Wireless Ad Hoc Networks: Understanding Chaotic Communication Infrastructure

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A. Project Summary

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Is decentralized communication infrastructure a significant alternative to the traditional, centrally driven systems that have historically prevailed? We often think of "infrastructures" as large-scale projects best attempted by large entities: Governments build roads and telecommunications companies provide phones. But historically, rural co-ops built roads as well, and farmers provided their own phones—although sometimes not very good ones. From the perspective of theories about the evolution of sociotechnical systems, law- and rule-making, and social informatics, is it useful, reasonable, or even possible to think about the small, disjointed efforts of co-ops and individuals as "infrastructures"? This study examines this question using the case of "Wireless Ethernet" (a.k.a. 802.11 or "Wi-Fi"), an important new technology. Despite (or perhaps because of) the lack of central planning, Wi-Fi is fast reaching "infrastructure" scale: Almost unknown two years ago, about 26.5 million Wi-Fi capable devices were sold in 2002.

This project proposes a three-year collaboration between the University of Illinois at Urbana-Champaign and Stanford University. The research design is a quantitative, qualitative, multi-level, multi-site, and multi-method investigation of centralizing and decentralizing actors and strategies. Illinois researchers will (i.) map the Wi-Fi "cloud" in a geographic area in a large Midwestern US city, generating two years of over-time data documenting how many of these networks are deployed, by whom, and for what purpose, using survey and unobtrusive traffic measurement. In addition, researchers will employ participant observation and documentary photography to analyze the groups behind decentralized Wi-Fi: (ii.) Free Wireless co-ops and (iii.) "Warchalkers," a subculture that seeks to map, mark, and use Wi-Fi provided by others. This will be done both in the US and, briefly, in London (the birthplace and global center of these cooperative movements). Simultaneously, researchers will follow (iv.) standards debates and software development of the tools that facilitate or restrict different arrangements of Wi-Fi systems. Stanford researchers will conduct case studies of (v.) corporate and campus users of Wi-Fi, and (vi.) national Wi-Fi networks and meta-networks that federate smaller units, using open-ended interview, industry data and research in corporate archives.

<u>Intellectual Merit</u>. The Internet is often cited as an example of a successful decentralized system, but the Internet is decentralized in some ways (routing), and centralized in others (the backbone, the domain name system). Understanding Wi-Fi will help us understand how formalization, provenance, visibility, and circumvention lead to different kinds of order in a system—centralization in some ways but not in others. This uses the case of Wi-Fi to move beyond the realization that rules and technology interpenetrate to elucidate how the two co-evolve in the creation of communication systems. This is to reconsider theories of communication infrastructure development in the light of important new technology, and to build our understanding of Wi-Fi technology specifically.

<u>Broader Impacts</u>. If ad-hoc wireless networking can provide widespread connectivity without a capital-intensive national infrastructure, this has profound practical implications, not least for the spectrum management policies of the FCC. The project is also a collaboration that will cross-train student researchers in law, engineering, and communication. It will pioneer network measurement techniques not previously used in social studies of technology. It also emphasizes nonacademic outreach via joint industry/policy/academic advisors and the use of comprehensible photo essays to enhance public and policymaker understanding of technical phenomena.

C. Project Description

Wireless Ad Hoc Networks: Understanding Chaotic Communication Infrastructure

I. Objectives and Significance

This project examines the nascent development of wireless local area networking, sometimes called "Wi-Fi" (Institute of Electrical and Electronics Engineers, 1999)[1] as a sociotechnical system of communication and as a communication infrastructure. The collection of systematic data about the use and social organization of Wi-Fi can usefully inform our theoretical understandings of communication infrastructure, not least because Wi-Fi offers a set of puzzles that are not easily explained using existing theory. The mixture of centralizing and decentralizing factors in Wi-Fi allow us to pose the central research question: ***Is decentralized communication network development a significant alternative to the traditional, centrally-driven communication systems that have historically prevailed?*** More specific research questions, detailed below, investigate the way that different kinds of formalization contribute to centrifugal and centripetal tendencies in a system's control, and how Wi-Fi compares to past systems. In addition, the close connection between law and technology in the case of Wi-Fi can inform new understandings of technology that rest upon more sophisticated theories of law and rule-making than have previously been employed. Finally, this project will directly contribute to pressing problems from public policy, industry, and engineering practice concerning innovation, electromagnetic spectrum management, and security.

I.1. The Wi-Fi Cloud as a Morphological Puzzle

Wireless data network deployment is currently proceeding along two starkly different paths. The best example of the first, the third-generation mobile phone ("3G"), extends the traditional model prevalent in cellular telephony: providers compete for a limited number of 3G spectrum licenses, invest in a centrally-planned and expensive network infrastructure, and offer voice and data wireless services to subscribers. The second path, exemplified in "Wireless Fidelity" (Wi-Fi), is more novel. Wi-Fi technology uses unlicensed portions of the spectrum, so that anyone can build a network (e.g., in a home, neighborhood, or university campus) for their own use, for sharing or for resale to others. While 3G promises top-down deployment of standardized, ubiquitous, but expensive mobile networks, Wi-Fi may allow the emergence of bottom-up, localized and cheap alternatives. While the costs imposed by the licensing process for 3G effectively prohibit a decentralized evolution, Wi-Fi is more flexible. At the same time that Wi-Fi permits the emergence of bottom-up infrastructure, it can just as easily serve to build top-down, centralized networks.

These Wi-Fi networks take advantage of the 1985 authorization of low-power unlicensed devices under the FCC's part 15 rules.[2] The possibilities of this novel approach to spectrum management have clearly captured many imaginations. Legal scholars suggest this could be the basis for creating an infrastructure for the "digital information commons"

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[1] To be precise we mean the wireless local area networks that operate on 2.4 GHz ISM and 5.7 GHz UNII bands and interoperate using IEEE 802.11 specifications. These are also called "ad-hoc wireless data networks," "wireless Ethernet," "wireless LANs" (WLANs), or referred to by sub-specification number (802.11a, 802.11b, etc.). The term "Wi-Fi" is promoted by an industry consortium as a quality mark; as it is brief and memorable we will use it here.

[2] Part 15 of Title 47 of the Code of Federal Regulations.

(Benkler, 1998). Local activists have embraced Wi-Fi as the solution they had been waiting for to get around the constraints imposed on them by local telephone monopolies. Regulators, taken with the recent commercial success of Wi-Fi, are considering expanding this approach to other parts of the RF spectrum. High-tech companies, from *Intel* to *Cisco* and *Nokia*, are devoting substantial resources to the development of Wi-Fi and its integration into a multitude of products. Network operators, from established *T-Mobile* to start-up *Boingo*, are racing to deploy commercial Wi-Fi networks.

