# MAPPING WLAN COVERAGE AS A POTENTIAL COMPLEMENTARY SOURCE FOR GPS-BASED NAVIGATION IN INDOOR ENVIRONMENTS

Scott Bell and Wook Jung

Department of Geography and Planning, University of Saskatchewan, 117 Science Pl, Saskatoon, SK, S7N 5C8 Canada
scott.bell@usask.ca & wook.jung@usask.ca

**ISPRS, WG I/5 (Integrated Systems for Sensor Georeferencing and Navigation)**

**KEY WORDS:** WLAN coverage**,** WiFi mapping, GPS, Wayfinding, and Indoor environment

**ABSTRACT:**

Enhanced-positioning systems are able to support the acquisition of accurate location information using wireless technology other than the Global Positioning System (GPS). These systems have the potential to supplement GPS where GPS is unreliable. In particular, enhanced-positioning systems can provide location information for navigational support and Location Based Services (LBS) indoors and in dense urban canyons and natural environments with extreme relief. The emergence of LBS and the widespread adoption of GPS-based navigation systems are largely a result of the accuracy with which GPS devices can determine location. The purpose of this study is to validate Wireless internet access points (WiFi APs) for determining location. This research follows three steps: 1.establish the accurate WiFi position for APs; 2. plot transects of signal strength for APs; and 3. interpolate a campus signal strength map from transect data for the University of Saskatchewan campus and validate that map. This is the first step towards the development of a non-GPS location system that can provide accurate location in a fashion that can be seamlessly integrated with GPS.

## 1. INTRODUCTION

Navigation and wayfinding are a routine part of our daily life. Navigation can be described as purposeful locomotion to reach a destination through space (Montello, 2005). Wayfinding is a special case of navigation; wayfinding is the motivated and goal-directed process of selecting a path to a destination (Golledge, 1999). Navigation technology based on GPS positioning has become increasingly ubiquitous as we strive for efficient and successful wayfinding (getting places without getting lost). These technologies represent the most recent in a long line of innovations throughout history that have altered navigation and wayfinding process. For example, the introduction of the internal combustion engine increased locomotion range and dramatically reduced travel time. Additionally, rapid urbanization and the changing urban landscape put additional stress on our wayfinding abilities. In order to make people's locomotion safer, cheaper Global Navigation Satellite System (GNSS) have become popular.

Location aware devices have primarily emerged over the past 15 years. Just as the removal of selective availability by Presidential decision directive in 1996 ushered in an era of dramatic growth in the use of personal GPS devices, the emergence of GPS-enabled smartphones have made location an area of commercial development (Clinton, 2000). Location Based Services (LBS) and the widespread adoption of GPS-based navigation systems have their genesis in the accurate and reliable nature of the certainty with which GPS devices can determine location. While navigation might be considered a special of LBS, in general LBS are associated with delivering information regarding commercial, public, and other services in the area surrounding the user to a mobile device (Steiniger et al., 2006). As a result, location has become a viable starting point for software development targeting handheld devices. Cell phone operating systems including Android, iPhone, and Windows Mobile are making it easier for software developers to integrate a person's current location into information retrieval and delivery. However, due to the relatively weak radio signal upon which GPS relies it is generally unavailable in indoor environments. Such environments include institutions (hospitals, universities), consumer and residential spaces (shopping centres, sprawling apartment complexes), and industrial and commercial buildings. The lack of GPS service in such environments may increase the cost and time to travel to unfamiliar indoor places. Therefore, the development of new location systems that can function with GPS-like accuracy in areas that GPS does not work is central to the extension of LBS into such environments (Borriello et al., 2005).

Many mobile devices, such as cell phones, smartphones, Personal Handheld Assistants (PDA), and laptops already provide LBS relying on GPS-based location as well as more uncertain location derived from WiFi or cellular based systems. Uncertainty and the consumers' lack of awareness of it are problems that must be addressed before widespread deployment of non-GPS location systems can be realized. It seems apparent that the viability of any non-GPS system (including GPS's soon to be available European counterpart, Galileo) dependes on achieving the location accuracy of GPS (sub-10 metre accuracy).

