Challenge: Ubiquitous Location-Aware Computing and the "Place Lab" Initiative

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ABSTRACT

To be widely adopted, location-aware computing must be as effortless, familiar and rewarding as web search tools like Google. We envisage the global scale Place Lab, consisting of an open software base and a community building activity as a way to bootstrap the broad adoption of location-aware computing. The initiative is a laboratory because it will also be a vehicle for research and instruction, especially in the formative stages. The authors draw on their experiences with campus and building-scale location systems to identify the technological and social barriers to a truly ubiquitous deployment. With a grasp of these "barriers to adoption," we present a usage scenario, the problems in realizing this scenario, and how these problems will be addressed. We conclude with a sketch of the multi-organization cooperative being formed to move this effort forward.

Categories and Subject Descriptors

C.2.4 [**Distributed Systems**]: *Distributed databases, Security, integrity, and protection; Spatial databases and GIS*;
H.1.2 [**User/Machine Systems**]: *human factors*;
H.4.3 [**Communications Applications**]: *Information browsers*;
H.5.4 [**Hypertext/Hypermedia**]: Architecture; User issues.

General Terms

Design, Economics, Experimentation, Security, Human Factors.

Keywords

Location-aware; context-aware; ubiquitous; positioning systems; WiFi; GPS; web services; wireless hotspots; wardriving.

1. INTRODUCTION

This paper presents a challenge to the research community. As a challenge paper, our objective is not to make a research contribution per se, but rather to describe an attractive opportunity that existing and future research can target.

We need a concerted interdisciplinary activity to make location-aware services valuable and readily accessible by a large user community in daily situations in the real world. The objective of the Place Lab initiative is to bootstrap such an activity through low-cost positioning technology in conjunction with a broad community-building effort that will create the large collection of location-enhanced web services needed to catalyze business models. This paper identifies and suggests ways to overcome three major barriers to realizing the vision of ubiquitous location-aware computing: low-cost, highly convenient position-sensing technology; making users comfortable with respect to their location privacy; and having existing web content easily customized to geographic locations.

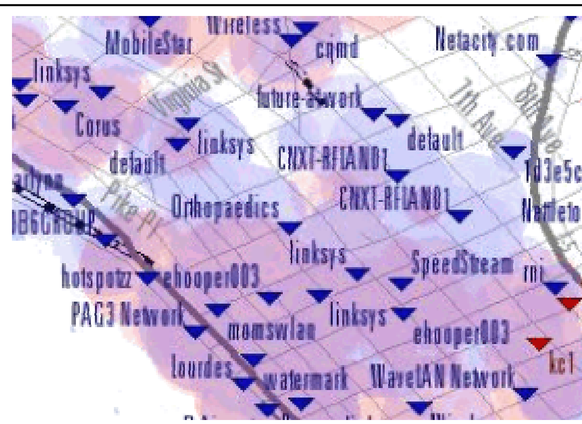


Figure 1: Seattle (shown here) and many other urban areas have WiFi coverage so dense that cells overlap. This wireless communications infrastructure holds the promise of offering a WiFi positioning system comparable to GPS. (Image from WiFiMaps.com)

Place Lab leverages the fact that many cities and towns around the world (e.g., Manhattan, downtown Seattle, the business district of Athens Georgia) have wireless hotspot coverage so dense that cells overlap. WiFi is now in the mainstream: 300 U.S. McDonald's restaurants are offering one-hour connections to customers buying a value-meal [10]. As this trend continues, it is likely that wherever you open your notebook computer or take out your PDA you will find hotspot coverage. Wireless hotspots offer a kind of ubiquitous information access, but what's missing, and what Place Lab will enable, is a way for your computer to know its location – to map hotspots to a geographic coordinate worldwide. We use the term *WiFi Positioning* to denote this capability of client-computed position using wireless access points (APs). The ideal is to make positioning available anywhere there are wireless cells, essentially creating a *Global WiFi Positioning System*[1].

