it "a distributed, coherent, reliable, autonomous, hierarchical database, the first and only one of its kind."[49] The DNS establishes a "domain name space" of hierarchical zones, each served by an authoritative nameserver. For example, the domain name "en.wikipedia.org" means the English-language subdomain of the Wikipedia domain, which is part of the .org (organization) generic top-level category within the DNS. Information is cached and replicated both horizontally—across multiple "root servers" or parallel local nameservers—and vertically—from a higher-level server down to subdomains.

Functionally, the DNS has two interfaces: a "front-end" resolution service for end-users, and a "back-end" registration service for network-connected resources. For end-users, the DNS seamlessly connects human-readable domain names, such as icanhascheezburger.com, with the numerical Internet Protocol (IP) addresses that the network's routers understand.[50] For those who wish to be reached, the DNS provides a mechanism to request a name, verify its availability, and associate it with an individual or organization.

As the DNS evolved, three distinct components developed: registries, registrars, and resolvers. A registry is the authoritative database for a top-level segment of the DNS, such as .com or .cz. The registry maintains the records of which names map to which IP addresses, and the official contact points for each registration.[51] Registrars interface directly with those who wish to register names.[52] The registrar function was originally combined with that of the registry; however, at least for the generic top-level domains such as .com and .org, competition among authorized registrars now ex-

[47] *See supra* note 1 and accompanying text.

[48] *See* ELLEN RONY & PETER RONY, THE DOMAIN NAME HANDBOOK (1998); J. Postel, *Domain Name System Structure and Delegation* (Network Working Group, RFC 1591, Mar. 1994), *available at* http://www.ietf.org/rfc/rfc1591.txt.

[49] Paul Vixie, *DNS Complexity*, ACM QUEUE, Apr. 2007, at 24, *available at* http://queue.acm.org/detail.cfm?id=1242499.

[50] This serves three purposes: people remember names better than numbers, the names can stay stable when the numbers (tied to network topology) change, and a single host can correspond to multiple network addresses. *See* J. Klensin, *Role of the Domain Name System (DNS)* 3 (Internet Engineering Task Force, RFC 3467, Feb. 2003), *available at* http://www.ietf.org/rfc/rfc3467.txt.

[51] A. Michael Froomkin, *Wrong Turn in Cyberspace: Using ICANN to Route Around the APA and the Constitution*, 50 DUKE L.J. 17, 41 (2000).

[52] *Id.* at 25 n.19.

ists.[53] Finally, individual devices and service providers can operate local resolvers that match a user's request for an address with the entry specified in the registry.[54] The resolver usually operates on a local cached copy of the registry at the user's Internet service provider.[55]

These concrete functions only partially capture the significance of the DNS. The unified addressing system is, on some level, what makes the Internet the Internet.[56] Without the ability to know that en.wikipedia.org is *the* English-language Wikipedia, there would be a collection of loosely connected private networks, rather than a single Internet.[57] And the DNS serves as a foundational infrastructure for new Internet applications and features because it is so universal.[58]

A review of the functions and history of the DNS reveals three key elements that allowed the system to scale effectively: resolution separated from transmission, distributed redundancy, and governance separated from technology.

First, the DNS is a specialized piece of Internet infrastructure. Its only function is to resolve addresses. The protocols for encoding and transmitting data packets are completely separate, as are those defining particular applications such as the World Wide Web and voice communication.[59] This separation helps the Internet to grow and develop. Scaling the addressing system, for example, is a challenge for the addressing system, not for the operators or users of other components of the Internet.

Second, as Paul Vixie noted, the DNS is a distributed, hierarchical, redundant system.[60] There is one authoritative DNS database for each top-level domain, but that database exists in many places. Billions of DNS queries take place every day, but the overwhelming majority do not go all the way to the central root servers. They are handled locally by caches and re-

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[53] This was a significant outcome of the transition of domain name governance to a quasi-private international governance organization. *See id.* at 24–25; *see also infra* Part III.C (discussing this transition).

[54] *See* Mockapetris, Domain Names—Concepts and Facilities, *supra* note 1, at 3.

[55] This description covers the runtime operation of the DNS. There are also policy functions handled by ICANN, the Internet Assigned Numbers Authority, and other bodies.

[56] "[T]he DNS provided critical uniqueness for names, and universal accessibility to them, as part of overall 'single Internet' and 'end to end' models." Klensin. *supra* note 50, at 5.

[57] *See* Werbach, *supra* note 45, at 355–56; Christopher Rhoads, *Endangered Domain*, WALL ST. J., Jan. 19, 2006, at A1 (explaining how the root contained in each domain name keeps the Internet operating as one cohesive system).

[58] *See* Klensin, *supra* note 50, at 2 ("In recent years, the DNS has become a database of convenience for the Internet . . . .").

[59] A. Michael Froomkin & Mark A. Lemley, *ICANN and Antitrust*, 2003 U. ILL. L. REV. 1, 6 n.19. Applications can be assigned to port numbers, which are part of the larger Internet addressing system, if not the DNS itself. The DNS also has a specialized component built in for email, known as the MX record. *Id.*

[60] *See* Vixie, *supra* note 49, at 24.

solvers. The distributed architecture of the DNS therefore promotes speed and reliability, which are important for core network infrastructure.

Third, the DNS is agnostic to how names are used. The DNS is a technical creation to manage an operational requirement of a network of networks. However, domain names that are at the center of important policy and economic activities become increasingly significant as the Internet grows. Domain names potentially intersect with the law of trademarks and defamation, for example.[61] In addition, the DNS's structure shapes the degree to which the Internet is truly international or inherently tilted toward the United States and other Western countries.[62] The Internet Corporation for Assigned Names and Numbers (ICANN), a quasi-private international body established by the U.S. government to oversee certain DNS management functions, has waded into these disputes.[63] However, the technical architecture of the DNS has remained the same. Although the DNS does not solve all the nontechnical problems in Internet addressing, it permits the battles around them to be fought in nontechnical domains.

II. FROM WHITE SPACES TO SPECTRUM DNS

The rudiments of a DNS for the wireless Internet are being developed as an outgrowth of the FCC's decision to authorize unlicensed white space devices around former broadcast television bands. To implement the white spaces decision, the FCC requires wireless devices to query a real-time database of utilization in the relevant frequency bands. In other words, wireless devices must check to make sure that the frequencies they intend to use are locally available before the devices actually use them. Properly designed, this system could be the basis for a distributed dynamic routing database, analogous to the DNS on the wired Internet.