Early Wi-Fi implementation over the past two years has produced a "cloud" of Wi-Fi connectivity in many metropolitan areas. In network design, the concept of a "cloud" is an abstraction for a single network whose internal implementation is irrelevant to the problem at hand. The Wi-Fi cloud is actually composed of heterogeneous networks that interoperate by accident as often as by intent. Centralized and decentralized frameworks coexist and interpenetrate. Formalized systems of rules, such as computer protocols, are built to support anarchists, and grassroots cooperatives affiliate with national corporations. Social movements (after Kling & Iacono, 1995) that arose to take advantage of the Wi-Fi cloud and to develop it create hybrid ecologies that defy existing conceptions of a system.

The entities that now provide the Wi-Fi cloud each produce connectivity for themselves by deploying Wi-Fi. Yet, third parties can also use this connectivity with the intent of the network's owner, through the owner's ignorance, by design, or by security failure. Many alternative forms of Wi-Fi provision are now being tried, and each of these has social and technical implications—in the shake-out between alternatives we can gather valuable data about technologies, rules, and centralization more generally (Arthur, 1994). Of course, an accurate characterization of the morphology of these systems is more complex than the simple centralized/decentralized dichotomy. The Internet is seen as the best example of a successful decentralized system, but the Internet is decentralized in some ways (routing), and centralized in others (the backbone, the domain name system). American culture has long privileged decentralized technology as ideally conducive to freedom and innovation (Marx, 1964). In this project, we do not intend to promote decentralization as necessarily superior, but to consider it and its consequences.

I.2. Toward a theory of communication network evolution

The communication system must move from being the context to the object of research: from "how people behave in the existing system" to "what the system itself will be" (Pool, 1974b, p. 33). As the phrase "sociotechnical system" (from Hughes, 1983) implies, this is not only a matter of technological change, but also of social arrangements and societal institutions. Our approach is to move toward a social science of communication network evolution (after Mansell, 1993).

The beginnings of such an understanding already exist. The strongest existing analyses of information and communication technologies (ICTs) *as systems* are historical analyses: these include radio (Douglas, 1989; McChesney, 1993; Smulyan, 1994), the telephone (Fischer, 1992; Pool, 1983a). These works have enjoyed a great historical distance from their object of study, yet the continuing advent of new technologies demands that as we investigate ICTs of the past we also concurrently investigate new technologies and emergent infrastructures such as Wi-Fi (Parker, 1973). This engagement is required of research when these systems "are more open to renegotiation," at or before their widespread adoption (p. 594). The immediacy of Wi-Fi also provides us with the chance to gather data about new systems that would otherwise be lost.

I.3. Project Goals

The present state of Wi-Fi then provides a unique opportunity to contribute to general knowledge about the development of sociotechnical systems (see III.1.a.). We see the above puzzles as a challenge to develop a new understanding of system transformation that can account for this "accidental" or "disorderly" cloud that seems simultaneously to exhibit the hallmarks of both chaos and a proto-utility, as both centralizing and decentralizing. Our approach analyzes what others have conceived of as "entities" or "groups" instead as overlapping sets and "fields" that work to strategically import and export both rules and indeterminacy (see III.1.b.). Technology acts as one carrier for this process, and law acts as another. While aiming toward theory-building, this work promises insight into previous theories (III.1.a) and will develop practical implications for Wi-Fi and public policy. To summarize, this project seeks to integrate, extend, test, and refine two streams of scholarship:

(1) Theories of communication infrastructure evolution
(2) Theories of law, rule-making, and order as applied to technology

To address these goals, this proposal outlines a 3-year multi-site, multi-level, multi-method collaboration between the University of Illinois at Urbana-Champaign and Stanford University, with the cooperation of Oxford University.

II. Background

II.1. Wi-Fi

In a beautiful metaphor, Alessandro Ovi has called Wi-Fi networks "water lilies."[3] In this metaphor the lily pad is the coverage of the network: the lilies grow independently, but they can eventually cover the surface of a pond (the Wi-Fi cloud). The lily pads overlap and some lilies can stifle others (interference). The stems of most lilies lead to the Internet through a fast corporate Ethernet or a home-office/small-office broadband connection. These Wi-Fi "access points" (or APs) are currently available, easy to configure and inexpensive.[4] The next two subsections define terms that help us to understand how Wi-Fi is both centralizing and decentralizing.

II.1.a. Wi-Fi Networks at Various Levels (Micro / Meso / Macro)

Wi-Fi network development occurs at many levels, each characterized by distinct evolution modalities and resulting in different communication systems. Centralization can be explained by the relations between three levels:[5]

Micro-level. Wi-Fi APs are set up by individuals for their exclusive use or to allow guests. An example might be a homeowner with a cable modem on the first floor and a home office on the second floor who does not want to run wiring to connect them, or a café owner who hopes to attract customers with laptops by providing an AP for free connectivity to a DSL connection. Also at the micro-level are peer-to-peer networks that can form spontaneously whenever two or more Wi-Fi devices are within range of each other: these can be used to share files or printers.

Meso-level. Wi-Fi networks are set up by organizations (e.g. a university campus, a corporate campus, a city, a civic organization, a wireless cooperative). These are explicitly set up to support many users (from dozens to thousands) across more than one AP. These may simply be linked APs,[6] but some meso-level networks use a more complicated "mesh" or peer-to-peer architecture (e.g. *Skypilot*).

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[3] See Negroponte, N. (2002, October). Being Wireless. *Wired 10*(10): http://www.wired.com/wired/archive/10.10/wireless.html.
[4] Although it is harder to configure them securely. At the time of writing, low-end access points were available for about $150, and the card that connects a laptop or desktop to a Wi-Fi access point for about $60.
[5] These are not the levels of analysis for the proposed study, but levels at which Wi-Fi networks exist.
[6] In 802.11 terminology, an extended service set (ESS).

