THE RED PROJECT
(rendering electromagnetic distributions)

The term "**electromagnetic spectrum**" refers to radiation in the range of frequencies between cosmic rays and radio. While this may sound off-putting to those without a background in physics or radio frequency engineering, the noun "spectrum" simply indicates a range, as the phrase "the political spectrum" is sometimes used to indicate a range of ideas. The spectrum used for communication is the range of electromagnetic radiation--the stuff that the familiar antennas of our cellular telephones and televisions are designed to send or receive. The concept of "the political spectrum" is a range organized by opinion (the "left" and "right" of this spectrum refers to historical seating arrangements in the French National Assembly). The electromagnetic spectrum is a range organized by frequency and wavelength--in other words, organized by the length of the wave (as in *wave*length, short*wave*, micro*wave* etc.).

The subset of these frequencies that can now be used for wireless communication is sometimes called "the radio spectrum" or "**the useful spectrum**." Consumer devices that use the spectrum have lately proliferated, including television receivers, garage door openers, baby monitors, video game controllers, wireless Internet routers, wireless headsets, and more. This proliferation is a marked transformation in the political control of the spectrum and the conceptualization of it among policymakers and technologists, with potentially large public consequences.

Any hint of broad changes in the use and concept of the spectrum is significant for society because regulation of the spectrum is the primary means by which governments exert control over a broad swath of human communication. For the last eighty years, ideas about spectrum scarcity have formed the foundation of legal reasoning about communication. The **idea that the spectrum is scarce** and users need advance permission to use it can be found justifying rules governing which words cannot be used on television, rules that say that cellular telephones must be able to track your location, and rules that specify that your landlord must allow you to put up a satellite TV dish, even if it is ugly. In short, some conceptualization of spectrum is a necessary condition for most of our reasoning about who can communicate electronically and how they should do so.

Your Own Radio Station?

Twenty years ago, the Federal Communications Commission of the United States embarked on an experiment where three small slices of "junk" (poorly penetrating) frequencies were allowed to be used **without getting anyone's permission** first. This was a radical idea, but consumer electronics manufacturers had argued that very low power transmitters could be combined with new spread spectrum technology to give protection enough from interfering signals, and they hoped to sell short range consumer devices like cordless phone handsets. While everyone can't have their own television station because frequencies are scarce, everyone might be able to have their own cordless phone if the transmission power is low enough. These are called "license-exempt" bands, "open," or "**unlicensed spectrum**."

Over the next two decades, the use of these unlicensed bands increased to support a diverse array of devices, including today's most popular wireless networking standard, "Wi-Fi." In 2002, unlicensed systems were so pervasive and commercially successful that some policymakers called broadly for **spectrum allocation reform** and the expansion of unlicensed bands, with Wi-Fi the exemplary successful application.[1] This is sometimes called "open spectrum." You could rephrase the above as, "Wi-Fi is an existence proof for the validity of the open spectrum argument".[2]

Advances in wireless technology, the present market success of Wi-Fi, and the allure of any policy proposal that sounds like "deregulation" have all combined to convince many people that unlicensed spectrum--spectrum that does not require permission to transmit--is now a viable way to manage a much larger amount of society's communication. However, by definition the use of unlicensed spectrum is **unplanned and decentralized**. Public policy statements and the scientific literature to date have characterized unlicensed as "messy" [3] and unpredictable, even when supporting it as an idea. If anyone can transmit without a license, this reasoning goes, how can we avoid crippling interference between transmitters? If we can't budget in advance for who will use what channel, how can we know if the scarce channels will be full or empty? Eventually, if anyone can turn on their own transmitter without permission, won't some locations become "congested" leading to the failure of communications?

This project hypothesizes the opposite of this reasoning: that ***unlicensed spectrum is very predictable***. We set out to find a way to guess in advance whether unlicensed spectrum would be used or not. Specifically, there has already been extensive social scientific research on the use of new technologies in society (sometimes called "the diffusion of innovations").[4] This past research already provides a way to guess which people will want which new technology. While this sort of thinking has often been used for marketing, in this project we use the current case of Wi-Fi as a way to analyze the

viability of unlicensed, decentralized communication systems in the field. In other words, in a situation where you don't need advance permission, is it possible to guess who will communicate using a particular technology?

Wi-Fi as a Test Case

Wi-Fi is a technology that allows computers to communicate without wires at high speeds over short distances. At a technology conference in late 1999, Steve Jobs introduced the Apple AirPort, the first Wi-Fi access point (AP). Jobs promised users, "it's a liberating experience to surf the Internet...while freely moving about your home or classroom." Users, however, have had other ideas about where they wanted to freely move. In the last few years the technology behind the AirPort and similar devices has become **very popular**.

Initially conceived as a technology to solve small networking problems in the home, it and its successors (e.g., WiMax) have instead become a contender for **the next generation of Internet infrastructure**.[5] Wi-Fi has even been deployed as a city and county-wide communication system.[6] In 2004 between 44 and 99 million users around the world spent $2.4 billion to use some of the over 2000 different kinds of devices that use Wi-Fi.[7]

In a beautiful metaphor, Alessandro Ovi has called Wi-Fi networks "**water lilies**".[8] 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.

While the story of Wi-Fi may ostensibly seem to be only about very short range communication, researchers have also seen it as a **bellwether for more extensive networks**--a decentralized, short range beginning to what could become a network with longer links [9] possibly through advanced routing and cooperation rather than improvements in range for individual transmitters.[10]

Guessing Wi-Fi Use in Advance

The Census divides the US into tracts. Tract group boundaries follow visible and identifiable landscape features such as roads, railroad tracks, rivers, or coastlines,

therefore we can readily identify them in the landscape with a key from the Census. Census tracts are defined by population and can vary dramatically in size. In this project, **researchers traveled to a number of neighborhoods** in Illinois and California repeatedly over a period of four years, measuring the number of Wi-Fi networks at every public place in each neighborhood during each visit. This is conceptually similar to what happens when any laptop user with a wireless card opens a laptop to see if wireless networks are present, in that we examine public information.