The technologies (WiFi, cellular, and Bluetooth) that could theoretically provide EPS have strengths and weaknesses. While it is well known that GPS does not work indoors or in areas with limited line of sight to the sky (urban and natural canyons), it is this limitation that makes the development of EPS so enticing. In general positioning systems' limitations fall into five categories: 1. non-global coverage, 2. accuracy, 3. security, 4. signal confusion, and 5. power consumption. Considering each location system in turn (GPS included) their weaknesses include:

- **GPS** (signal confusion and power consumption): GPS has a significant advantage in terms of positioning accuracy and reliability in outdoor settings but is unreliable indoors and in dense urban and natural canyons because of signal multipath, scattering, and attenuation (Zhou, 2006).. This Delays in signal acquisition may consume more power than systems relying on local signals. (Weyn and

Schrooyen, 2008). Futhermore, when a GPS-enabled device is in indoors it is continuously looking for visible satellites, consuming precious battery power.

- **Assisted GPS** (signal confusion): Assisted GPS (A-GPS) integrates GPS functionality with cell phone technology (Weyn and Schrooyen, 2008). A-GPS takes measurements of signals from nearby cell phone towers and reports time and distance readings back to the network. It uses these to determining an approximate location as an initial step towards collecting visible satellite information. For this reason, A-GPS doesn't need to acquire visible satellite information for preliminary location determination (Zandbergen, 2009). Although A-GPS is less accurate than a conventional GPS it is suitable for mobile devices as it is faster and consumes less power.
- **GSM** (accuracy and security): the Global System for Mobile communication (GSM) is a digital cellphone protocol used around the world. However, since the technology was developed to support telecommunication the nominal array of towers through which a device communicates is sparse. The optimal array (from an economic perspective) would be the minimum number of towers to cover the expected number of users and call volume. The relatively long range of communication, compared with WiFi and Bluetooth, results in substantial location uncertainty. Even when two towers are within range the area over which a user's possible location resides is quite large. Furthermore, since cellphones requires two-way communication a users' identity is also communicated, presenting security issues.
- **Bluetooth Technology** (non-global coverage): Bluetooth wireless technology was developed as a global standard for short-range data transfer between devices (Bluetooth, 2010). This technology provides a high level of security between pairs of devices. In order to maintain lower energy consumption Bluetooth's maximum data transfer rate is 1Mbps. Bluetooth is essentially a cable-replacement protocol with a short-range (Madhavapeddy and Tse, 2005). Bluetooth technology in most mobile devices has a range of less than 10meters. A Bluetooth system would require an AP array much more dense than WiFi.
- **WiFi Technology** (accuracy, signal confusion, and security): WiFi represents a wireless connection between a WiFi enabled device and wired internet server through distributed APs. Many indoor environments use WiFi as the primary wireless data transfer infrastructure. (Prasithsangaree et al., 2002). In particular, IEEE 802.11 b/g/a/n represent standard WiFi protocols defined by raw data transfer rate and signal frequency. For indoor LBS, WiFi is a common technology for localization (Weyn and Klepal, 2009). However, most WiFi-based LBS fail to provide acceptable accuracy. WiFi-based services also have potential risks including location spoofing and location database manipulation attacks (Tippenhauer et al., 2009).

## 2. NECESSITY OF ENHANCED POSITIONING SYSTEM (EPS)

EPS has the potential to fill gaps in the currently available GPS technology and to provide accurate location information by taking advantages of wireless technology. Many existing LBS use WiFi technology as an alternative indoor positioning source; unfortunately most of them fail to provide sufficient accuracy or clearly communicate levels of location uncertainty (Gallagher et al., 2009). For example, Skyhook provides a widely used hybrid positioning system that combines GPS, GSM, and WiFi positioning for mobile devices, such as laptops, PDAs, and smartphone, (SkyhookWireless, 2010). A WiFi-based positioning system relies on gathering accurate AP Ids and locations for use in determining a devices current location (Jones et al., 2007). Skyhook (and others) has been collecting 802.11 WiFi AP location information and measure signal strength through web-based updates (users entering X, Y coordinates of APs), purposefully signal detection to determine AP location ("wardriving"), and passive signal detection and communication with Skyhook.

Wardriving is the process of evaluating the availability of WiFi networks through passive data collection. Wardriving is primarily preformed in urban areas with dense WiFi availability. Generally the wardriving process involves capturing signal strength and determining AP location; most wardriving integrates GPS (Kim et al., 2006). The estimated location of both APs and signal fingerprints may increase the error for determining locations estimated location may differ from true. This in turn causes problems for current location determination that rely on triangulation or trilateration, both of which depend on the discrete location of APs. The error between the estimated and true location of APs location and reference point will increase uncertainty in any location relying on such AP locations.