At this level, wireless Community Networks (see Schuler, 1994, 1996) and Open Wireless Cooperatives (co-ops) are especially noteworthy. They have used this unlicensed spectrum to deploy open, free networks for use by any resident of a particular community or visitors. Among the most notable are the *Bay Area Wireless User Group* and *Seattle Wireless*, but many others have emerged around the world.[7]

Macro-level. Some Wi-Fi networks have a broad geographic footprint , or are "meta-networks" enabling sharing across micro- and meso-level networks.[8] One of the early nationwide Wi-Fi providers is *Wayport*, founded in 1995. It currently operates hundreds of Wi-Fi locations around the US, including airports and hotel chains. *Surf and Sip*, a more recent entry, has focused instead on locating its APs in restaurants and cafés. This year, *T-mobile* has begun offering Wi-Fi access in addition to its traditional cellular phone service. These three examples illustrate three different business approaches and economic arrangements to the deployment of macro Wi-Fi networks: the first uses a few agreements with nationwide hotels, the second crafts individual deals with many small business owners, and the third leverages an existing technical organization and antenna sites of its cellular network. Yet another approach, followed by *Boingo* and *iPass*, is to "federate" existing networks by offering centralized sign-up and billing facilities, along with connectivity software and technical assistance.

II.1.b. Affiliation, Nodes, and Density on Wi-Fi Networks

The three concepts *affiliation*, *nodes*, and *density* will help us to understand the ways that portions of the network relate:

Affiliations. A variety of protocols and software packages exist or are currently being developed to allow different kinds of affiliation between the above network levels. For instance, a meso-level provider of Wi-Fi access in a single geographic area can affiliate with a macro-level network to allow all macro-level subscribers access to the geographic network and vice versa. New protocols seek to allow micro-level networks to form and affiliate with meso- level community wireless to provide cooperative access in a single community—all of the micro-level Wi-Fi networks on a single city street can affiliate to provide unified coverage to that street.

Nodes. The nodes of a single Wi-Fi network are users with a Wi-Fi-capable device (such as a card in a laptop). Wi-Fi use ranges from Internet browsing and e-mail for home users, to coordination of medical procedures for EMS workers.[9] Users are simultaneously members of networks at various levels: for example, they can use a home Wi-Fi network while at home, a campus Wi-Fi when at work, a cooperative network while at a café, and a roaming network when traveling. They can manage these memberships themselves by subscribing to several services, or some affiliations can be handled structurally by agreements between the network providers (e.g., between corporate meso-level network and a geographic macro-level network).

Density. Even though Wi-Fi is very new, in some areas (such as the San Francisco Bay Area) the density of Wi-Fi networks is already reaching the point of collapse, partly because a very limited amount of spectrum was assigned by the FCC, so that network success quickly leads to congestion. In this way, limitations on Wi-Fi networks are similar to those of traditional networks. There is, however, an interesting new twist on this history

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[7] See for example one directory of these community networks at http://www.personaltelco.net/index.cgi/WirelessCommunities.

[8] No standards exist for true 802.11 roaming. Roaming solutions are proprietary and any roaming that involves nodes from more than one vendor may not work. Technically, macro-networks provide shared authentication—a user is allowed access from one of many ESSs, but may not move across ESS boundaries in real-time.

[9] This research team is also planning to study the potential of Wi-Fi for education and emergency response (through a relationship with Cal(IT)^2 http://www.calit2.net/).

because Wi-Fi devices can also be configured to relay traffic between other nodes when they are not directly engaged in communication. The total capacity of the resulting *mesh network* actually increases with the number of devices within range – a virtuous cycle of capacity then replaces the vicious cycle of congestion. For such a communication system to operate successfully, technology must be complemented by law: rules are needed to govern the conditions under which third-party nodes relay traffic, covering reliability, privacy, and liability. No workable set of rules for this sort of interaction presently exists.

II.2. An Illustration: Warchalking

We will now consider an engine of decentralization in the area of Wi-Fi. As a consequence of the multifaceted origins of the various Wi-Fi networks, finding connectivity – and contracting for access – can be much more confusing than, say, subscribing to telephone service. On the corporate side, companies like *Boingo* address that need, operating macro-level networks that offer convenience for a price. "Warchalking" is the grass-roots equivalent, a decentralized *Boingo*.

Warchalking began in London on June 24, 2002 with Matt Jones, a former management consultant with the online moniker "Black Belt Jones." Jones noticed that he could obtain free Wi-Fi at several locations around the city when he stumbled upon "open" micro-level networks, and wished that he could share these hard-won discoveries. He designed three symbols that—when marked on buildings with chalk—would indicate that a Wi-Fi AP was near. He posted these on his personal Web site.[10] This received worldwide media coverage within two days and spawned "Warchalkers" in most major cities where Wi-Fi exists.[11] Black Belt Jones was inspired by the diverse lexicon of "hobo signs" prevalent in the depression-era United States (see Figure 1): the Warchalking symbol for a closed node is the same as the hobo sign meaning "nothing to be gained here" (for a review of hobo signs, see Richards & Associates, 1974; Vandertie, 1995). Driving around with an antenna to find wireless networks is analogously called "Wardriving."[12]

Warchalking started in London and remains strongest there, but it is also now global. This activity is intensely social, technical, and legal: the most significant Warchalking occurs not with chalk, but with bits. A number of Warchalkers have developed Web-based geographic information systems using free open-source tools and public map data.[13] These public connectivity directories allow any node to determine the density of APs in a given geographic area, these maps allow micro networks to work as though they are a macro network without any explicit affiliation. This has been surrounded by controversy: governments are considering whether or not unauthorized use of Wi-Fi should be considered theft. Telecom CEOs have made public statements urging the criminalization of Warchalking on the grounds that unauthorized users decrease performance for the network's owners.[14] Activists have responded by developing new software tools that prioritize traffic so that "guests" on a Wi-Fi node will never degrade performance for the owner, and will only be able to share when excess capacity is available. In addition, new

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[10] The verb coined by Jones to mean the activity of finding and marking Wi-Fi access, "Warchalking," is a reference to "war dialer" software used by hackers (neé crackers) to call all of the telephone numbers in a given set of exchanges looking for the handshaking tones of a modem. The name "war dialer" is itself a reference to the 1983 hacker movie *War Games* starring Matthew Broderick.