The location-enhanced web is one of those technologies, like the web itself, which increases in worth the more ubiquitous it becomes. More users will motivate creative developers to produce more services and content, which drives investment in infrastructure, and greater usage. To bootstrap this cycle, Place Lab software lowers the cost of entry: it uses standard WiFi-equipped mobile computers along with a browser toolbar, called the "Place Bar," to manage WiFi Positioning, including maintaining a user-specified level of location privacy. Whenever a user turns on their notebook in the presence of a beaconing access point, the Place Bar looks up the MAC addresses of nearby hotspots in a cached directory and determines the user's location. The Place Bar can then connect users to web content relevant to that location, such as a restaurant, hotel, or micro-travel blog sites; services, like proximate yellow pages; and a wave of place-enhanced pages such as a match-maker that compares your likes and dislikes with other people in the same hotspot zone.

The remainder of this paper outlines the Place Lab initiative. The following two sections present a usage scenario and a discussion of what, exactly, we see Place Lab enabling. We then explore three of the hard problems we have identified along with some approaches for solving them. We conclude with a sketch of the multi-organization cooperative being formed to move this effort forward and a historical perspective on location-aware computing.

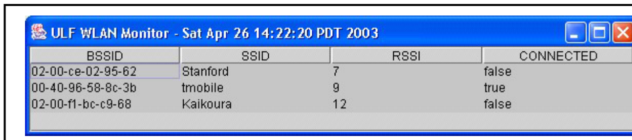
2. A USAGE SCENARIO

A *Global WiFi Positioning System* is analogous to the Global Positioning System (GPS) in that position determination is carried out entirely on the client, as is the case with GPS handsets. For positioning, GPS uses a time-of-arrival (TOA) algorithm whereas with WiFi Positioning the methods studied fall into three groups (a) association with access points; (b) signal strength of AP beacons; (c) signal strength of multiple AP beacons [1]. Each of these WiFi location methods rely on access points beaconing a globally unique 48-bit identifier, the Basic Service Set Identifier (BSSID), that is the same format as an IEEE 802 MAC address. With access point ranges of 100 meters or so, these methods provide between 100 and 3 meter precision, and their practicality has been well demonstrated [1][4][8][9]. In Place Lab we see client-based WiFi Positioning algorithms that calculate position from APs as ongoing research and so this is a component that will be easily replaced by researchers.

With this background, it is now possible to describe the user experience. A Place Lab user subscribes to databases, potentially from multiple providers, that the client WiFi Positioning algorithms use to convert an access point BSSID (plus signal strengths) into a geographic position. We expect these databases would be updated once a week or so and might cover large geographic regions such as North America, Europe or Asia. Over time we see this collection of WiFi Positioning databases growing to include every access point in the world (later we describe some ideas on how to bootstrap and maintain the databases). Given such a collection of databases, whenever the client receives BSSID beacons they are able to calculate position *without* additional network communication. This client-based calculation of position-without-communication is a fundamental principal of the privacy mechanism proposed for Place Lab.

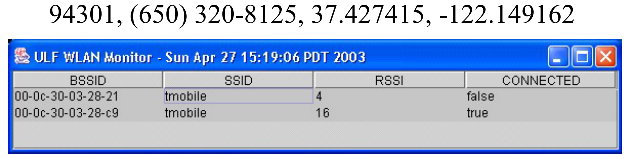
In our scenario, a user with a WiFi equipped notebook computer and a WiFi Positioning database is able to determine their position, to some variable precision, at any hotspot in the world. WiFi Positioning might be integrated into Microsoft's "Streets & Trips" client mapping software or, it may be integrated into a web browser to communicate with *location-enhanced web services* (LEWS). Enhancing web pages and web services with location information is a principal focus of Place Lab, and is a powerful concept first proposed in Mobisaic [17].

On visiting a location-enhanced web service, the user is able to *trade privacy of their location for utility of the web service*. We imagine a Place Lab component, the *Place Bar*, which integrates WiFi Positioning into the user's web browser and allows users to flexibly send location information at various fidelities to LEWS sites. For example, the user might choose to reveal only one of these about their location: country; state (prefecture, canton, province, etc.); city; neighborhood; postal code; street; street address; and longitude/latitude. See Table 1, for examples of location-enhanced web services that might use different fidelities of locations.