We then used the demographic information from the US Census to develop a model that would statistically predict the density of Wi-Fi networks using demographics. This is **our method for "guessing" (predicting) wireless distributions**. To test it, next we compared our ability to predict networks to places that we did not initially measure. (We found that it worked well.) We also downloaded public Wi-Fi datasets from WiGLE and wifimaps.com and compared our measurements to theirs. In our tests, our predictions have explained from 84-91% of the variance in Wi-Fi network density.

Finally, for this Web site we assembled a database containing the Census demographics for the entire US. When a user of the RED project enters an address, our software retrieves the demographics from the database and makes a prediction. This is then presented as a red overlay on top of Yahoo! Maps for that address. We initially predicted Wi-Fi network density using **race, age, income, educational attainment, and population density**. (We continue to refine our methods for predicting the distribution of Wi-Fi.)

Unlike an academic research paper on this topic in a traditional journal (see further reading), this Web application allows users to use Yahoo! Maps to visualize and "fly around" our statistical predictions. Statistical models with many variables can be very difficult to conceptualize mentally. By examining our predictions about Wi-Fi using a place that you know, we hope you'll be interested in the same questions we have been asking. **Is it possible to predict communications (or spectrum use) in advance?** Is it necessary to restrict communication to only a few people who have obtained licenses? What kind of people use Wi-Fi? Will the spectrum allocated for unlicensed devices "fill up" anytime soon? How much do we need?

Map

Figure 1 presents the main interface to the map, and the Web-based application's home page.

Figure 1. Initial interface to The RED Project mapserver.

Tour

We suggest using The RED Project map to examine places that you know. In this tour, we will describe some of the places that we visited for this research project, and our reactions to the predictions of wireless communication there. From this section, you can visit the electromagnetic spectrum of five neighborhoods in the United States.

Stop 1. Lake View, Chicago

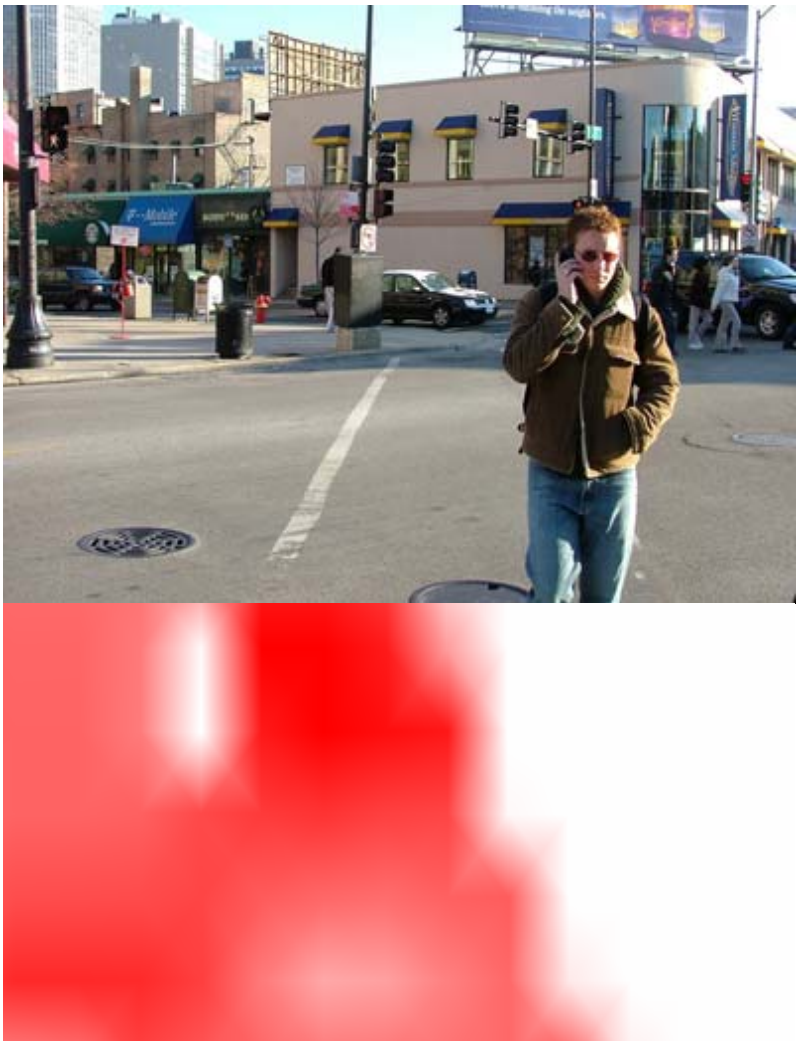

Figure 2. A photograph of Lake View and the corresponding output from The RED Project wireless visualization. (Photo Credit: Hope Hall)