[11] Hammersley, Ben. (2002, July 4). Warchalking. *The Guardian Online.* http://www.guardian.co.uk/online/story/0,3605,748499,00.html

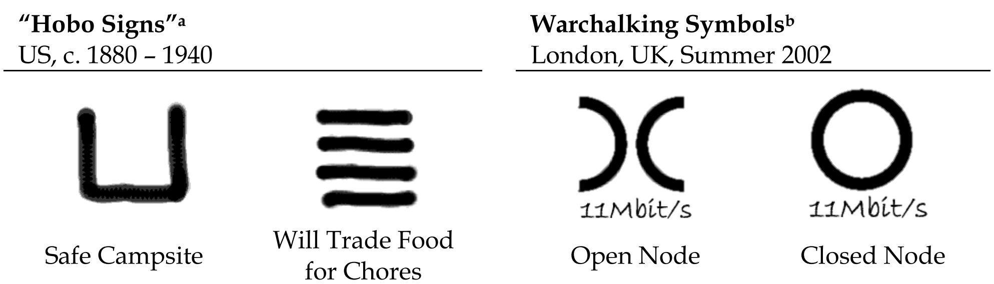
[12] Wardriving predates Warchalking: Jones was likely aware of this as it was received first mention in the UK trade press over a year earlier: Leyden, John. (2001, March 29). War Driving: The Latest Hacker Fad. *The Register*. http://www.theregister.co.uk/content/8/17976.html

[13] See, e.g., NODEDB at www.consume.net, www.wifimaps.com, http://www.netstumbler.com/.

[14] Under a strict reading of US law, these activities would be illegal, but there have been no prosecutions.

software allows micro-level networks to affiliate into a larger macro- system, but from the bottom-up.[15]

FIGURE 1. *Sybmol Comparison*



[a] Adapted from Vandertie (1995) and Richards (1974).
[b] Taken from http://www.Warchalking.org/

In this section we have explained key concepts and features of Wi-Fi and provided examples that may help to explain different routes to centralization. We will next explain our research approach and later return to the features of this illustration as examples.

III. Overall Research Approach

III.1 Theoretical Framework

The overall search for a model for communication infrastructure development is grounded in two literatures: (a) theories of large-scale sociotechnical system development, including communication systems (the telephone, radio, television, and Internet), and (b) process theories of social order, law and rule-making. In addition to our primary research question (see sec. I.), in this section we will develop two subsidiary research questions informed by these streams of research.

III.1.a. Social Shaping and the Study of Large-Scale Sociotechnical Systems

Large-scale systems demand different analytics than other technologies (Hughes, 1987). Hughes' groundbreaking synthesis of the technical, political, economic, and the social in the development of electric systems (Hughes, 1983) advanced a loosely-structured model of four phases: (1) invention and development, (2) transfer across region or society, (3) growth in scale leading to the emergence and solution of critical problems, and then (4) the acquisition of momentum. Hughes was explicitly influenced by early systems theory (Parsons, 1951, 1966, 1971), itself an outgrowth of Wiener's cybernetics (1948). Recent scholarly work explaining the origin of the Internet itself has been institutional (Norberg & O'Neill, 1996), but it has also explicitly adopted an approach to sociotechnical systems influenced by Hughes (Abbate, 1999). Subsequent work in the area of actor-network theory (Madeleine Akrich, 1992; Madeline Akrich & Latour, 1992; Latour, 1992) derived from the sociology of science (Latour, 1987) also addressed large systems but with different conclusions. Callon's examination of the French effort to produce an electric automobile particularly challenges the existence of a phase model and the analytic separation of the technical and the economic (Callon, 1987).[16]

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[15] E.g., the Sonoma County, CA Wi-Fi Cooperative's *NoCatAuth* package (see http://nocat.net/).
[16] We do not mean to conflate actor-network theory (used by Callon) and historical approaches to sociotechnical systems (Hughes), but to indicate that both have been fruitful ways to understand these systems.

Communication Systems. The last 15 years have seen a new vigor in the study of sociotechnical systems *of communication*, especially studies employing historical methods (Streeter, 1996a). Many of these studies were inspired by the social constructivist movement in technology studies (Bijker, Hughes, & Pinch, 1987; Bijker & Law, 1992; for an overview, see Hacking, 1999), sometimes called "social shaping" (Williams & Edge, 1996). The idea that communication (e.g., Silverstone, 1999) or communication technology (e.g., Innis, 1950, 1964) is a privileged site for studying society has been advanced normatively but also empirically. In this project we are particularly concerned with empirical studies that might inform our study of Wi-Fi.

Decentralization. We find some evidence that any given large system is special—each is so different that each requires its own analysis (Fischer, 1985). Some studies link ICTs directly to the centralization of control (Beniger, 1986), but it would be fairer to say that ICTs simultaneously promote centralization and decentralization for different uses: they allow "effective action in many directions" (Pool, 1974a, p. 7). In analyzing the early development of radio, Douglas (1989) refines the concepts of strategy and structure from the history of the corporation (Chandler, 1962, 1977; Noble, 1979). In a parallel to Wi-Fi co-ops and activists, Douglas details how a realistic grassroots challenge to centralization was mounted by amateur enthusiasts and what she terms "the cult of the boy operator" before 1920. Other authors concur that, "by 1914…the largest system of communication by radio in the United States…was an ad hoc, nonprofit network run by…hobbyists" (Streeter, 1996b, p. 65). There are many parallels beyond radio; wireless co-ops are reminiscent of early telephone co-ops (Fischer, 1987a, 1987b) and may be similar to wireline-based community networks that provide Internet service (Rogers, Collins-Jarvis, & Schmitz, 1994; Schmitz, Rogers, Phillips, & Paschal, 1995; Silver, forthcoming), neighborhood projects (Hampton & Wellman, 1999, 2000), and public access centers (Straubhaar, LaPastina, Lentz, Main, & Taylor, 2000). (For a more detailed review, see Harrison & Stephen, 1999; O'Neil, 2002.)

Law and Policy. The historical studies above and others focusing on the political economy of broadcasting (McChesney, 1993) have taken law and public policy to be the profound central factor explaining the form of the system. Other landmark considerations of communication systems also foreground the role of law; e.g., de Sola Pool's work did so within a framework of "soft" technological determinism and liberal optimism (Pool, 1983a, 1983b). While past study of sociotechnical systems have considered law to be a context or a mediating variable, the literature specific to communication systems suggests five grounds for the primary role of the state through law and policy: the compelling state interest (1) in national defense, (2) managing spectrum scarcity (or its perceived scarcity), (3) law enforcement (or state surveillance), (4) democratic participation (or censorship and public opinion management), and (5) economic development (communication technology as a "critical input" for other technologies). Other infrastructures share some of these grounds, but all five are present to some degree in any communication system.