To achieve such a result, however, the database must not be limited to white space devices alone. The FCC and industry must also take care to avoid the mistakes and failings of the current DNS infrastructure. These flaws include the imposition of artificial scarcities, the creation of a private monopolist, and the bureaucratization of technical management functions.[64] The Internet may have been a happy accident, but there is no excuse today for ignoring the infrastructural demands of its next instantiation.

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[61] *See generally* MILTON L. MUELLER, RULING THE ROOT: INTERNET GOVERNANCE AND THE TAMING OF CYBERSPACE (2002) (detailing the tortured history of domain name management); Kesan & Shah, *supra* note 46, at 200 (noting trademark owners' interest in limiting DNS competition to protect their trademarks).

[62] *See* Werbach, *supra* note 45, at 359 (noting that English is built into the DNS because the DNS grew out of an American system); Geoff Huston, *Addressing the Future Internet*, ISP COLUMN, Feb. 2007, http://www.potaroo.net/ispcol/2007-02/address-paper.html (explaining the significance of proposed international domain names).

[63] *See infra* Part III.C.

[64] *See* Kesan & Shah, *supra* note 46, at 184–85.

A. The White Space Database

The white space database presents a singular opportunity to apply the DNS model to wireless communication. When the FCC allocated spectrum for broadcast television in the 1940s, it deliberately left many channels dark to avoid interference.[65] For example, channel 4 was licensed in New York but not in Philadelphia, so that receivers in each city would not become confused by overlapping signals.[66] Many other frequencies in the TV broadcast bands remain unused as interference protection. Moreover, not every available channel is licensed in each city, and many licensees do not actually transmit, especially with most viewers receiving television content through cable or satellite connections rather than over the air. A 2005 study by the public interest group Free Press confirmed that most TV broadcast channels are simply not in use.[67] The digital TV transition did not substantially change this fact.[68]

These so-called TV white spaces[69] are perhaps the most egregious example of the inefficiency of the current spectrum allocation regime. They are considered "beachfront spectrum"—they are highly attractive because of their location on the low end of the frequency chart. Generally, the lower the frequency, the better the propagation of a wireless signal.[70] A lower-frequency system can serve a larger geographic area and penetrate obstructions such as trees and building walls more easily than a higher-frequency system. Lower frequencies tend to be dedicated to older services, and thus are less likely to be made available for new systems.[71] These broadcast frequencies have the capability to support valuable wireless broadband services, and might be especially useful for delivering broadband connectivity in rural areas.[72]

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65 *See* NUECHTERLEIN & WEISER, *supra* note 28, at 234–35; Meinrath & Calabrese, *supra* note 23, at 497.

66 Werbach, *supra* note 18, at 895; WEISER, *supra* note 18, at 26.

67 *See* Ben Scott & Michael Calabrese, *Measuring the TV "White Space" Available for Unlicensed Wireless Broadband*, FREE PRESS, Dec. 2, 2005, at 1, *available at* http://www.freepress.net/docs/whitespace_analysis.pdf (analyzing white space in markets across the United States to demonstrate that virtually every market in the country has unoccupied broadcast channels allocated for broadcasting that are not actually in use). *See also* Spectrum Occupancy Measurements, *supra* note 20.

68 *See* Meinrath & Calabrese, *supra* note 23, at 497 (noting that after the completion of the digital television transition, the amount of white space in most of the nation's 210 local television markets will greatly exceed the amount of occupied spectrum even in major cities).

69 The designation is something of a misnomer, as there is nothing inherently linking the subject frequencies to television broadcasting beyond historical legacy.

70 Werbach, *supra* note 18, at 906.

71 *Id.*

72 *See* Crawford, *supra note* 17, at 1002; Meinrath & Calabrese, *supra* note 23, at 501; Pierre de Vries, *Populating the Vacant Channels: The Case for Allocating Unused Spectrum in the Digital TV Bands to Unlicensed Use for Broadband and Wireless Innovation* 7 (New Am. Found., Working Paper No. 14, 2006), *available at* http://www.newamerica.net/files/WorkingPaper14.DTVWhiteSpace.deVries.pdf (explaining the criticisms of limiting white space usage to rural areas); J.H.

In 2004, the FCC sought comment on whether to allow unlicensed devices to transmit in the TV white spaces.[73] Advocates and technical experts weighed in on both sides regarding the potential for interference. Broadcasters expressed concern that unlicensed white space devices would harm TV reception.[74] Manufacturers and users of wireless microphones, which operate in these bands, expressed similar objections.[75] The FCC concluded in 2006 that unlicensed white space devices could operate without producing excessive interference.[76] It initiated a testing process for prototype devices to verify this finding.[77] Companies such as Microsoft, Philips, and Motorola developed the prototype equipment. The testing concluded in October 2008 with the FCC finding that white space devices could detect and avoid nearby television systems and wireless microphones.[78]

In November 2008, the FCC allocated the TV white spaces for unlicensed use.[79] This means that new wireless devices will be able to engage in local, ad hoc sharing of these frequencies, similar to how WiFi devices operate today. However, important issues must be resolved before the white space order can go into effect. The FCC left significant technical and implementation issues to a later stage of the proceeding.[80] In March 2009, the incumbent TV broadcasters sued the FCC to overturn the decision.[81] And during the same period, President Obama's nominee as FCC Chairman, Julius Genachowski, took over from the Bush Administration's Kevin Martin.

Snider, *Reclaiming the Vast Wasteland: The Economic Case for Re-Allocating the Unused Spectrum (White Space) Between TV Channels 2 and 51 to Unlicensed Service* 6 (New America Foundation, Working Paper No. 13, 2006), *available at* http://www.newamerica.net/files/WorkingPaper13.UnlicensedEconCase.Snider.pdf (explaining that low frequency spectrum, or use of white spaces, for broadband can reduce rural broadband deployment costs).

[73] Notice of Proposed Rulemaking, Unlicensed Operation in the TV Broadcast Bands, ET Docket No. 04-186, FCC 04-113 (2004), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-04-113A1.pdf.

[74] Unlicensed Operation in the TV Broadcast Bands, 74 Fed. Reg. 7314, 7316 (Feb. 17, 2009).

[75] *Id.* (describing objections by wireless microphone manufacturer Shure, Inc.). There are a handful of other authorized uses of the bands, including auxiliary transmission services for broadcasters and cable television head-end systems.

[76] *In re* Unlicensed Operation in the TV Broadcast Bands, First Report and Order and Further Notice of Proposed Rule Making, 21 F.C.C.R. 12,266 (Oct. 18, 2006).