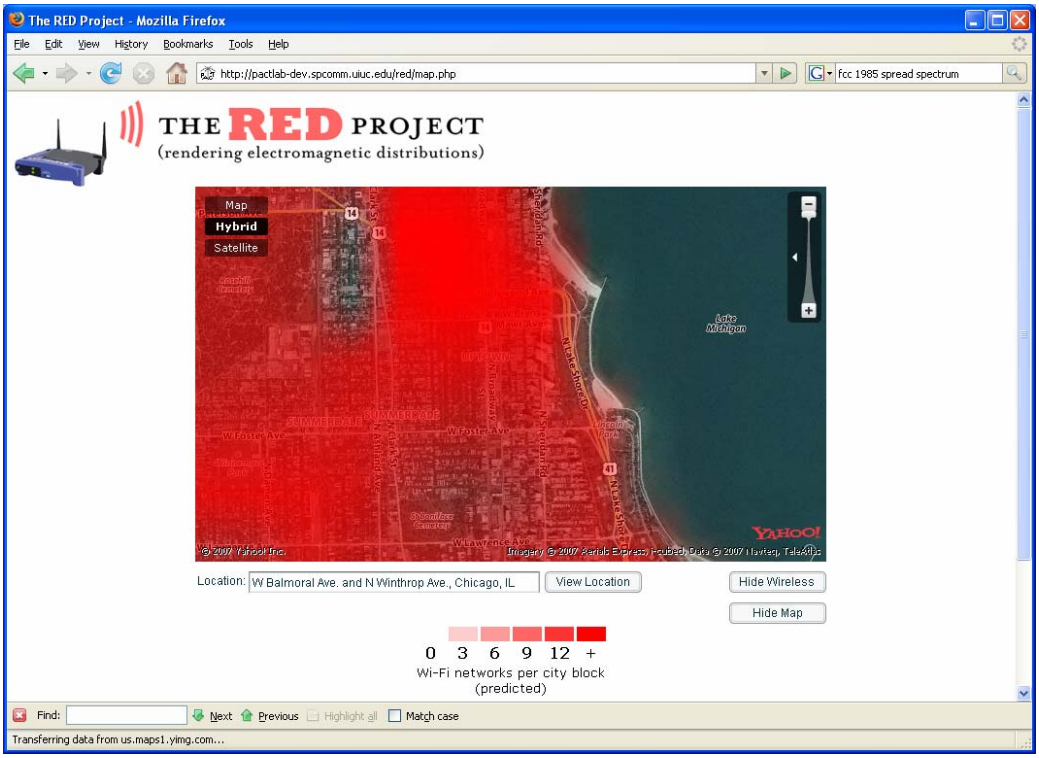

Figure 3. Lake View rendered inside The RED Project's visualization interface.

The first stop is in the Chicago neighborhood of Lake View. This area is home to a number of well-known high-end retail franchises and luxury apartments and condominiums. The 2000 Census tells us that Lake View is the Chicago Community Area (a historical demographic boundary) where those employed in the profession "Information Technology and Management" are most likely to live. As might be expected, Lake View contains the highest density of Wi-Fi that we measured in this research project. However, the brightest spot of red on the map is directly adjacent to an area with no red at all -- one of the lowest predicted densities of wireless (East of Rosehill Cemetary). The residents of the Census tract we visited reported themselves to be 86% white in 2000. The tract had low unemployment (2%) with a per capita income of $54,280. The median age was 35. Almost all residents (95%) had a high school diploma. Despite the affluence and education in this area, notice the high degree of variation in the amount of wireless communication that is predicted here. Even though it seems obvious that people with more money will have more advanced technology (like Wi-Fi), a single factor like affluence doesn't do a good job of predicting wireless use in this affluent neighborhood.

Stop 2. Devon Avenue, Chicago

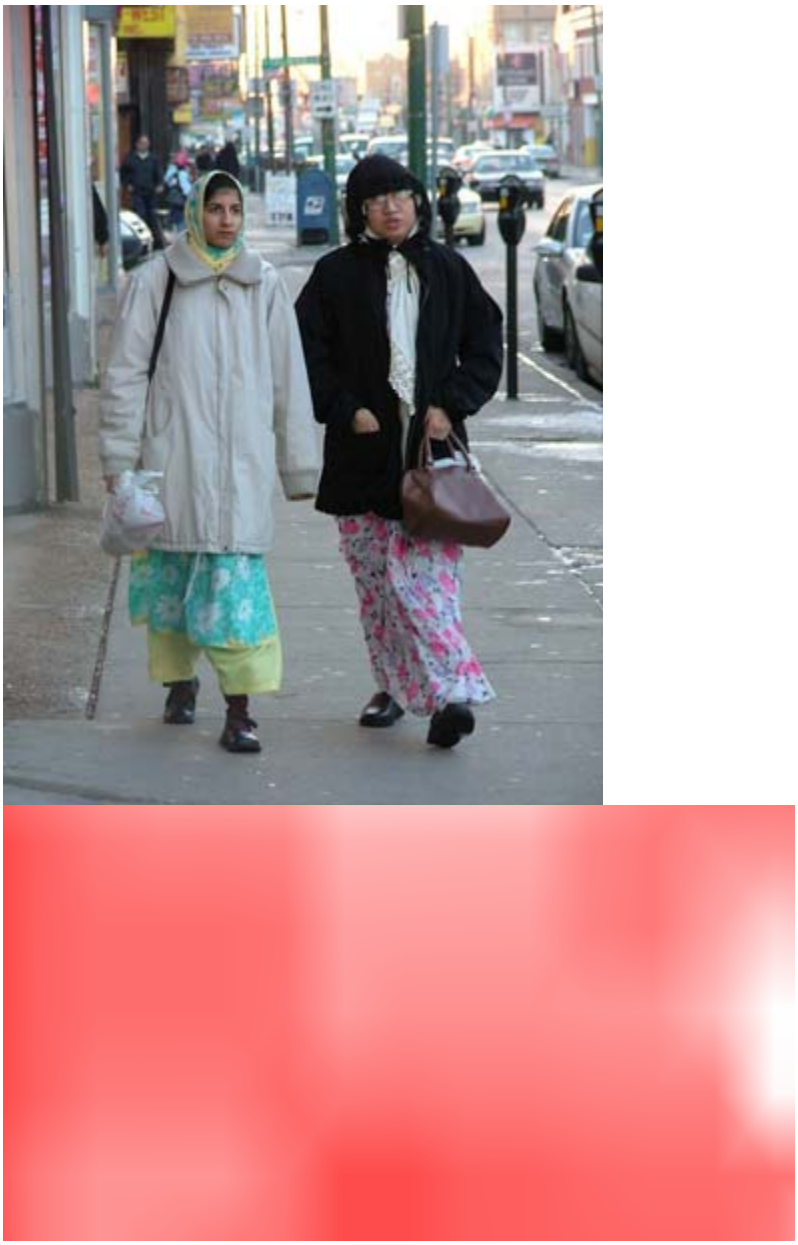

Figure 4. A photograph of Devon Avenue and the corresponding output from The RED Project wireless visualization. (Photo Credit: Hope Hall)