To recap, this literature suggests to us *how* systems come to be centralized, emphasizes that law is key to understanding communication systems, and also offers useful parallels in decentralization movements that arose at the advent of many previous technologies of communication. Our subsidiary research question derived from this literature is then: ***How does the case of Wi-Fi confirm or confound previous understandings of (a) system development, and (b) centralization?***

III.1.b. Centralization and Process Theories of Rule-Making and Order

Much of social science considers technology as at least an extension of the political (Winner, 1980). In some frameworks, society is built from rules inscribed within technology (Latour, 1991), or technology is popularly seen as a substitute for legal rules (Lessig, 1999). A new understanding of the evolution of communication infrastructure is called for in part because our existing understandings do not theoretically elaborate and model this substitution and interpenetration of technology and law, or their relation to centralization.

Law and Technic as Substitutes. In Wi-Fi we find that the important struggles are occurring largely within the class of technical elites (similar to Marvin's analysis of electricity, 1988) that mobilize law and technology as move and countermove. That is, some security standards for wireless are to be implemented in law and others in software protocol. Internet service providers are using subscriber agreements and lawsuits in concert with electronic monitoring and blocking of traffic to manage their networks. Lessig (1999; 2001) recently popularized the idea that technology can function as law—an idea with a longer history. However, while our models of infrastructure development provide us with robust concepts to reason about systems and technics, such as "reverse salients" (Hughes, 1991) and "inscription" (Madeline Akrich & Latour, 1992), they do not provide a generalized vocabulary to reason about law and rules, for good reason. The literature on technological systems *does* consider policy and law, indeed some of its greatest successes have had direct application to them (Morone & Woodhouse, 1989; Perrow, 1999) but there has been no great need to think that law should appear in these except as (1) context, (2) implication, or as (3) a mediating factor. As stated above, we find rules to instead be a central factor, particularly in explaining morphology of communication infrastructures.

Law as Process. We seek to explain centralization and decentralization by modeling the strategic formalization of rules employed by different groups. To do this, we turn to anthropological theories of rule-making and social order, particularly Moore's "Law as Process" (1978).[17] There are many ways in which rule-making has been seen as situated within complex systems (Moore, 1986; Strathern, 1999; Wagner, 1981). In Moore's approach, order is conceived as arising from a large number of overlapping "semi-autonomous social fields:" groupings that can produce shared symbols, rules, and coerce or induce compliance (Moore, 1973). A field could be a corporation, co-op, or Warchalking group. "Rules" include laws but are not restricted to law: while the provenance of the rule is important, all forms of rule are analytically considered, even including binding, yet unwritten understandings.

Regularization and Indeterminacy. Moore's theory of order is a dance with two steps. First, the codification of rules that tends to harden social relations and reduce options, or "regularization." Second, the exploitation and generation of indeterminacy that expands options, or "situational adjustment" (Moore & Myerhoff, 1975, p. 233-235). Power is exercised across fields when a rule is exported or imported from one field to another, and interpreted in the light of existing social relations, as a law about computer crime could be formulated, promulgated, and ignored. Individuals who have the most power are often those who act as connections ("points of articulation") between fields. As written, Moore's theory does not deal with technology; we significantly amend and expand Moore's conception of order to emphasize that these connections may not be humans, but artifacts (Madeline Akrich & Latour, 1992), and that coexstensive and substitutable legal and technical mechanisms for encapsulating (or inscribing) rules suggest that law and technology can be conceived as structurally similar in social relations.

To clarify, let us return briefly to the illustration presented in section II.3. B*oth* the centralized commercial macro-network and a Warchalker's decentralized map seek a high degree of formalization, but in different ways. Some formalization is legal (the proposed criminalization of Warchalking), technical (the development of software protocols that allow co-op affiliation), and social (the practice of Warchalking and the Warchalker's symbolic lexicon). At the same time, some strategies depend upon increasing the indeterminacy in rules produced by others: the warchalkers argue that computer crime statutes can be interpreted to suit them. In this vein, we expect that the details of formalization, provenance,

[17] Moore would not say "rulemakeing" but "reglementation," we prefer rulemaking for simplicity.

visibility, and circumvention of rules will tell us how different areas of the Wi-Fi system are transformed into more or less centralized parts.

In sum, we seek an understanding of communications infrastructure development where both legal and technical concepts (1) shape behavior as cognitive categories and brute coercion, (2) are semi-abstract reflections of social and technological conditions, and (3) are sources of allusion that can be drawn upon strategically to "legitimate or discredit behavior, affect social relationships, and communicate all manner of messages" (Moore, 1978, p. 255). Rules *and* artifacts then both form vocabulary in "a manipulable, value-laden language" (Moore, 1969). Our subsidiary research question within this framework is then: ***How are moves toward centralization shaped, made or unmade using (a) rules and (b) technology?*** (and what are the consequences of these moves?) That is, tandards are one way to export rules, laws are a second, contracts are a third, and social life is lived through the manipulation of powerful cultural symbols related to both of them, such as "criminal," "theft," "open-source," "access," and "freedom."

III.2 Project Structure and Empirical Methods

III.2.a. Project Team and Location

The primary settings for this research will be the Midwestern US, the San Francisco Bay Area, and (briefly) London, UK. The proposed project will be a 3-year effort of the PI at the University of Illinois, in cooperation with the subaward PI at Stanford University with privileged access to relevant data there. The PI will also be cooperating with Oxford University (see supplemental letter) for access to some groups in London.

III.2.b. Sample

This project will employ purposive sampling and supplemental snowball sampling to gather data from five *overlapping sets* (hereafter referred to by number):

(SET 1) Wi-Fi Networks. Researchers will select part of a census tract in a large Midwestern city to sample a Wi-Fi "cloud." The sampled geographic area must (1) contain Wi-Fi activity, (2) contain open nodes provided by a co-op, (3) contain Warchalking, and for purposes of measurement, it must be (4) small enough for a research team to traverse it on foot in a few hours (e.g., a census block group).[18] By sampling geographically, we aim to capture some of the diversity of those deploying APs. In addition to the rationales given above (II.1), we anticipate that some APs will be deployed for reasons we did not foresee.

(SET 2) Open Wireless Cooperatives. Researchers will select one active co-op, ideally within the geographic area of set 1. This must be a volunteer group providing Wi-Fi connectivity to unknown users at no charge. Researchers will also select founding figures from pioneering co-ops in London (e.g., *consume.net*).

(SET 3) Warchalkers. Researchers will select several active Warchalking groups and individuals—that is those who seek to map and mark (with chalk, charcoal, or a database entry) existing Wi-Fi nodes. These will be identified by online "bragging" and contributions to Warchalking databases, and possibly by snowball sampling from the first groups. At least one group should be marking in the geographic area defined by set 1, and at least one group will be active in the London area (the area with the most Warchalking activity). The founding and influential figures of the Warchalking movement will also be selected.