[77] *See id* at 12,283–84 (measurement procedures).

[78] FCC OFFICE OF ENGINEERING AND TECHNOLOGY, EVALUATION OF THE PERFORMANCE OF PROTOTYPE TV-BAND WHITE SPACE DEVICES PHASE II, FCC/OET 08-TR-1005, at 27–30 (Oct. 15, 2008), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/DA-08-2243A3.pdf.

[79] Unlicensed Operation in the TV Broadcast Bands, Second Report and Order and Memorandum Opinion and Order, 23 F.C.C.R. 16,807 (Nov. 14, 2008) [hereinafter White Spaces Order].

[80] *See id.*

[81] *See* Matthew Lasar, *Broadcasters Sue FCC Over White Space Broadband Decision*, ARS TECHNICA, Mar. 3, 2009, http://arstechnica.com/tech-policy/news/2009/03/broadcasters-sue-fcc-over-white-space-broadband-decision.ars.

Therefore, at this moment, there is a significant opportunity to shape the white space proceeding. The FCC's November 2008 Report and Order was a statement of intent to move forward, but the actual structure can still be shaped. At the same time the regulatory process is moving forward, the 802.22 subgroup of the Institute of Electrical and Electronics Engineers (IEEE) is developing technical standards for devices that could operate in the white spaces.[82]

The FCC's November 2008 order introduced the new requirement that a database be used to protect against interference from white space devices.[83] TV white space devices would be required to incorporate geolocation capabilities, meaning they would have the ability to determine their physical location either directly or through communication with a fixed base station.[84] Before transmitting, each device would have to check the white space database to identify broadcasters and others operating in that area.[85] This way, the device could be sure it was "in the clear" to use a vacant channel.

The white space database emerged from the FCC proceeding as a pragmatic solution to a narrow concern, but has the potential to become something much greater. The database was a response to the broadcasters' objections that regulators could not rely on the spectrum-sensing capabilities of white space devices themselves to protect pre-existing users. However, the few lines in the FCC order concerning the database leave open a great deal of room to determine how it should be structured, implemented, and governed. The database will be a piece of software and networking infrastructure, analogous to the DNS. And there is no fundamental reason it must be limited to broadcast white spaces.[86]

A coalition called the White Spaces Database Group has taken the lead in recommending the architecture for the system.[87] The group proposed a structure broadly similar to the DNS, with the possibility for distributed data storage and a split between registries and registrars (which it calls repositories and service providers), as well as the potential for dedicated resolvers

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[82] The 802.22 standards group is under the same general group of Ethernet-based networking standards as 802.11, which houses the various flavors and derivatives of WiFi. IEEE 802 LAN/MAN Standards Committee, http://grouper.ieee.org/groups/802/ (last visited Feb. 20, 2010).

[83] White Spaces Order, *supra* note 79, at 16,809. The order also encouraged other mechanisms such as spectrum sensing to prevent interference. *Id.*

[84] *Id.* at 16,810–11.

[85] *Id.* at 16,808.

[86] *See* Michael Calabrese, *The End of Spectrum 'Scarcity': Building on the TV Bands Database to Access Unused Public Airwaves* 9–10 (New Am. Found., Working Paper No. 25, June 2009), *available at* http://www.newamerica.net/files/Calabrese_WorkingPaper25_EndSpectrumScarcity.pdf (advocating the use of bands reserved for federal agencies).

[87] *See ex parte* filing of the White Spaces Database Group, Unlicensed Operation in the TV Broadcast Bands, ET Docket No. 04-186 (FCC Office of Eng'g & Tech. Apr. 10, 2009) [hereinafter White Spaces Database Group]. Membership in the group includes Comsearch, Dell, Fox, Google, Microsoft, Motorola, NCTA, MSTV, NetLogix, Neustar, and the Public Interest Spectrum Coalition. *Id*

(called query services).[88] In short, the white space database could be the foundation for a DNS of the wireless spectrum. The FCC issued a public notice in November 2009 seeking applications to manage the .[89]

B. Comparing Interference to Addressing

Spectrum management and Internet addressing are both mechanisms for conflict resolution. In wireless communication, the potential conflict is between two systems that cannot effectively communicate at the same time, a phenomenon known as interference.[90] In addressing, the conflict is between two systems that claim the same domain name.[91] The DNS solves this conflict by authoritatively linking an Internet protocol address (which is both unique and itself tied to the physical topology of the network) with a domain name.[92] The equivalent process for spectrum is usually handled by the FCC, through its command-and-control allocation of frequencies to designated licensees.[93]

Although they serve the same basic function, the DNS and current spectrum management techniques work in very different ways. Spectrum management is prophylactic and fixed. The government decides ahead of time how a set of frequencies can be used and writes those into its licenses. The DNS, on the other hand, does not associate a name to an IP address until the prospective user of that name registers it. Registration only requires a check that the name is unassigned. And the registration can be changed or transferred at any time. This user-controlled system is therefore dynamic where traditional spectrum allocation is static and inefficient.[94]

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[88] *Id.*

[89] Office of Engineering and Technology Invites Proposals from Entities Seeking to be Designated TV Band Device Database Managers, Public Notice, DA 09-2479, ET Docket No. 04-186 (Nov. 25, 2009), 2009 WL 4073959, *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/DA-09-2479A1.doc. For Google's plan, see Proposal by Google Inc. to Provide a TV Band Device Management Solution, Unlicensed Operation in the TV Broadcast Bands, DA 09-2479, ET Docket No. 04-186 (Jan. 4, 2010), *available at* http://www.scribd.com/doc/24784912/01-04-10-Google-White-Spaces-Database-Proposal.

[90] As I explain in *Supercommons*, interference is something of a misnomer. The wireless signals do not prevent each other from being received. They make it difficult for one or both sets of devices to distinguish the desired signal from unrelated noise. *See* Werbach, *supra* note 18, at 887–88.

[91] Addresses do not necessarily need to be globally unique to avoid this problem. DHCP and NATs allow a hierarchical structure where only a portion of the network is subject to DNS. *See infra* text accompanying notes 106–109.

[92] The mapping need not be one-to-one. Several domain names can be aliased to one IP address, or multiple IP addresses can be pointed to the same domain name.