BSSID	SSID	RSSI	CONNECTED
02-00-ce-02-95-62	Stanford	7	false
00-40-96-58-8c-3b	tmobile	9	true
02-00-f1-bc-c9-68	Kaikoura	12	false

(a) **Starbucks,** 2000 El Camino Real, Palo Alto, CA 94301, (650) 320-8125, 37.427415, -122.149162



BSSID	SSID	RSSI	CONNECTED
00-0c-30-03-28-21	tmobile	4	false
00-0c-30-03-28-c9	tmobile	16	true

(b) **Gate 86**, United Airlines,
San Francisco International Airport

Figure 1: *WiFi Positioning* uses client received AP MAC identifiers and signal strengths to privately compute a position, which may also have user meaningful "places" associated with it.

[1] Cellular technologies including GSM, Mobitex, and Bluetooth are candidates for inclusion in future versions of the database.

Table 1: WiFi Positioning model of client-calculated location means that users can trade privacy (location fidelity) for utility on an interactive case-by-case, web page at-a-time basis, or by other means to be developed.

Users may choose to reveal their current	In exchange for this location-enhanced web service
City	Web logs (Blogs) for a city's activities. (cityblogs.com)
Postal (zip) code	Yellow pages listing for drugstores. (yp.yahoo.com)
Street address	The place and time for the next bus. (nextbus.com)
Longitude/latitude	My position on the shopping mall map (stanfordshop.com)

In summary, the Place Lab usage scenario involves users with WiFi-enabled notebook computers and PDAs. They first download a WiFi Positioning database and refresh it periodically. Then, as they travel in and around WiFi APs, they may visit location-enhanced web services and use the Place Bar to push location information into these web services while controlling, to a fine degree, the personal information being revealed.

3. WHAT WILL PLACE LAB ENABLE

This proposal is about creating a broad activity to bootstrap location-enhanced applications. First and foremost our desire is to break out of the cycle in which we are mired:

- there are few users of location-enhanced applications, because…
- there are few valuable location-enhanced applications, because…
- there are few developers inventing location-enhanced applications, because…
- the target user community is small, because…
- there is no common platform/infrastructure for location-enhanced applications, because…
- users and infrastructure providers won't invest in new location-capable hardware, because…
- there are few users of location-enhanced applications.

Clearly this simplification misses significant issues[2], however, we believe the general cycle holds true. Our proposal to break out of this pattern is to make location-capable hardware (and interaction) so low cost that even low-to-medium value applications become worthwhile to a large number of users. Once a significantly sized leading-edge user community starts to form, developers and content producers have a forum to innovate and introduce higher value applications. Place Lab then, is taking on the grand challenge of moving (a form of) location-aware computing from the research laboratory, where it has been languishing for the last decade, to the real world.

We see four things that Place Lab will enable:

1. *A technology framework that lowers the bar for location-enhanced web service development and use.*

   For developers, the creation and deployment of applications using a familiar web "cgi" services model plus some small amount of place-aware server libraries. For users the interaction is the familiar web browser plus some one-click-install WiFi Positioning capability with personal location-privacy management.

2. *A leading-edge developer and user community grown from a grass roots effort.*

   A user and developer base that we believe can be grown from University web service classes, WiFi clubs, and enthusiasts. The growth of the user community depends on the energy in the developer community, which in turn depends on how well we lower the bar for application development. There is an analogy to DoCoMo's iMode which led to an unparalleled creative activity in the creation of iMode content and services in part because many people could already write HTML and web services.

3. *A real world laboratory in which location algorithms, privacy, place and social issues can be explored.*

   A researcher at Dartmouth could write a new algorithm for WiFi positioning, a researcher at Berkeley might devise a new User Interaction model for specifying which web services really needs my location, and each could introduce their component onto thousands of volunteer systems around the country and obtain measurable results in return. There is an analogy to the TREC corpus that created a common ground for running experiments, devised metrics of "precision" and "recall," and facilitated comparative research in the information retrieval field.

4. *A foundation for context-aware and proactive computing research in the real world.*

   We often think of location-awareness as a first step towards context-aware [15] and proactive applications [16]. One thing that Place Lab might enable is the movement of a user community in this direction as well. We hope it won't take long before developers move from the simple concept of location to more contextually rich notions of place, the people in a place, and the activities than go on in a place. The expectation is that the majority of this experimentation can happen at the web services side where there is the most freedom for innovation.