(SET 4) Software. Wi-Fi communication is made possible by a number of software packages and standards: several of these will be under development during the time period of this project. Researchers will sample software that is being used in the above sets, or standards and protocols to which actors in set 2 and set 3 seek to contribute. An example

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[18] Chicago, IL; Indianapolis, IN; and St. Louis, MO are possible candidates. Each city is has a population of over one million residents, matches the criteria of set 1, and is reachable from the research institution.

might be the *NoCatAuth* authentication package that allows a Wi-Fi access point purchased for a home or apartment network (set 1) to affiliate with a co-op (set 2), developed cooperatively by a community wireless network in Sonoma, CA.

(SET 5) Corporate/Campus Networks. The researchers will select a small number (we anticipate from 2-4) of meso-level Wi-Fi networks in the San Francisco Bay Area and conduct open-ended interview and analysis of corporate archives. [19] As we wish to secure some access to key figures and internal corporate and university archives, the primary sampling criterion will be access. This will be coordinated from Stanford University.

(SET 6) Commercial (nationwide) networks. Researchers will use industry data, analyst reports and interviews with representatives of the commercial Wi-Fi networks to assess the spread of commercial Wi-Fi coverage in the US. This is essential to contrast top-down deployment of the infrastructure with the grass-roots alternative. In particular, we will seek to analyze the ways in which commercial and community networks simultaneously compete and cooperate.[20] This will also be coordinated from Stanford University.

Supplements. Other sets of data will be employed as the project evolves. Although it is not systematically gathered, the Warchalker's databases that are the focus of set 2 and set 3 produce data that are extensions and comparisons to our set 1 data. In addition, the project will be flexible enough to add small datasets opportunistically: For example, preliminary research with set 2 will likely indicate that there are just a few electronic fora in the world used by community wireless activists and Warchalkers from different areas to exchange strategies.[21] These may be subject to content analysis or as a source of further interviews.

Let us emphasize again that these are overlapping sets: some Warchalkers (set 3) are also open wireless activists (set 2) and work for a corporation that employs Wi-Fi, using common software (set 4) in each of these contexts and potentially affiliating with a nationwide network (set 6). Additionally, the Warchalking, open wireless nodes, and corporation just mentioned might all be within the geographic area defined by set 1.

Finally, we note that the above multi-level multi-site sampling strategy structured around overlapping sets, fields, and potential supplements is intended to serve a research design that is well-specified, yet still flexible enough (in the spirit of theoretical sampling: Glaser & Strauss, 1967) to allow researchers to follow the data relevant to the theoretical base (III.1., above). This is also an attempt to acknowledge the nuances of this context. Readers may note our intentional omission of familiar groupings like "users" and "producers." Miller, Slater, & Suchman (forthcoming) demonstrate that the evidence gleaned from ethnographic user/producer studies of ICTs to date indicates that the separation of consumption from provision, production, and access is a serious error: these are practices and relations ("use," "production"), not groups ("user," "producer").

III.2.c. Procedures, Instrumentation, and Analysis

As each sample will be approached in a distinct setting and using multiple methods, the relationship between samples and methods is detailed in Table 1.

Measuring the Cloud. During Year 1, Quarter 1, to test instrumentation and procedures researchers will construct and operate a single experimental community wireless AP at the University of Illinois as a co-op (set 2) would. The AP will be located either at the

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[19] Note that the subcontractor at Stanford has established access to set four through past research, and that the San Francisco Bay Area is the headquarters for most of the commercial national networks and a large number of leading corporate networks.

[20] The subcontractor has already established access to this data through past research.

[21] The channel #wireless on the Freenode internet relay chat network for open source developers is often referred to on Web pages as one such forum.

PACT laboratory (see p. H-1) or in cooperation with existing community groups.[22] This gives the researchers practice in the techniques of actors from all sets.

Researchers will then apply a refined version of a Warchalker's method to the cloud in the sampled neighborhood. Existing maps provided by Warchalkers will also be consulted, but we will undertake our own monthly sampling of the cloud for three reasons: to obtain (1) **over-time** data, (2) **more systematic** data collection, and (3) **additional variables**. Teams of two researchers will use inexpensive palmtop computers as a sampling platform (p. H-1) modeled on what is used by Warchalkers.[23]

TABLE 1. *Overview of Samples and Methods*

University of Illinois at Urbana-Champaign:[a]

Overlapping Set	*Setting*	*Units of Analysis*[b]	*Methods*
1. Wi-Fi Networks	The Wi-Fi "Cloud" in a defined Midwestern Urban Neighborhood	Access Point, Oganization *(Micro-, Meso-, Macro-)*	Network Measurement, Survey
2. Co-ops	Cloud and nearby	Activist Group[c] *(Meso-)*	Participant observ., Interview
3. Warchalkers	London (influential figures), Cloud and nearby	Group,[c] Individual *(Micro- or none)*	Participant observ., Interview
4. Software	Public documents, Internet	Debate *(Micro-, Meso, Macro-)*	Discourse Analysis, Content Analysis

Stanford University:[a]

Overlapping Set	*Setting*	*Units of Analysis*[b]	*Methods*
5. Corporate/ Campus Networks	Commercial, for-fee centrally planned network deployment	Topography/ strategy *(Meso-)*	Case study, Interview, Archival Research
6. Commercial Nationwide Networks	Commercial, for-fee centrally planned network deployment	Business model, Topography/ strategy *(Macro-)*	Case study, Industry data, Interview

[a] Institution with primary responsibility.
[b] The Network level(s) to be encountered are listed in parentheses.
[c] More formally, we will consider these as semi-autonomous social fields (Moore, 1973).

The output from existing Warchalker databases (see samples, below) triangulates the source of each Wi-Fi AP using GPS, records an identifier (SSID), and measures signal strength to estimate the AP's coverage. We will develop software tools to measure additional variables, such as: (a) the presence or absence of some of the software in set 4, (b) the presence or absence of some forms of encryption, and/or (c) the amount of traffic on the network. We will also consult existing public data sources (Census data, municipal data,

[22] The area around the university contains a more traditional community network (PrairieNet) as well as an independent community media center and a "open" wireless activist group (formerly the Champaign-Urbana Grassroots Wireless Internet Project, or CUGWIP, now shortened to CU-W).
[23] Warchalkers and wardrivers use (more expensive) laptops.