[93] *See* Werbach, *supra* note 18, at 870–71; Noam, *supra* note 29; FCC, SPECTRUM POLICY TASK FORCE REPORT, *supra* note 22, at 3; *see also* Benkler, *supra* note 29, at 315–16 (presenting Coase's critique of this system). In unlicensed bands, the FCC establishes technical requirements for devices, which then manage interference locally. *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, 783–84 (1998).

[94] *See* Werbach, *supra* note 18, at 919–20.

At first blush, there are substantial differences between the resolution function of domain names and spectrum management.[95] "Interference" with a domain name means using the exact same string of alphanumeric characters. Two domain names that vary by a single character may coexist without difficulty. With wireless systems, however, interference is a complex and contentious concept.[96] Whether a system interferes is not a stable physical property; it depends on the system allegedly interfered with.[97] The physics of wireless communication produce many spillover effects between systems.[98] An interference determination is further complicated by the nature of exclusive licenses. Incumbent licensees have every incentive to make their devices cheap rather than robust to interference, and to use the regulatory process to claim interference is occurring.[99] The battles over low-power FM radio and white spaces show how intense these conflicts can become.[100] A cursory duplication check and a simple first-in-time allocation rule, as the DNS uses, therefore do not suffice for wireless.

On further examination, however, the lines are not so clean in the DNS case, either. Because domain names are human-readable strings, there are situations where a user may confuse them even if a computer does not. This becomes important when a particular domain name has economic value associated with it, which is widely the case with commercial websites and overlapping trademarks.[101] Under both the Anti-Cybersquatting Consumer Protection Act in U.S. law[102] and the Uniform Dispute Resolution Process of ICANN,[103] a registrant may be forbidden from using a domain name even if it is not identical to one already registered or trademarked.[104] So-called cybersquatting that is malicious or creates consumer confusion is prohibited. As the number of lawsuits in this area demonstrates, deciding when cybersquatting has occurred is complicated and contentious.[105] The analogy to spectrum interference debates is therefore not so far-fetched.

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[95] Jim Speta first encouraged me to consider this point.

[96] *See* Yochai Benkler, *Some Economics of Wireless Communications*, 16 HARV. J.L. & TECH. 25, 39–40 (2002); Werbach, *supra* note 18, at 887–88; David Weinberger, *The Myth of Interference*, SALON, Mar. 12, 2003, http://dir.salon.com/story/tech/feature/2003/03/12/spectrum/index.html.

[97] *See* Werbach, *supra* note 18, at 887–89.

[98] *See id.*

[99] *See id.* at 961.

[100] *See* Stuart Minor Benjamin, *The Logic of Scarcity: Idle Spectrum as a First Amendment Violation*, 52 DUKE L.J. 1, 13–17 (2002) (lower power FM); Snider, *supra* note 72, at 2 (white spaces).

[101] *See* MUELLER, *supra* note 61, at 22–23.

[102] Anticybersquatting Consumer Protection Act, 15 U.S.C. § 1125(d) (2006).

[103] Uniform Domain Name Dispute Resolution Policy, ICANN, Oct. 24, 1999, http://www.icann.org/en/udrp/udrp-policy-24oct99.htm.

[104] *See* MUELLER, *supra* note 61, at 22–23; Patrick D. Kelley, Note, *Emerging Patterns in Arbitration Under the Uniform Domain-Name Dispute-Resolution Policy*, 17 BERKELEY TECH. L.J. 181, 181 (2002).

[105] *See* Jacqueline D. Lipton, *Beyond Cybersquatting: Taking Domain Name Disputes Past Trademark Policy*, 40 WAKE FOREST L. REV. 1361, 1381–83 (2005) (categorizing domain name disputes).

At a technical level, the closest analogy between dynamic spectrum brokering and Internet addressing is DHCP, the Dynamic Host Configuration Protocol.[106] DHCP is one of many "hacks" to adapt the Internet architecture developed for small-scale research internetworking to the requirements of today's commercial-scale global infrastructure.[107] Because of the technical characteristics of the Internet Protocol (IP) and historical address-allocation policies, most Internet service providers cannot easily give each of their customers a unique IP address.[108] Mobile access and nomadic connections to WiFi hotspots complicate the problem even further. The solution is to assign users an address dynamically from a common pool, each time they log on. Even if they have a broadband connection, most residential users do not remain connected all the time. DHCP makes dynamic IP address updates transparent to users.

With DHCP, a relatively small pool of IP addresses can be shared by a relatively large pool of users. Each user ties up an address only when he or she actually needs it. This efficiency gain parallels the greater efficiency that a more dynamic structure could bring to spectrum allocation. The problem with DHCP, and the related technique of Network Address Translation, is that they, as already noted, were post hoc hacks rather than core Internet infrastructure like the DNS. Because DHCP allocates addresses locally, there is no uniform mechanism to associate users and addresses across the network. The absence of end-to-end visibility adds complexity to the Internet, and creates problems for some applications.[109] For example, an application to transfer files or allow remote logins from one computer to another across the network would need a way other than a fixed address to find the other host. DNS for wireless communication would marry the efficiency gains of DHCP with the canonical reliability of DNS.

As discussed below, conflict resolution is in truth only an intermediate function of both the DNS and spectrum allocation.[110] Both the Internet address space and the spectrum are notional constructs only.[111] Conflicts over

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[106] Froomkin & Lemley, *supa* note 59, at 6 n.19 (explaining DHCP); T. Maseng & T. Ulversoy, *Dynamic Frequency Broker and Cognitive Radio*, 2008 PROC. OF IET SEMINAR ON COGNITIVE RADIO & SOFTWARE DEFINED RADIOS: TECH. & TECHNIQUES *4 (Sept. 2008), available at http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4656355 (making the analogy to DHCP).

[107] *See* Joshua L. Mindel & Marvin A. Sirbu, *Regulatory Treatment of IP Transport and Services*, *in* COMMUNICATIONS POLICY IN TRANSITION: THE INTERNET AND BEYOND 59, 74 (Benjamin M. Compaine & Shane M. Greenstein eds., 2001); *Upgrading the Internet*, ECONOMIST, Mar. 24, 2001, at 31–34.

[108] *See* Werbach, *supra* note 45, at 361–63.

[109] Marjory S. Blumenthal & David D. Clark, *Rethinking the Design of the Internet: The End-to-End Arguments vs. The Brave New World*, *in* COMMUNICATIONS POLICY IN TRANSITION, *supra* note 107, at 91–92.

[110] *See* Klensin, *supra* note 50, at 8.