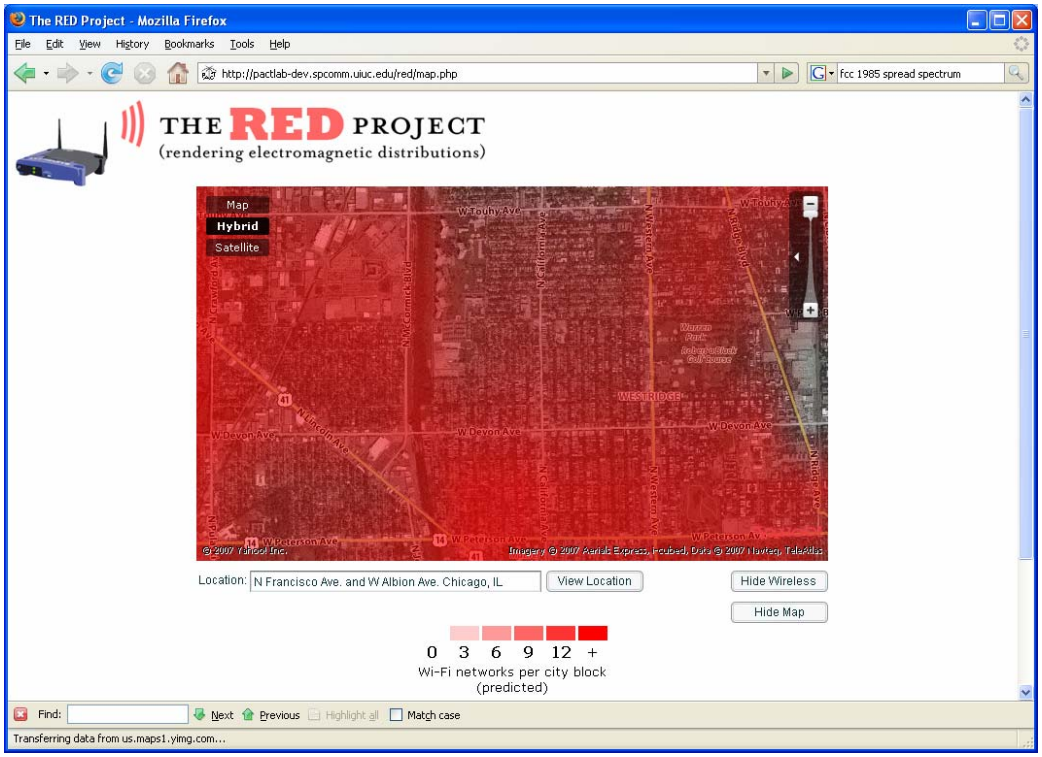

Figure 5. Devon Avenue rendered inside The RED Project's visualization interface.

The second stop on our tour is formally named "West Ridge," but this area of Chicago is best locally known as "Devon Avenue" after its thriving multicultural commercial district. (Devon Avenue is also signposted as three other names: Gandhi Marg, Mohammed Ali Jinnah Way, and Golda Meier Blvd.) 64% of the people in the Census tract we visited identified themselves as white in 2000. Unemployment was low (4%), 80% of residents said they had a high school diploma. The per-capita income was just one-third of our last stop, at $17,573, and the median age is 33. Despite the drop in income, we found a large amount of Wi-Fi use here. The word "immigrant" isn't usually popularly linked with high technology. The portion of this neighborhood that we visited was reported to be 42% immigrants in 2000, mainly from South Asia. Do the lighter red spots on the map represent concentrations of immigrants? This seems unlikely. Other researchers have found that immigrants from some South Asian countries are far more likely to use high technology than Americans with similar incomes. Aside from its South Asian population, this area also contains the largest Hasidic community in the Midwestern United States, and was historically called the "Golden Ghetto" after the immigration of East European Jews. Orthodox Jewish sects often ban television and are

deeply ambivalent about the Internet, sometimes allowing it only if it is necessary for work.