USGS aerial maps) for the selected neighborhood. This combination of methods is intended to creatively and unobtrusively gather behavioral data relevant to Wi-Fi (informed by Webb, Campbell, Schwartz, & Sechrest, 2000). We hope to understand how the different nodes interfere with or reinforce each other in a small setting, and to observe the adoption (or failure) of security protocols and new standards studied as part of set 4. The cloud will be sampled from Year 1, Q1 to Year 3, Q1.

Ethnography of Activists and Warchalkers. Set 2 and 3 will be approached via participant observation and open-ended interview. In the first summer of year 1, the PI will travel to interview and, if possible, conduct participant observation with prominent Warchalkers (e.g., Black Belt Jones) and the co-op community in London: the "founding figures" of Warchalking. Recall that other participants will be contacted near the cloud (Year 1, Q3 to Year 2, Q4).

Ethnographic methods were chosen for the rich qualitative data that will allow us to develop an understanding of each person's participation in many overlapping semi-autonomous social fields. Qualitative work will be subjected to rigorous evaluation criteria (Altheide & Johnson, 1994; Lincoln, 1995) and considered in concert with successful methods previously applied to community networks (O'Neil, 2002) and similar "community media" (Jankowski, 1991). Some portions of observation and interview will be recorded and some practices of these groups will be photographed with the assistance of a professional documentary photographer (see p. F-1 to F-3, consultant justification). We recognize that some groups will not be amenable to participant observation and we will use open-ended interview as a fallback method in this case.

Survey of Wi-Fi Providers. During year 3 (Q1) a survey instrument will be designed and mailed to each of the providers in set 1.[24] As we take a grounded approach to this project (Glaser & Strauss, 1967)—we hope to construct a refined theoretical understanding informed by past theories of sociotechnical system evolution, process theories of law, and social informatics, and then to use the survey instrument to gather systematic quantitative data and refine this theory. We anticipate questions will focus on the *practicalities* surrounding the deployment of the access point, as other methods in the project are better-suited to address *motivation*.

Tracking the Commercial Providers. Throughout the project's first two years, in parallel with our efforts to document and analyze the development of grass-roots networks, we will chart the evolution of commercial Wi-Fi network offerings at the macro- and meso-level (set 5 and 6), as described in Table 1, employing an evolving case study design (Yin, 1994). Note that the timeline expressed above reserves three quarters of Year 3 for follow-up, analysis, and write-up, also leaving a buffer in case schedules slip.

III.2.d. Use-Case Scenario: Zhrodague

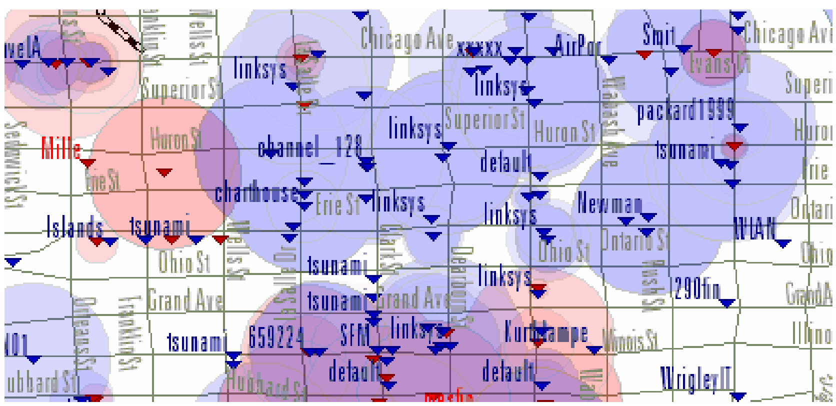
To illustrate the above methods, let us consider a single group within this data collection.[25] Zhrodague is Pittsburgh, PA group of computer programmers, self-defined as "a collection of computing facilities and the admins who wield them."[26] The Zhrodague group encompasses a *Quake* clan, an Internet-only TV channel, and works together on a variety of open source projects. Figure 2 depicts output from one of these, the Zhrodague Mapserver – Zhrodague employed open source mapserver software and census data generated by a University of Minnesota project (funded by NASA), then repurposed these to

[24] If it is difficult or too invasive to determine the owners of the Wi-Fi nodes, a survey may be mailed to every household and business in the sample area, as the geographic area will be small.
[25] This case is not hypothetical, but because Zhrodague is in Pittsburgh, it would not be sampled in this study.
[26] See http://www.zhrodague.net/.

map Wi-Fi.[27] Some members of Zhrodague also work for the Pittsburgh Wireless Community (*pghwireless*) a co-op which raises money to install $200 mail-order computers ("Wal-Mart Specials") in participating businesses to provide an open wireless cloud.[28] During the day, the members of Zhrodague work as computer consultants for businesses.[29] At least one member of Zhrodague installs the same Wi-Fi networks during the day as a consultant that he maps at night as a Warchalker and competes with as a co-op activist.

Our methods would track *pghwireless's* network and nearby alternatives over 2 years, compare data with the Zhrodague mapserver, participant-observe Zhrodague and *pghwireless*, survey *pghwireless*, Zhrodague, and other providers of Wi-Fi nodes in the sample area, produce a case study of a national "meta" network that *pghwireless* affiliates with, and this macro-network's centralized competitors. While Zhrodague is a grassroots effort, the literature reviewed above suggests that they are highly organized, using rules in software to export their brand of organization, and to produce indeterminacy surrounding rules made in law and competing models of social relations. Fine-grained multi-method analyses like this one will allow us to build a very detailed understanding of decentralizing tendencies, amateur movements, and their ultimate viability and significance.

FIGURE 2. *Sample Output From a Warchalking Database*



Chicago, IL (from Zhrodague Mapserver) ▼ = access point

III.2.e. Protection of Human Subjects

We are well aware of the sensitive nature of projects that involve even the *perception* of criminal behavior (Warchalking, hacking) and we will take every measure to protect our participants. Of equal concern is the perception that researchers measuring the Wi-Fi cloud in set 1 are eavesdropping. We emphasize that our method does *not* involve collection of the contents of Wi-Fi traffic: it is akin to mapping telephone poles, not tapping telephone lines.[30] Procedures will be established to insure that all researchers are properly briefed and sensitized to these ethical concerns: they will be trained particularly in answering questions about the nature of the measurement and in handling confidential materials.

[27] The mapserver is a very prominent one—it contains over 100,000 nodes and receives submissions from Warchalkers far beyond Pittsburgh: e.g., the screen shown is not for Pittsburgh, but for Chicago.
[28] See http://www.pghwireless.com/.
[29] e.g., one resume boasts a specialty of "securing Wi-Fi networks."
[30] IRB approval for this project is pending.