4. HARD PROBLEMS

We have identified at least three hard problems that stand in the way of realizing Place Lab:

1. How to bootstrap and manage a worldwide hotspot database for positioning?
2. What is the trust model at the client, what is being revealed, and how can we avoid the "big brother" hot button?

[2] Such as privacy, which is turning into a major barrier even for something as valuable as E911.

3. How to associate any page on the web with a place in the real world where it might be useful? How can multiple pages appropriate for a location be organized for easy browsing?

These problems, and probably many more, must be addressed by the research community as this challenge moves forward. In the following sections we describe potential solution directions.

4.1 How to Bootstrap a Global WiFi Positioning Database?

Today there are an estimated 60 million WiFi chips in use and that number is predicted to double in 2004 [5]. Many of these chips are sold into mobile platforms, but still, that's a lot of access points! Up until now we haven't distinguished between commercial hotspots provided by companies like T-Mobile, independent hotspots that are popular with coffee houses and bookstores, public-access hotspots run by "clubs" such as NYC Wireless, private APs owned by your neighbors, and all the flavors in between. Whether we incorporate all AP candidates in our databases or filter based on some criteria will be a decision that undoubtedly will be influenced by the ongoing debate in WiFi community on the legality of scanning for APs. For the sake of this systems discussion (rather than a social, ethical, or legal point of view) we can assume we will want to map any and all 802.11 beaconing radio sources.

The challenge is how to bootstrap and manage this world wide hotspot database. We already mentioned that we can manage scale by segmenting the database into geographic regions. But we need to take into account the dynamic nature of the data due to new installations and the fact that people, especially students, tend to move their APs whenever they go home for summer vacation. We suggest three techniques used in conjunction: (1) seed with war-driving data [2][19]; (2) use geographic statistical methods to enhance; and (3) employ a distributed contributor mechanism [20][21]

War-driving is a relatively new phenomenon and refers to hobbyists and hackers using *netstumbler* software [23] (and variants) on WiFi and GPS equipped mobile computers in order to map out the locations of WiFi access points. Generally this data is uploaded to web sites and shared in order to answer the questions: "what public-access hotspots are near this location." This data collection method is also quite useful for answering the Place Lab question: "what location is near this hotspot." (Note that GPS output may not be the best format, but there exists an entire industry for converting between addresses and longitude/latitude values).

The first technique to bootstrap a WiFi Positioning database is to generate war-driving data for a region, such as the UCSD campus and town of La Jolla. The idea is to create a rough, incomplete map of the hotspots in an area. With this database, notebook computer and PDA users without GPS can start contributing more information into the database. For example, assume a user goes to a Starbuck's and receives beacons from three APs but only two are in the database. The third AP can then be added to the database with some high confidence that it is near the location of the other two APs. Data can also be added when an unknown AP is detected temporarily between two known APs. This collection of techniques for refining the details of the WiFi Positioning database as a side effect of people using their mobile computers is the second, geographic statistical technique.

Clearly, the data being collected by the geographic statistical technique would be much more useful if it was sent back into the infrastructure and then redistributed to all users as part of the WiFi Positioning database. The third technique is to employ a distributed contributor update mechanism for the WiFi Positioning database similar to the one made famous by the CDDB service:

> *"For example, when you insert a music CD in your computer, the software player application on your computer uses our service to first identify the CD, and then display the artist, title, tracklist, and other information to you instantly. Most commercial music CDs do not contain any of this information on the CD itself. That's why we created the service. One of the most interesting features of the service is that it provides a forum for exchange of music information between fans. . . . . One of the jobs of the CDDB service is to construct a database from thousands of these submissions every day from all over the world. The service compares edits from multiple submissions, reconciles duplicate entries, corrects errors, combines many submissions into individual records, etc. The result over the many years that the service has been in existence is a massive database compiled from many sources, and made instantly available by high-speed servers with dependable, worldwide, around-the-clock access. That is the CDDB service."* – *www.gracenote.com*

The WiFi Positioning database could aggregate and statistically process AP sightings, and even use the distributed contributor model to improve the precision of the data over time. In some situations, users might be presented with the current location information that is being sent off to the location-enhanced web service. If users notice an error in the location, or the database just holds the city and not the street, the user could enter the corrected or more precise location information that would eventually be added to the database. Of course, users should not be able to corrupt the database. Statistical methods coupled with authoritative sources of hotspot location can be used to ensure high-quality.