Stop 3. West Humboldt Park, Chicago

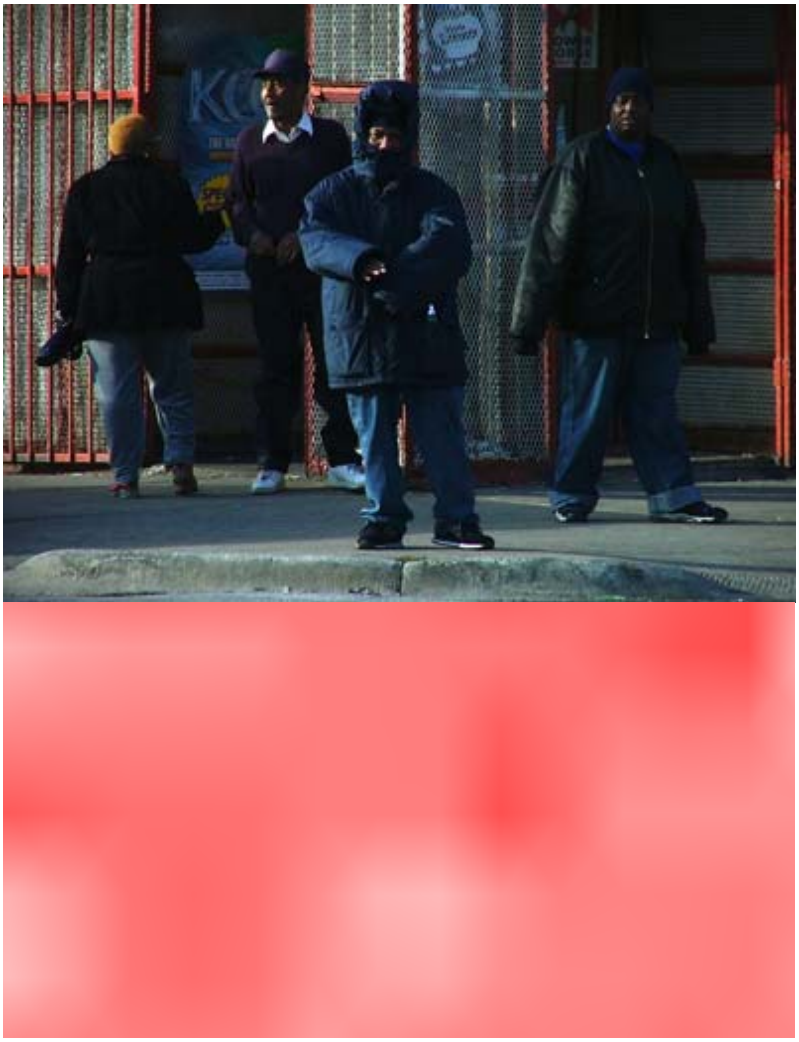

Figure 6. A photograph of West Humboldt Park and the corresponding output from The RED Project wireless visualization. (Photo Credit: Hope Hall)

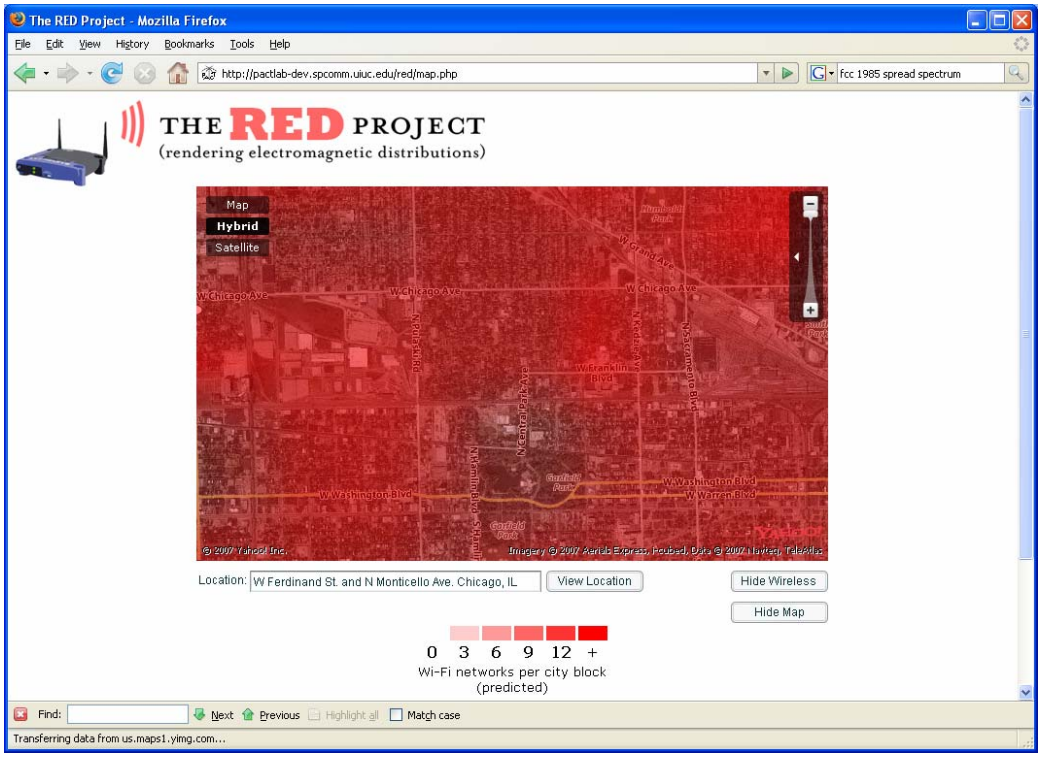

Figure 7. West Humboldt Park rendered inside The RED Project's visualization interface.

The third stop of our tour is the Chicago neighborhood of West Humboldt Park. The Humboldt Park community area is one of the poorest in the Chicago metropolitan area. The residents of the Census tract we visited were 97% black in the 2000 Census, with high unemployment (13%), a per capita income of $9,060, and a median age of 25. The low median age represents larger families and households than are found in the other neighborhoods visited so far. 56% of residents here had a high school diploma. Although we found much less wireless here, again a single factor like race or income alone cannot do a good job of explaining wireless communication. It seems obvious that the poor can't afford to participate in expensive new communication technology like wireless computing, but in fact people of all incomes feel that communication is essential, and are willing to spend money on it. For example, after cellular phones became widespread, some poor communities became much more likely to use them than more affluent populations. From the map, this doesn't seem to be the case for Wi-Fi, however, as the reds are much lighter than most of Lake View or Devon Avenue.