IV. Dissemination and Impact of the Proposed Research

Given the potential broad relevance of this project in both practical and theoretical terms, every effort will be made for the results to be distributed via relevant scholarly journals such as the *Journal of Communication, Communications of the ACM, Telecommunications Policy*, *Journal of Law and Society,* and *Technology and Culture*.

IV.1. Contributions to Fundamental Knowledge

We hope to contribute a new model which better integrates rule-making and technology-building in the development of communication systems and can be used to explain the evolution of systems of communication in the future, particularly elaborating and theorizing the relationship between technology and law, and the role of both in centralization and morphology. Recall our central question (from sec. I): *Is decentralized communication network development a significant alternative to the traditional, centrally-driven communication systems that have historically prevailed?*

The early history of the Internet suggests that the decentralization is very significant (Hart, Bar, & Reed, 1992), and this study of Wi-Fi promises a better understanding of the mechanisms that support and restrict a decentralized topography and institutional structure. Even if over the course of the three years co-ops prove not to be viable, Warchalking disappears, and small Wi-Fi providers all go bankrupt, still the path from the current order to centralized momentum or stability can yield valuable insights, including contributions to the literatures reviewed above, such as the appropriateness of stage-models, the ideological underpinnings of technology activism, and the societal consequences of new ICTs.

IV.2. Contributions to Practical Applications

The specialists who develop the software and standards in the area of Wi-Fi (and in ICTs more generally) are in need of more practical tools to understand and integrate social norms and technology development, particularly in the area of order and rule-making. In the area of Internet infrastructure development, Blumenthal and Clark have explicitly called for a greater reliance on social and legal mechanisms for organizing networks, and highlighted the need for research toward them (2001). In addition, in the relevant industry sectors (equipment design and manufacture as well as service provision), the business models and marketing strategies for Wi-Fi are very much still open questions that this project could begin to close.

IV.3. Contributions to Education and Human Resources

As it involves a grounded, reflexive research design and an involved data collection, this project entails a close collaboration between faculty and students of all levels. We take seriously the challenge to integrate research in the educational environment, and have explicitly planned an active role for graduate and undergraduate researchers (see section F). The project will require involvement from students with experience in computer science, communication, and law; this then enacts (and demonstrates the value of) cross-disciplinary training. The project promotes a "new breed" of graduate student that can think across this disciplinary triad.

IV.4. Contributions to Public Policy

In the short-term, many regulatory decisions relevant to Wi-Fi that would be informed by our results will be made during the time span of this project. Much more exciting, however, are the long-term contributions to public policy. In the domain of innovation, Part 15 of the FCC rules is itself an 18-year experiment in communication infrastructure development—802.11 networks were the result of this regulatory experiment, as was Metricom Ricochet and some species of garage door opener. Our results would provide valuable evidence that speaks to this policy, when combined with data on other infrastructure attempts (including failures, e.g., Cherry, 2002).[31] In the domain of policymaking, our hoped-for findings about rule-making and the evolution of communication systems should be of significant utility to policymakers and industry bodies that wish to understand the evolution of new communication infrastructures. If decentralized infrastructures (like a co-op's hopes for Wi-Fi) are viable as "disorderly utilities," or "chaotic infrastructures" this suggests a very different approach to technology policy involving an emphasis on training "users" to produce their own systems, coupled with strong mandated interconnection. If they are not, this suggests a reconsideration of the legal mechanisms controlling entry into new regulated ICT markets.

V. Resources and Qualifications

V.1. Christian Sandvig (PI)

This project logically extends the PI's existing work that investigates the interplay between social, technical and legal mechanisms of control in the development of new computer and communication technology, approached by combining theoretical approaches from communication, computing, and law. This project continues the broad inquiry that begun in the PI's dissertation (Sandvig, 2002) and is related to other work on public policy and the accommodation of new ICTs (Bar & Sandvig, 2000; Sandvig, 2001, forthcoming).

The PI's background includes communication, law, and computing. Before entering graduate school, the PI worked as a computer programmer and continues to work as a consultant in software engineering. He holds a Ph.D. and M.A. in Communication from Stanford University, specializing in Communication Technology and Policy, where he taught in the Public Policy Program; the Science, Technology, and Society Program; and the Communication Department. After receipt of the Ph.D. (2002), Sandvig was a Markle Foundation Information Policy Fellow at Oxford University. In addition, in August Sandvig served as a Visiting Fellow of the Oxford Internet Institute, where he proposes to return to complete some of the fieldwork for this project (see attached letter).

V.2. François Bar (Subaward PI)

Francois Bar is Assistant Professor of Communication at Stanford University. This project is an extension of Bar's research on the economic, strategic and social dimensions of computer networking (Bar, 1990, 1995; Bar, Borrus, & Steinberg, 1995; Bar et al., 2000; Bar & Riis, 2000). The subaward PI's experience spans engineering, planning, communication and public policy. He received the Ph.D. in city and regional planning from University of California at Berkeley (1990), has studied at Harvard's J. F. Kennedy School of Government and he holds a Diplome d'Ingenieur from the Ecole Nationale des Ponts et Chausees (ENPC), Paris, France.

V.3. Advisory Committee

A three-member senior academic/industry advisory committee has been formed to vet the implementation of the research design and offer general guidance via electronic means. Each member listed is familiar with the proposal and has agreed to participate.

Monroe E. Price is Danciger Professor of Law at the Cardozo School of Law, Yeshiva University where he also directs the Squadron Program in Law, Media, and Society. Price is a past member of the School of Social Science at the Institute for Advanced Study in Princeton, and former Dean at Cardozo. His most recent book is Media and Sovereignty

[31] This is really both a short-term and a long-term issue: recent statements in the popular press by the FCC Chairman indicate the intent to move toward further use of unlicensed spectrum where possible (Lemann, 2002).

(MIT Press, 2002). **Barbara Simons** is founder and co-chair of the Association for Computing Machinery (ACM) US public policy committee, and a fellow of both the ACM and the American Association for the Advancement of Science. Simons holds the PhD in Computer Science from the University of California, Berkeley and is a past president of the ACM. **David T. Witkowski** is Director, Worldwide Applications Engineering at Xpedion Design Systems in Santa Clara, CA. Witkowski holds a BSEE (RF/Wireless) from the University Of California, Davis. His experience in radio spans 25 years; and includes systems based on various IEEE 802 standards including Ethernet, Token-Ring, and 802.11/802.11b (Wi-Fi).

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