[111] That the DNS is an arbitrary system created by Internet protocol definitions should be obvious. The illusory character of the spectrum is less intuitive, but equally accurate. *See* Werbach, *supra* note 18, at 882.

names and frequencies are important only to the degree they have economic or social consequences. A system that minimizes conflicts and controversy, but too heavily constrains productive use of the resource in question, would be a poor tradeoff. The ultimate goal of the DNS, as described above, was to scale the Internet.[112] The ultimate goal of spectrum management should likewise be to scale wireless capacity.[113]

The DNS, for its many flaws, has allowed the Internet to grow from a purely research-oriented system linking a few thousand networks in 1983 to the global backbone of commerce, entertainment, communication, and government activity in 2010. To achieve something similar in spectrum requires an infrastructure for dynamic and distributed intermediation of spectrum allocation decisions, just as the DNS provides dynamic and distributed intermediation of address allocation decisions.

III. THE SPECTRUM NETWORKING DATABASE

A. How the System Would Work

As has already been noted, a great deal of technical work is underway to facilitate real-time sharing of wireless capacity. The next step is to envision an intermediary that would broker requests for secondary access. A number of experts have incorporated some form of brokering into their technical protocols for dynamic spectrum access, or DSA.[114] Viewing the problem from the other direction, though, the brokering mechanism should be the primary infrastructure for spectrum allocation, with particular technical schemes for sharing as subsidiary elements.[115] Putting the brokering engine at the center emphasizes the structural and policy elements to be addressed. I call the universal brokering engine the SND, or spectrum networking database.

The foundation for the SND is the reference architecture the White Spaces Database Group proposed to the FCC.[116] This architecture involves

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[112] *See supra* Part I.B.

[113] *See* Benkler, *supra* note 96, at 30–47; Werbach, *supra* note 18, at 864–67.

[114] *See, e.g.*, Milind M. Buddhikot et al., *DIMSUMnet: New Directions in Wireless Networking Using Coordinated Dynamic Spectrum Access*, 2005 PROC. OF WOWMOM: SIXTH IEEE INT'L SYMP. ON WORLD OF WIRELESS MOBILE & MULTIMEDIA NETWORKS; Maseng & Ulversoy, *supra* note 106; Vladimir Brik et al., *DSAP: A Protocol for Coordinated Spectrum Access*, FIRST IEEE DYSPAN INT'L SYMP. ON NEW FRONTIERS IN DYNAMIC SPECTRUM ACCESS NETWORKS 611 (2005); Peng Qihang et al., *A Distributed Spectrum Sensing Scheme Based on Credibility and Evidence Theory in Cognitive Radio Context*, 17TH IEEE INT'L SYMP. ON PERSONAL, INDOOR & MOBILE RADIO COMM. *1–5 (2006).

[115] In a prior article, I envisioned a model for spectrum starting with a universal open entry privilege, cabined by tort-like and trademark-like liability rules. Werbach, *supra* note 18, at 929–50. The system described here could fit within that still-broader framework.

[116] White Spaces Database Group, *supra* note 87, at 3–9.

three main elements: the repository, the registrar, and the query service.[117] The repository would be the actual database of frequencies, locations, and authorized users. It is analogous to the DNS "root" database of domain names.[118] The repository would be fed from existing FCC spectrum allocation databases, such as the Universal Licensing Service, as well as from registrars. Registrars would obtain information from spectrum users. One kind of users would be protected entities, such as the incumbent broadcasters and wireless microphone operators. Another would be white space devices seeking secondary access to the spectrum. The registrar function parallels the competing registrars that users pay to register and maintain their domain names. Finally, the query service would check a device request against the available capacity in the database.[119] This function is analogous to the resolver software that Internet service providers and personal computers use to determine the proper path to a domain name.

The SND would adapt architectural elements of the DNS to spectrum. At the core, the database would map blocks of spectrum to authorized users of that spectrum, just as the DNS maps domain names to servers on the Internet. The database would be granular as to frequencies and location, at a minimum. Before a device could operate, it would query the SND to identify available transmission opportunities in its local area and at the desired frequencies. The database would return one of two results: that the requested spectrum allows no authorized transmitters, or information about the incumbent networks and devices authorized to operate there. If the requested spectrum were empty, the device could register itself as operating in that band and location, and begin transmitting. If the requested spectrum were occupied, the device could not operate unless it either met criteria for low-power or ultra-wideband underlay operation[120] consistent with the incumbent users, or it negotiated a license or lease from the incumbent.

Like the DNS, the SND structure could be hierarchical, which would avoid bottlenecks and facilitate greater local variation. At the top would be redundant root servers, parallel to the multiple root servers for the DNS. Local SND servers would query these root servers regularly and cache the results. Each SND server would therefore have an updated "map" of the spectrum in its geographical reach.

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[117] Some or all of these could be combined in a single company. The White Spaces Database Group also refers to device registrars and stand-alone query services as "service providers." *Id.*

[118] Like the DNS root, the repository would likely be replicated across many servers for redundancy and geographical dispersal. Unlike DNS, which has a single registry operator for each top-level domain, there might be more than one repository operator at the top level for the spectrum database. Parallel registry operators would have to mirror their contents regularly to assure consistency.

[119] This service might also be integrated into the registrar function.

[120] Ultra-wideband (UWB) is a technique that spreads a wireless signal across a very large range of frequencies. Under basic principles of information theory, the wider the coding of a channel, the lower the power required. With UWB, the power output is so low that the signal falls below the "noise floor," and is effectively invisible to other systems, even in the same band. Werbach, *supra* note 18, at 894–95.

Both the DNS and the White Space Database Group proposal separate the functions of registries (which store canonical data) and registrars (which interface with end-users and insert data into the registry). This approach allows for competition and provides a check on the excessive power of a monopoly registry. However, it is not without its own dangers. For domain names, registrar competition is largely circumscribed to price. There is little incentive for new or better service, so registrars engage in a "race to the bottom" to offer the cheapest registrations.[121] A high "wholesale" price for the .com domain registry exacerbated this error, giving registrars little room to maneuver.[122] Spectrum registrars should have flexibility to innovate, so long as they meet the basic technical and business requirements to participate in the process.

For the system to operate effectively, all dynamic devices would need unique identifiers, so they could be tracked and managed through the database.[123] A certification process would need to be established to ensure that devices operate as specified, including responding to shutoff commands from the database. That process could be run directly by the FCC or delegated to private bodies, as with most communications equipment certification today.