Stop 4. The Town of Sidney, Illinois

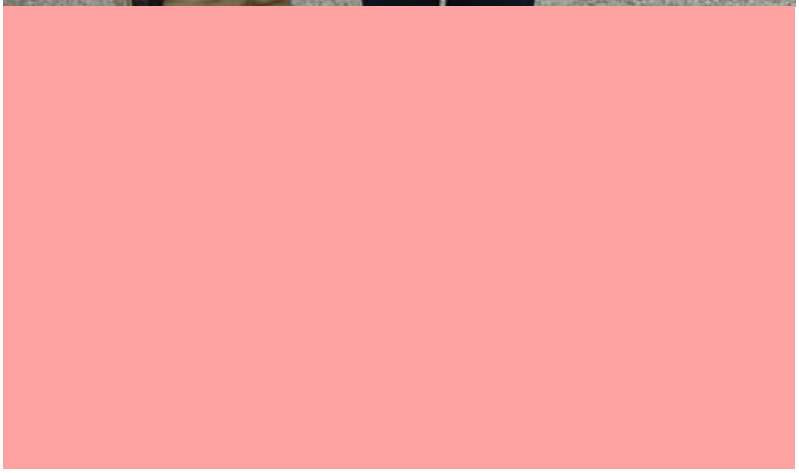

Figure 8. A photograph of Sidney and the corresponding output from The RED Project wireless visualization. (Photo Credit: Hope Hall)

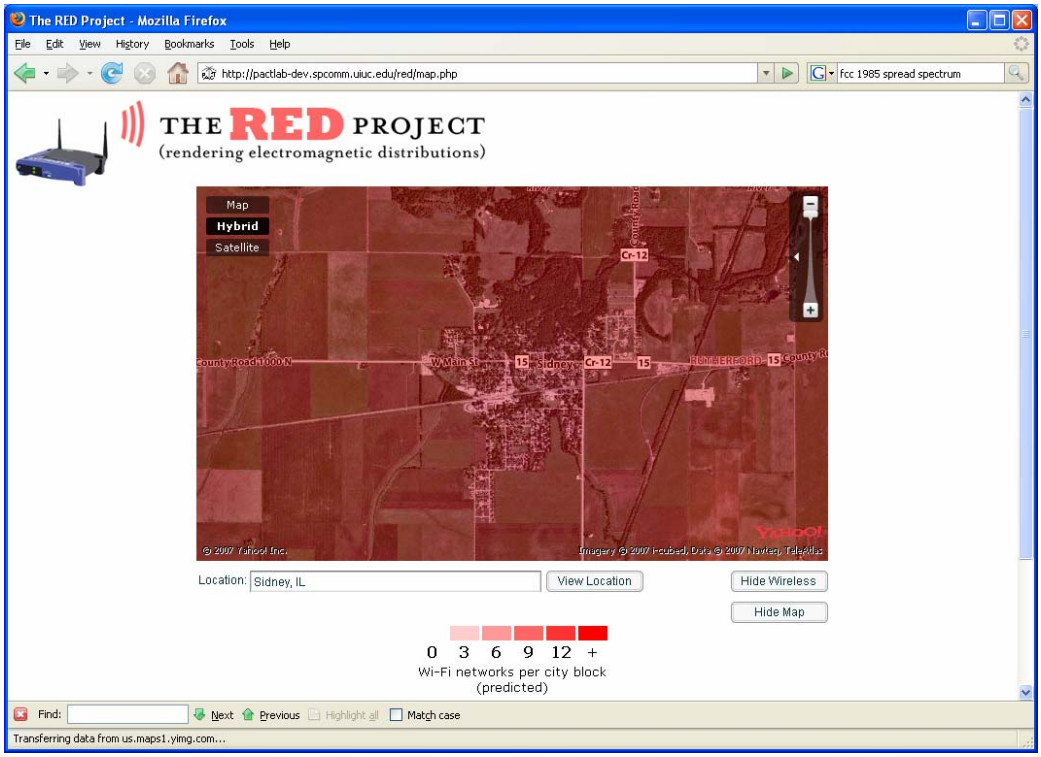

Figure 9. Sidney rendered inside The RED Project's visualization interface.

The town of Sidney, Illinois contains about 1,000 people, but because US Census Tracts are much larger than that, Sidney's contribution to the Wi-Fi use in the area is difficult to ascertain. Although a prediction can be made, the map is all one color, showing no local variation. Residents of Sidney and the surrounding area were 98% white in the 2000 Census. The per capita income was $20,085. 49% of residents had a high school diploma, and the median age was 38. This census tract reported 3% unemployment. About one-third of the US population lives in rural areas, although many accounts of technology and communication don't pay these people much attention. The difficulty in using Census tracts to understand small towns is just one illustration of this lacuna. Despite the problems with measuring and describing rural places, the uniform coloring of this wireless map may be unintentionally accurate. Wi-Fi varies substantially from block to block in cities because the buildings absorb the signals and prevent them from traveling long distances. In flat, treeless areas like Central Illinois there is nothing to stop the signals. With nothing to get in the way, a low-powered transmission from a farmhouse's 2nd floor window can easily travel miles. Some empty fields in rural Illinois are filled with these Wi-Fi signals, although they are devoid of people.