4.2 What is the Trust Model & What is Being Revealed?

Whenever a location system is developed we can expect to hear shouts of "big brother!" Some of the news headlines that came out of the Active Badge location systems include: "big brother pinned to your chest," "Orwellian dream come true, a badge that pinpoints you," "badges monitor staff." This sociological reaction around location-tracking and privacy has rarely been taken seriously by the research community. Researchers are still proposing location "tracking" systems that lack a privacy mechanism that people on the street would trust. This is probably one of the reasons why we have such a difficult time moving location systems from the research laboratory to real world usage.

Whether *we* think "big brother" is a legitimate risk is not the issue. Rather, the issue is that a large part of the population doesn't want to give up their location privacy in order to get the benefit of a "friend finder" application. They don't see the benefits outweighing the risks, which for some people may include issues of stalking and personal security. On the other hand, people are willing to enter credit card data, phone numbers, and other personal information into web sites not because it is less of a risk, but because they do view the benefits outweighing those risks.

The privacy problem is due in part to the choices we present people: either opt-in or opt-out with no levels in between. When opting-in the systems we design generally send location to a central server, that we expect users to trust. Most users do not trust centralized location tracking servers run by the government, large corporations, or even your University's IT staff. As an example you can look at the debate over E-911 in congress.

For Place Lab the questions "when I'm using this what am I revealing?" and "when I'm *not* using this what am I revealing?" are make-or-break questions for adoption. Our approach is two fold: (1) client-only position calculation; and (2) multi-fidelity location revelation.

Client-only position calculation is the antithesis of the "big brother" location server: all computation of a device's location occurs at the trusted client. GPS is a good example of this model. In the case of Place Lab, the inputs to the computation are AP beacons received at the client and a cached copy of a database that allows mapping the WiFi beacons (possibly with signal strength data) to locations. At this basic level of WiFi Positioning, if a client does not use the APs for communication, then a totally private positioning system is possible.

Generally, we think people would want to interact with some location-enhanced service or fetch some location-specific content so communication would be a normal part of the usage model. However, it is worth noting that the private disconnected mode is worth exploring. First, there are times when you may be near APs that are available for positioning but not available for communication (they might be private, belong to another provider, or maybe you didn't pay your T-Mobile bill last month). In these cases you might interact with offline web content in an "occasionally connected computing" (OCC) model supported by .NET and other frameworks. For example, if the Zagat restaurant guide was an OCC location-enhanced site, you could make the content available offline and use it with live location information. In this way, you could get information about nearby restaurants without actually revealing location data to the Zagat server.

4.3 How to Associate Web Pages to Places?

One of the challenges in the place-enhanced Web is content discovery: "how do you find information associated with a location?" The most obvious approach is to ask content-providers to annotate their pages with location information. However, how is this "geocoding" structured? Are pages to be tied to specific coordinates? How big is the region around a coordinate for which the page is still relevant? To further complicate matters these regions are unlikely to be simple rectangles and will undoubtedly overlap with each other.

Location forms a natural hierarchy. A coordinate is contained within a room, a room is contained on a floor of a building, the floor is within the building, the building is on a street, the street is in a neighborhood, which is in a city, and so on. However, this isn't the only type of hierarchy that makes sense. Sometimes we may be more interested in the organizational hierarchy of a place. For example, a coordinate may be viewed as being in someone's office, that office belongs to a company that is spread over multiple sites that are structured by an organization chart. The person in the office may belong the program committee of a conference that is sponsored by a technical society. Which of these hierarchies is most relevant depends very much on the context under which the user is at that particular location. Yet another dimension can be added if we consider time at a particular place. We may be seeking information about what was in this place before and what is scheduled to happen here in the future (e.g., historical records and upcoming events). The point is that places are very rich in meaning and it isn't all tied to coordinate systems.

There are two main approaches to dealing with this problem: asking content providers (and third parties) to code their pages with location information; or deriving the locations associated with a page through observation of users' browsing habits. In the first case, we may not get many associations at all since we have put an extra burden on content providers. In the second case, we have to determine how privacy preserving aggregation techniques can be used to collaboratively associate pages with locations. An important issue is where to store and compute these associations.