Devices would need the ability to communicate with the database, either through an existing Internet connection or via a dedicated wireless control channel. A wireless "control plane" for administrative communications would parallel the "out of band" architecture of the SS7 signaling network on the public switched telephone network.[124] On the Internet, signaling information uses the same physical channel as the information payload, but utilizes specialized protocols such as Border Gateway Protocol for connecting networks and the DNS protocol for domain name resolution queries.[125] The SND would need a separate wireless channel for administrative communication, because the entire purpose of the system is to establish a physical wireless connection in a particular spectrum block. This channel could utilize existing unlicensed frequencies, which are already available throughout the United States, and in some cases are globally harmonized.[126]

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[121] *See* Froomkin & Lemley, *supa* note 59, at 66–67 (explaining how ICANN's Uniform Dispute Resolution Process short-circuited opportunities for registrars to compete on grounds other than price).

[122] *See* Kesan & Shah, *supra* note 46, at 184–85.

[123] This would be one point of distinction between the new adaptive wireless devices and the legacy static devices entitled to protection.

[124] *See* Kevin Werbach, *Meta Service Providers: The Internet's SS7 Network*, RELEASE 1.0, Dec. 15, 1999, at 1, 2–3, *available at* http://cdn.oreilly.com/radar/r1/12-99.pdf.

[125] K. Lougheed & Y. Rekhter, *A Border Gateway Protocol (BGP)* (Network Working Group, RFC 1105, 1989), *available at* http://www.ietf.org/rfc/rfc1105.txt.

[126] *In re* 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, Notice of Proposed Rulemaking, 18 F.C.C.R. 11581 (June 4, 2003).

Protected incumbent allocations in the SND could be classified in several ways. Some existing uses would preclude any potentially interfering transmissions. Military systems, radio astronomy bands, avionics, medical devices, and heavily utilized commercial systems such as cellular telephone service could be designated for maximum protection.[127] Other bands might be subject to "easements" for low-power use, without permission from existing users.[128] Others could be available on an unlicensed basis when not in use, as with the TV white spaces under the FCC order.[129] Still others might be available subject to negotiation with the incumbent—assuming there is one.[130] The SND could manage interference because devices would need to query it prior to initiating transmissions. If a device were determined to be operating improperly, due to equipment failure or operator misuse, the system would issue a "no channel available" message, preventing it from transmitting.

Technical standards for devices would need to be established. As noted previously, the IEEE 802.22 group is developing standards, but they envision a more limited white space database compared to the broader SND vision sketched out here. The standards adopted would significantly influence the scope and flexibility of the SND. At an extreme, devices would have full flexibility in selecting spectrum bands, access models, and transmission modalities. The reality is that such flexible radios are not yet feasible to build, let alone affordable to sell, despite rapidly advancing research. The functionality of devices will involve cost–performance tradeoffs. The architects of the SND will have to determine how and where to restrict those tradeoffs. For example, how often must devices query the database, and should baseline etiquettes be mandated for DSA devices to coexist with each other?

Furthermore, devices might operate on an ad hoc basis, handling all the spectrum access negotiation themselves, or they might be tied to fixed base stations. The value of a fixed base station is that a mobile device need only find and establish contact with the base station, which can have a dedicated link to the SND. The base station can ensure that the mobile device complies with the constraints of its authorization. The mobile device would not be able to operate without confirmation from a base station, so if it were moved outside the specified transmission area, it would cease to transmit without authorization from another base station. The architecture in this case would parallel that of cellular telephone networks. Mobile phone

[127] It is worth pointing out, however, that even these systems, with the exception of radio astronomy, could at some point become more flexible and dynamic. Public sector spectrum users could participate in the SND infrastructure on a case-by-case basis. For radio astronomy, though, there is to date no way to negotiate with a quasar, so a strict zone of inclusion is needed.

[128] *See* Faulhaber & Farber, *supra* note 29, at 14.

[129] White Spaces Order, *supra* note 79, at 16,808–10.

[130] *See infra* Part III.B.

handsets operate by locating a transmission tower, which authorizes them to communicate, assigns them temporary frequency slots, and handles "back-haul" of the communication onto the larger network backbone.[131]

B. Benefits

The power of this system lies in its flexibility. The same basic architecture could be applied in one set of frequencies (such as the former broadcast television bands) in a limited geographic area, or it could encompass the entire usable spectrum nationwide. Moreover, the structure is agnostic between the two competing allocation mechanisms for more efficient spectrum use: property and commons. If a frequency band were designated for unlicensed use, the SND would provide the technical restrictions such as power limits on that band, and authorize transmission. If the frequency band were licensed, the SND would allow the licensee to specify terms for secondary access. These terms could include, for example, open entry so long as the licensee has priority and override capability, requirement of a reservation or "lease" for the system seeking access,[132] or real-time access payments using either a fixed or auctioned price.[133]

Furthermore, the SND would allow for a new category of spectrum allocation that is neither property nor commons. In this scenario, rather than designating frequencies as either licensed or unlicensed, as it does today, the FCC could establish a set of initial access algorithms for the SND. These algorithms could vary depending on the nature of the spectrum involved and the use cases. For some very high "millimeter wave" frequencies, for example, the FCC has already established a reservation system, through which users can sign up to operate point-to-point links on a first-come, first-served basis.[134] In other cases, the FCC might designate a primary user (such as a wide-area high-power system) and a category of secondary or unlicensed users with rights to operate below certain power thresholds or when the primary user was not. The approach could be used for so-called ATC (ancillary terrestrial component), in which frequencies designated for satellite uplink are reused for terrestrial service through de-

[131] *See* NUECHTERLEIN & WEISER, *supra* note 28, at 265–66.

[132] *See* Peha & Panichpapiboon, *supra* note 42, at 605; Maseng & Ulversoy, *supra* note 106, at 3. Note that this could be the "unlicensed park" model suggested by spectrum property advocates, where an equipment vendor buys the spectrum and charges for devices. *See* Werbach, *supra* note 18, at 957. The SND establishes the foundational infrastructure to make this approach more feasible.

[133] *See ex parte* filing of Richard S. Whitt, Google, Service Rules for the 690-746, 747-762, and 777-792 MHz Bands, WC Nos. 06-150, 06-129, PS No. 06-229, WT No. 96-86 (FCC Wireline Competition Bureau) (May 21, 2007), *available at* http://fjallfoss.fcc.gov/prod/ecfs/retrieve.cgi?native_or_pdf=pdf&id_document=6519412640.