Stop 5. South Central Los Angeles

Figure 10. A photograph of South Central Los Angeles and the corresponding output from The RED Project wireless visualization. (Photo Credit: Hope Hall)

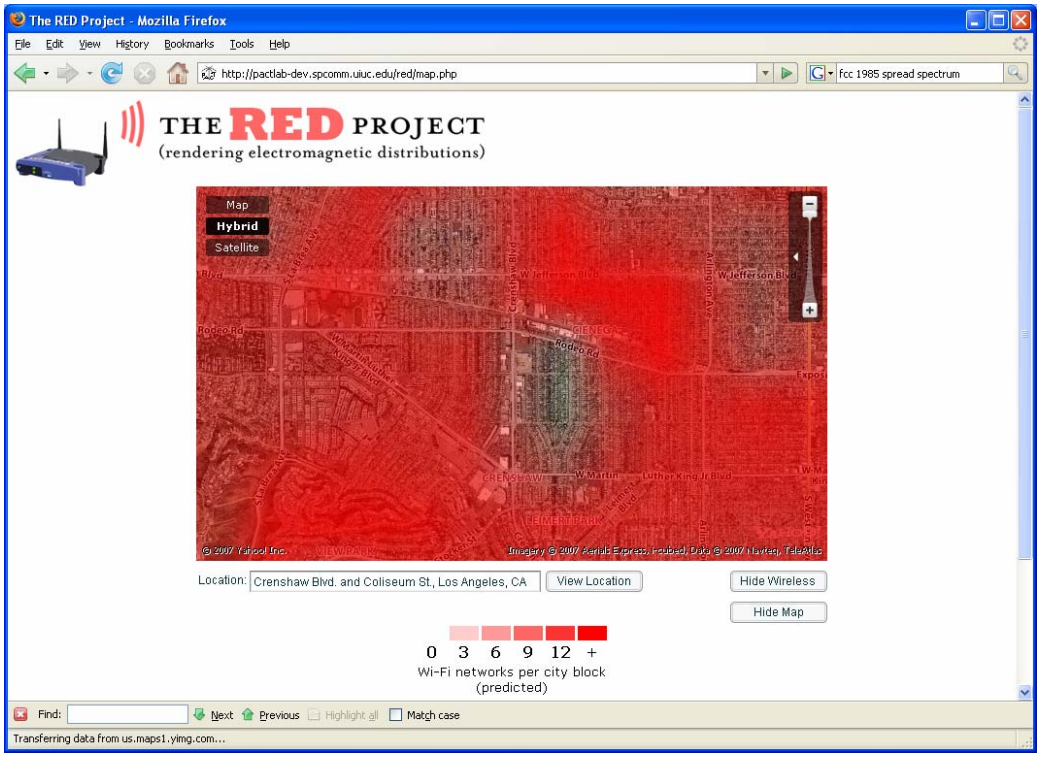

Figure 11. South Central Los Angeles rendered inside The RED Project's visualization interface.

Officially, these neighborhoods of Los Angeles have names like "King Estates" and "University Expo Park West," but in conversation they are better known as part of South Central LA. Despite the generally low incomes, this area shows a wide variation in predicted wireless use. Demographically, in some ways this area is similar to Humboldt Park, but in the areas we visited the level of education is lower. But what explains the blank spot just to the West of the map's center? This spot (like its surroundings) was reported to be predominantly black (74%) in the 2000 Census. 36% of residents reported holding a high school diploma and 3% were unemployed in 2000. One intuitive explanation might be that this represents a pocket of poverty, where people are unlikely to own computers. In fact, the residents in this blank spot reported a higher income than the surrounding areas ($25,568). In contrast, the deeper red areas North of Exposition Boulevard were significantly poorer ($14,034 per capita). Instead, this spot could be explained as a pocket of age: the blank spot has a much higher median age (47) than the surrounding areas, and older people are less likely to use newer computer technology like Wi-Fi. These competing explanations demonstrate the difficulty of reasoning about complex social situations (like technology use), even with a lot of information. Any unexpected or unexplainable situation that we find on these maps could be caused by the

inaccuracy of the Census or an error in our methods of prediction. The error could also be in our preconceptions.

Frequently Asked Questions

I. Questions about the map

What does it mean when the map turns red?
The map is our prediction of the likelihood that you can detect Wi-Fi networks at a given place in the United States. This is our prediction of the density of wireless networks (not traffic). The more red, the more networks we predict.

How big is a "city block"?
This value means that if you had a full city block with this density (i.e. same shade of red) you would find that many wireless networks on that block. A city block is usually measured as 1/20 of a mile (264 ft.) on each side, which is just about 70,000 square feet.

My whole neighborhood looks the same color - is it possible to see more detail?
First, try using the Yahoo! Maps plus (+) button to zoom in. It is possible to make more detailed predictions using our methods, but this public mapserver is limited to **tract-**level prediction. The US Census is organized into chunks of land called **tracts**. In the words of the US Census, "Census tracts are small, relatively permanent statistical subdivisions of a county...[that] usually have between 2,500 and 8,000 persons...[and] are designed to be homogeneous with respect to population characteristics, economic status, and living conditions." (from census.gov). Tract sizes vary based on the number of people living in any area, but in the average city a tract spans several blocks. So although you can get our prediction of how your neighborhood wireless may differ from another neighborhood, you won't be able to predict whether your house is receiving more wireless than the house across the street.

I found an urban / downtown / densely populated area without any wireless. Is that accurate?
Probably. Traditionally, cities are thought to be full of wireless signals, but we found very densely populated areas that had comparatively little wireless. See our tour.

I found a suburban / quiet / sparsely populated area with a huge amount of wireless. Is that accurate?

Probably. Traditionally, high-density downtown areas are thought to be full of wireless signals, but we found that some populations (some kinds of people) produce far more wireless than one might otherwise expect. See our tour.

Rural areas seem to have a lot of wireless. Is that accurate?
Some rural areas have lower population densities than any areas that we have measured, so we do not have as much confidence in our ability to predict Wi-Fi in rural areas. Rural areas are also sometimes poorly served by the US Census tract system. See the discussion of Sidney, Illinois in our tour.