Even when we have these associations in place, we must still tackle the problem of how to present this information to the user. What happens when a user asks for information associated with a place? What will they see in the browser? The associated pages will have to be indexed in some way. This may be by some of the hierarchies we discussed above but they could also be organized by what we know about the user's current context and what they are likely to be most interested in. This could be based on past experience (implying that we may employ some machine learning techniques) or be specific to more explicit information such as calendar and preference data.

5. COMMUNITY BUILDING

Our approach to developing Place Lab will be to rely on a seeded grass roots effort. The seed will be the development of a hotspot database, code to compute a location fix, the Place Bar for the web browser to relay selected location information, and server-side code to allow web services/applications to process location information. These elements will initially be provided to some partner universities that are already exploring the location-aware computing space. We will provide assistance in using these elements in undergraduate project courses and graduate research projects. Our hope is to spur the development of a wide range of novel applications that will make the case for larger investments in location infrastructures and explore the issues of location privacy and collaborative filtering of location data. We are choosing universities because we can easily construct smaller WiFi Positioning databases to cover university campuses and their environs and because universities bring together the cross-disciplinary interests and skills needed to really explore this space.

Some examples of initial applications may be: campus guides with historical information [4]; campus event advertisements; friend-finders using buddy lists [7]; notes and bulletin boards tied to geographical locations [6]; navigation aids for walking, disabled access, and public transportation [22]; memory aids to help people determine when they may have last seen each other

[11][14]. Many, if not all of these, have been built before. However, they have been limited to a single short-lived deployment and tied to only one region of operation (where the developers were able to deploy the required infrastructure).

In this case, web services accessed from WiFi notebook computers and PDAs create a potential audience of thousands rather than tens of users. In addition application code will be collected on a shared web site and made available to the entire community so that we can build on each others' efforts. WiFi infrastructure will be ubiquitous (and certainly so on the campuses we will be seeding) so that the required infrastructure will already be in place. We will, as described earlier, need to automate the mapping of access points.

6. HISTORICAL PERSPECTIVE

When a group of researchers deployed the PARCTAB (the first mobile location-aware computer system), they ran into a set of problems that arise again and again in location-aware systems [18]. This computer was designed for an office setting using room-sized infrared cells for communication and location. Before long people asked to take the PARCTAB home because they wanted the same "ubiquitous" information access at home as in the office. This request was satisfied but there was no way to accommodate users who asked for outdoor (where infrared is difficult at best) and car access. Similarly the Active Campus and RADAR infrastructures do not foster ubiquitous usage because they require administrators to perform offline calibration of WiFi access points in each new locale. The lesson is that ubiquitous systems that cover only a subset of the places where people perform their activities are less desirable.

A second and probably more painful lesson learned in our deployments of location systems is around privacy. The PARCTAB (as well as most systems that followed) was designed with a centralized location server where all location sightings were stored and which was generally readable by others in the lab. Not only was the notion of location tracking abhorrent to most people outside the lab (including the popular press) but some co-workers within the lab were also reluctant to adopt the system over the long term because of the privacy issue.

Although many Ubiquitous Computing location systems have been built as trackers with central location servers, there are notable exceptions including HP's CoolTown [3] and MIT's Cricket [13]. Cricket for example, uses RF and ultrasound beacons in indoor environments to provide a scalable, private location system. It has only been in the last year or so that the adoption of WiFi access points has created the a situation where ubiquitous location-aware computing can grow outside the research laboratory with minimal additional hardware.

7. CONCLUSION

Place Lab is a community-based effort to make location-aware computing a reality on a mass scale and in real-life situations. The approach is based on exploiting the proliferation of wireless networking hotspots that can provide location fixes comparable to GPS in urban settings but also function indoors where GPS does not. A downloaded and continually updated distributed contributor database will allow clients to compute their own locations and divulge their location information only when they want to. Services accessed through a web browser will provide users rich information and services associated with their location.

We plan on seeding several universities with the necessary elements to develop Place Lab enabled applications and expect students to spearhead the development of relevant and valuable location-aware applications. Our goal is to break the cycle that is preventing location-aware usage models from developing on a large scale.

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