[134] *In re* Allocations and Service Rules for the 71–76 GHz, 81–86 GHz and 92–95 GHz Bands, Report and Order, 18 F.C.C.R. 23,318, 23,339–41 (2003); Weiser & Hatfield, *supra* note 34, at 690 & n.125.

vices able to determine the angle of signal arrival.[135] And it could be used for sharing spectrum with radar systems that rotate or operate only during circumscribed time periods.[136]

As one concrete example, the FCC recently attempted to promote the deployment of a nationwide interoperable public safety wireless network using the so-called D Block of frequencies in the 700 MHz bands being vacated by analog UHF television channels.[137] The Commission sought to auction the block subject to the condition that the winner construct a network capable of both commercial service and public safety use, with the public safety users having override capability in times of need.[138] The funds from the auction were to be used to purchase equipment for the public safety users.[139] The auction in 2008 failed when no bidder offered the reserve price.[140] The FCC is now evaluating other options, both for the 700 MHz D Block and for a nationwide interoperable public safety system.

Under an SND model, the public safety goal could be achieved more readily. The FCC would designate frequencies in which public safety systems had a guaranteed override capability. The simplest option would be then to allocate the system for auction to a private operator, who would get the spectrum subject to that limitation. Or the spectrum could be made available as unlicensed, subject to the same condition. The public safety override would then be incorporated into the technical rules for unlicensed devices approved by the FCC to operate in the band, and into the relevant technical standards. As a variant, a royalty on each compliant device could be used to fund the purchase of public safety equipment, although that would require additional questions about the best funding mechanism for that goal. In other words, the SND itself does not solve the public safety problem, but it creates a much larger toolkit for policymakers to employ.

A collateral benefit of this database-driven approach would be future-proofing. One of the great challenges of wireless communication is that as technology evolves and usage patterns change, bands may become more or less heavily used. Incumbent systems, however, can be expensive to clear out of bands, even when they are not very active. Clearing systems from

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[135] *In re* Flexibility for Delivery of Communications by Mobile Satellite Service Providers in the 2 GHz Band, the L-Band, and the 1.6/2.4 Bands, Report and Order and Notice of Proposed Rulemaking, 18 F.C.C.R. 1962 (Feb. 10, 2003); Werbach, *supra* note 18, at 897, 926.

[136] Michael J. Marcus, New Am. Found., New Approaches to Private Sector Sharing of Federal Government Spectrum, Issue Brief No. 26, at 3, 6 (June 2009), *available at* http://www.newamerica.net/files/Marcus_IssueBrief26_SharingGovtSpectrum.pdf.

[137] *See* Crawford, *supra* note 17, at 973–74.

[138] *See id.*; Auction of 700 MHz Band Licenses Scheduled for January 16, 2008, Comment Sought on Competitive Bidding Procedures for Auction 73, Public Notice, 22 F.C.C.R. 15,004, 15,005–06 (Aug. 17, 2007).

[139] *See* Crawford, *supra* note 17, at 968–74.

[140] *Id.* at 989; Alejandro Valencia, *The FCC's Regulatory Mulligan: Exploring the Options in the Wake of a Failed D Block Auction*, 10 N.C. J.L. & TECH. 313, 354 (2009).

the bands given to 2G and 3G cellular systems was extremely expensive, and in some cases the installed base of devices makes reallocation effectively infeasible.[141] With an SND architecture, the FCC could change the allocation algorithm when conditions changed significantly. Because all devices would be required to operate under the constraints of the SND, migration and adaptation would be automatic.[142]

The presence of the SND as a market-making intermediary would make this approach superior to a pure property rights regime. Relying on individual spectrum owners to negotiate with potential entrants falls victim to the tragedy of the anticommons.[143] There are many externalities and complications of interference and wireless utilization that property owners are ill-suited to take into account.[144] A pure property system for spectrum is like the old host table for Internet addresses.[145] It becomes a bottleneck because it has no real-time global visibility.

The SND would serve the same purpose as the New York Stock Exchange: creating the trust and liquidity necessary for a well-functioning market. The NYSE assigns unique ticker symbols to each stock, but this is a relatively trivial aspect of its activity. The more important functions of the NYSE include serving as the locus for a set of rules, some private and some government-imposed, that create well-defined rights as the basis for transactions. Similar intermediaries exist in other markets, such as commodities and energy.

Collective mechanisms such as exchanges and government regulation become necessary when the efficient distribution of property rights is too difficult to achieve through bilateral transactions. As Thomas Merrill and Henry Smith have noted, property functions both in rem (as a thing against the world) and in personam (as a bundle of rights attaching to an owner).[146] Coase advocated property rights in spectrum by emphasizing the in personam rights in wireless equipment, rather than the notional in rem rights in spectrum frequencies.[147] The problem, as Merrill and Smith observe, is that

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[141] *See* Peter Cramton, Evan Kwerel & John Williams, *Efficient Relocation of Spectrum Incumbents*, 41 J.L. & ECON. 647 (1998).

[142] There would still be costs, especially in the initial switchover to SND-based devices. And some old devices would stop working and have to be replaced. But the process would be far smoother and more efficient than it is today.

[143] *See* MICHAEL HELLER, THE GRIDLOCK ECONOMY 89–99 (2008) (noting that the difficulty involved in coordinating numerous rights holders may defeat socially desirable goals).

[144] *See* Werbach, *supra* note 18, at 866, 874, 928 (noting methods of sharing frequencies, which may be impractical for private entities to administer).

[145] *See supra* notes 46–47 and accompanying text.

[146] *See* Thomas W. Merrill & Henry E. Smith, *What Happened to Property in Law and Economics?*, 111 YALE L.J. 357, 359, 385–88 (2002). Merrill and Smith assert that the in rem character of property has been excessively submerged in contemporary law and economic scholarship. *See id.*

[147] *Id.* at 371; *see* Coase, *supra* note 31, at 25–35; *see also* Werbach, *supra* note 18, at 872–73, 887–91, 939 (expanding on Coase's point).

the complexity and uncertainty of spectrum use rights makes private transactional regimes unworkable or far too limiting.[148] The traditional, inefficient solution is command-and-control regulation. The SND provides a multilateral mechanism to incorporate new spectrum allocation techniques based on commons and property rights.