How do you make these predictions?
We assembled a handheld device that would detect Wi-Fi signals (in much the same way a laptop does) and connected it to a GPS receiver (this is commonly known as wardriving). We then traveled to a number of neighborhoods in Illinois and California repeatedly over a period of four years, measuring the number of Wi-Fi networks at every public place in each neighborhood during each visit. We then used the demographic information from the US Census to develop a model that would statistically predict the density of Wi-Fi networks using demographics. Next, we compared our ability to predict networks to places that we did not initially measure. (We found that it worked well.) We also downloaded public Wi-Fi datasets from WiGLE and wifimaps.com (now defunct) and compared our measurements to theirs. Finally, we assembled a database containing the Census demographics for every census tract in the entire US. When you enter an address, our software retrieves the demographics from the database and makes a prediction. This is then presented as an overlay on top of Yahoo! Maps for that address. We are currently predicting Wi-Fi network density using:

race
age
income
educational attainment
population density

We are continually trying to improve our predictions and we welcome your help in the discussion forum.

How accurate are these predictions?
In our tests, our predictions have explained from 84-91% of the variance in Wi-Fi network density. That's pretty good. In comparison, some current methods assume only that where there are more people, there will be more wireless. If we use this simpler method of predicting wireless, it explains only about 37% of the variance.

II. Questions about the project

What is the purpose of this project?
The RED Project is a proof of concept to demonstrate that it is possible to accurately predict the distribution of use of the electromagnetic spectrum (specifically Wi-Fi Internet) using publicly available demographics (see How do you make these predictions?).

Can I use this map to find free Wi-Fi?
Many of the Wi-Fi networks shown here are likely to be encrypted or otherwise secured, so this service is not a particularly helpful tool to use to find free Wi-Fi.

Can hackers use this map to steal Wi-Fi?
Since Wi-Fi is relatively common, hackers can probably find it anyway without recourse to this map.

This is very interesting and I'd like to contribute to the project. What can I do?
Contribute to the discussion forum and tell us if our predictions are right in your neighborhood. Suggest your own interpretations of places on our tour, or suggest your own locations for a tour.

III. Technical problems

I can't see anything! What's wrong?
First, check the minimum system requirements below. If you meet these requirements, you may be having a temporary problem connecting to either our server or Yahoo! Maps. Our best advice is to use the fastest Internet connection possible. It may help to try again later.

What are the minimum system requirements?
Macromedia Flash Player 8+ and a broadband Internet connection. Any recent web browser should work. Any recent operating system should work. Any recent processor should work. (If your processor is too slow or busy with other programs, the map may become unresponsive.)

It says "Predicting Wireless" but no red markings appear. What's wrong?
You may have a good Internet connection to Yahoo! Maps, but you may not have a good Internet connection to our server, or our prediction server may be busy. Please try again later.

No satellite photos appear, error messages appear instead of satellite photos, or satellite photos appear only over some sections of the map. What's wrong?
You may have a good Internet connection to our wireless prediction server, but a poor Internet connection to Yahoo! Maps. All of our map data comes from Yahoo! maps. If you receive a message similar to: "Image not available. Zoom out or reload to try again." This comes from Yahoo! Maps and is out of our control. We suggest you try a different location, try to zoom out (press "-"), reload, and/or switch to "Map" view instead of "Satellite" or "Hybrid" using the black buttons on the upper left of Yahoo! Maps.

I can't use the mouse to drag the map to a different location. What's wrong?
If you have a number of other applications running, or if your computer's processor is too slow, it is possible that the map may become unresponsive -- especially while drawing the wireless. It may work if you try a different (faster) computer, if you close all other applications, or if you don't try to manipulate the map until the last set of predictions has fully loaded.

IV. More Information

What can I read to find out more information on this topic?

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Grubesic, T. H., & Murray, A. T. (2004). "Where" matters: Location and Wi-Fi access. *Journal of Urban Technology, 11*(1), 1-28.

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See also:

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Notes

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[2] Werbach, K. (2002, October). Open Spectrum: The New Wireless Paradigm. *Spectrum Series Working Paper* #6. Washington, D.C.: New America Foundation. http://werbach.com/docs/new_wireless_paradigm.htm

[3] Abernathy, K. (2002). My Vision of the Future of American Spectrum Policy: Remarks of FCC Commissioner Kathleen Q. Abernathy before the 6th annual conference on Technology and Society. Washington, D.C., USA. http://www.fcc.gov/Speeches/Abernathy/2002/spkqa228.html

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[6] Gillett, S. E., Lehr, W. H., & Osorio, C. (2004). Local Government Broadband Initiatives. *Telecommunications Policy 28*(7/8): 537-558.

[7] See academic work such as Bar, F. & Galperin, H. (2004). Building the Wireless Internet Infrastructure: From Cordless Ethernet Archipelagos to Wireless Grids. *Communications & Strategies 54*(2): 45-68 and see also press reports such as Legon, J. (2005, March 13.) "Get ready to tune in to wireless Net." CNN. http://www.cnn.com/2003/TECH/ptech/03/12/wifi.growth/, market research such as Hales, P. (2005, March 29). "Wireless networks set to go through the roof: Worth billions soon, says report." *The Inquirer: Research and Markets*. http://www.theinquirer.net/?article=22198, and trade groups such as Wi-Fi Alliance, The. (2005). "Wi-Fi Backgrounder." http://www.wi-fi.org/OpenSection/backgrounder.asp?TID=5

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Appendix A. Project Technologies

Plug-in(s) you will need to view this project:

Flash 8 Plug-In (ver. 8.0+) (browser application providing fluid vector-based graphics and interface)

Development and data handling applications:

Yahoo! Maps API (Embeds maps in Adobe Flash)

PostGIS (Geographic querying for PostgreSQL)
GeoDa (Interactive geospatial statistics package)
Kismet (802.11 layer 2 packet sniffer)
Ethereal (Open source network protocol analyzer)
SPSS (Statistical analysis software)
ArcGIS (Geographic information system)
PHP 5.0.4 (PHP Hypertext Preprocessor)

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