Adoption of the SND would not be costless. The database infrastructure itself would require funding mechanisms, although there are several endogenous mechanisms, such as device royalties and annual license renewal fees, that could be used. A bigger issue is the cost of new devices. More adaptive wireless devices require more computational power, making them more expensive. Ensuring that devices comply with the SND would certainly add overhead compared with standard issue mobile phones, although the amount would depend on the type of device and the complexity of the database system that is adopted. For spectrum such as the white spaces, where no devices currently are authorized, these costs go into the design of systems to operate there. If the SND is extended to frequencies that are already in use, there would be switching costs if old devices must be replaced. Transition mechanisms, such as using the SND for secondary access initially, could mitigate these costs. Moreover, since users typically replace their mobile phones every few years, SND detection capabilities could be gradually introduced. Further work will be needed to evaluate various potential deployment scenarios.

C. A Note About Governance

The final and perhaps greatest challenge for implementation of an SND is the governance structure. Domain names are the technical axis around which the Internet rotates. It has long been clear that control over domain name allocation was perhaps the closest proxy to a central governance function for the resolutely distributed Internet. The U.S. government, originally through the National Science Foundation, and later through the Department of Commerce and White House staff, exerts limited but explicit oversight over the DNS.[149] Operational decisions generally reside with ICANN, a quasi-public, quasi-international body that has been a locus of controversy since its inception.[150]

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[148] *See* Merrill & Smith, *supra* note 146, at 373–74; *see also* Werbach, *supra* note 18, at 902–03 (elaborating on the difficulty of applying a property regime to spectrum due to the transactional complexities). Merrill and Smith would prefer an in rem emphasis on rights in spectrum itself. *See* Merrill & Smith, *supra* note 146, at 373–74. This, however, is even more problematic because spectrum is simply not a "thing" in the sense of physical property. Werbach, *supra* note 18, at 902.

[149] Werbach, *supra* note 45, at 408.

[150] Froomkin, *supra* note 51, at 102–03; Kesan & Shah, *supra* note 46, at 178–79, 199–200; Jonathan Weinberg, *ICANN and the Problem of Legitimacy*, 50 DUKE L.J. 187, 209–17 (2000).

This Essay is not the place to catalog ICANN's structural flaws and missteps.[151] Suffice it to say that governance for the DNS has not been a smooth process. It is unlikely to be a simple one for spectrum. That being said, many of ICANN's challenges do not apply to the SND. ICANN attempts the impossible challenges of being both public and private, as well as being both global and subject to national laws. It is nominally a technical coordination body, which finds itself engaged in significant policy debates, without sufficient procedural and substantive protections.[152] The proposal in this Essay is for a system squarely subject to national regulatory authority of the United States.[153] The SND is an implementation mechanism for policy decisions made and enforced elsewhere, just like the DNS.

Nonetheless, the implementation of the SND would raise a number of important governance questions. Competition among repositories, registrars, and query services should address the market power concerns that ICANN faced in dealing with a monopoly registry for global top-level domain names.[154] However, there would need to be some public oversight of the system, at least initially. The FCC would need to define basic rules and enforcement mechanisms for operation of repositories, much as it oversees private databases for telephone number portability.[155] The National Telecommunications and Information Administration would also need to be involved to the extent government spectrum is subject to the SND.[156] At the point where repository management becomes purely a technical matter, the government agencies could privatize it.[157]

CONCLUSION

The SND vision adapts the three architectural attributes of the DNS to spectrum.

First, the SND would allow a wireless device to ask the question, "Am I permitted to transmit here, and if so, how?" Today, the answer is hardwired into the device. Even an unlicensed device such as a WiFi node is

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[151] *See generally* Werbach, *supra* note 45, at 357–61, 408 (discussing criticisms of ICANN).

[152] *See* Froomkin, *supra* note 51, at 95–105.

[153] There is no reason the SND model cannot be used in other countries, or for dynamically allocating spectrum across national borders.

[154] *See, e.g.*, Froomkin & Lemley, *supra* note 59, at 56.

[155] *See generally* 47 U.S.C. §§ 150(30), 251(b)(2) (2006) (requiring local number portability); *In re* Telephone Number Portability, First Report and Order and Further Notice of Proposed Rulemaking, 11 F.C.C.R. 8352 (1996) (implementing this requirement).

[156] A mechanism for override in the case of national emergencies or other law enforcement and public safety needs could also be incorporated into the system. This would raise many serious security issues, and other concerns that would need to be addressed.

[157] This would be similar to the way the FCC turned over certification of terminal attachments for the telephone network to a private body after concluding it no longer needed to oversee the process. *See In re* 2000 Biennial Review of Part 68 of the Commission's Rules and Regulations, Report and Order, 15 F.C.C.R. 24,944 (Dec. 21, 2000).

strictly limited in the frequencies, power levels, and protocols it can employ, regardless of its actual local environment. Resolution—the process of matching the physical device with the virtual communications space—is paired with the function of transmission. The DNS breaks this linkage for Internet traffic. Special-purpose infrastructure handles the process of resolving the location of a network address. Sending and receiving information is a separate function, which can employ a wide variety of technical mechanisms for efficient transmission. The SND is similar because it establishes a special-purpose element of wireless communications infrastructure that is distinct from the transmission process itself.

Second, the SND would be a fundamentally distributed system. Wireless devices would query local copies of the database, just as Internet service providers query local domain name caches. Consistency of data would need to be assured, but as the DNS demonstrates, that is not incompatible with multiple redundant copies or competing service providers. For the white space database, the FCC has not yet specified whether there can be multiple registrars or repositories. There is little disagreement on the value of competition between registrars, and allowing for multiple repositories could also have salutary effects. The DNS has suffered because a single entity, NSI, was given control over the registry function for the .com top-level domain.[158]

Third, the SND can be agnostic as to uses. As described above, virtually any policy regime and type of application can be mapped into the database, so long as it is designed with sufficient flexibility and scalability to handle them. Disputes over the boundaries of spectrum rights will not disappear, but they will be separated from disputes over the basic allocation of spectrum.

Creating a DNS for spectrum would generate tremendous benefits. Both wireless communication and Internet addressing are activities requiring conflict resolution. The conflicts in wireless communication are between two or more users who wish to communicate, and the conflicts in Internet addressing are between two or more users who want the same identifier. The ultimate goal, however, is not to resolve the conflicts, but to promote communication and productive activity. What mitigates interference going forward is deployment of smarter devices that can use spectrum in more efficient ways—through both property rights transactions and commons.

The DNS removed the bottleneck of the host table system and allowed for massive growth in the still-decentralized Internet. If the SND could have a small fraction of that success in the spectrum domain, it would be a tremendous boon for economic activity, innovation, and open communication.

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[158] *See* MUELLER, *supra* note 61, at 181–82; Weinberg, *supra* note 150, at 198–99.