Skyhook Wireless is an example of a commercial enterprise collecting AP locations and integrating it with wardriving data. The primary method relies on consumer participation and is a good example of Volunteered Geographic Information (VGI) (Goodchild, 2007). Anyone ca enter AP information on Skyhook's webpage, including Media Access Control (MAC) address, and geographic coordinates. However, there are several issues. First, the collected information could contain unreliable/false information because there is no requirement or restriction for submitting one's own AP information. Submitted information could be intentionally falsified. Furthermore, the submitted AP/router information can change over time and is only updated if a user takes the time to do so. In particular, MAC addresses are the unique identity for each AP but its address can be easily replaced (Tippenhauer et al., 2009). Second, if someone only has limited knowledge about either a WiFi AP/router or geographic coordinate system, there is a higher likelihood of providing incorrect information. Finally, Skyhook's map-based data entry system (Figure 1) does not provide a particularly high resolution map. Skyhook Wireless explains that they are constantly updating and optimizing their positioning determination method and reference database, which contains information regarding APs location and signal strength (Morgan et al., 2006). However, their optimized process might not find all critical errors.


Figure 1. Skyhook 'Submit a Wi-Fi Access Point' Page

## 3. OPPORTUNITIES AND CHALLENGES

Demand for new mobile device applications is rapidly expanding. Software-based applications are able to improve the capability of enabled-technology (hardware-based) in many mobile devices. Most new smartphones include various wireless technologies, such as WiFi, A-GPS (or GPS), Bluetooth, and GSM. Each of these systems can contribute to the integration and development of LBS. Together WiFi, A-GPS, and other included technology are widely used for alternative positioning system (Weyn and Schrooyen, 2008).

A software-based enhanced positioning system could provide supplementary information for mobile device users interested in LBS and navigation. Use of multiple wireless technologies can moderate uncertainty. While a single wireless sensor-based system device would experience a dramatic reduction or complete loss of signal, resulting in an inability to determine current location, overlapping systems can maintain some level of location information while communicating the corresponding reduction in location certainty. For instance, when a GPS device is taken indoors the device is no longer location-aware. However, if such a system was complemented with an additional sensor or multiple sensors, the overlapping location awareness would continue to update current location. When no dramatic change in location certainty occurs the system could appear seamless to the user; on the other hand if there was a decrease in certainty, as would occur if the overlapping location system was GSM-based or based on the location of a single WiFi AP the user could be provided with complementary information regarding the reduction in certainty.

### 3.1 The Structural framework for an Enhanced Positioning System

The implementation of a location determination algorithm is an essential step in providing accurate positioning service with EPS. Wireless technology-based positioning systems can determine location of using one of three methods (Kaemarungsi and Krishnamurthy, 2004):

- Triangulation – computes location based on the geometric properties of triangles such as the angle of arrival and distance to the device from APs (Muthukrishnan et al., 2005). It requires at least two known APs.
- Trilateration – computes the intersections of sphere surfaces given distance from the centers to the intersection (Li et al., 2006). It requires at least three known APs. Four base stations are required for 3D location (since WiFi does not provide altitude information elevation is not possible from a WiFi-based EPS).
- Fingerprinting – determines location based on matching process between signal strength in current location and measured signal strength in the reference database (Borriello et al., 2005).

### 3.2 Structural requirements for EPS:

- Precise APs Location: Having precise location of APs is the first criteria for building a reference database for EPS. True location of available APs significantly increases the accuracy of WiFi-based positioning (Kim et al., 2006).
- Flexible attribute table: Additional attribute data may provide more flexibility so each AP's attribute table should contain spatial (geographic coordinate information and relative location) and non-spatial detail for each AP (SSID, BSSID, MAC address, Signal Strength (dbm), Collected time, and maximum range under ideal circumstance).
- Data validation: Wi-Fi connectivity is rapidly growing. The validation process should consider not only newly installed APs, but also old APs, which can be update, removed, or replaced. For these reasons the AP location database should be updated and validated periodically.
- Reference Database: Once all required data is obtained, all attribute information should be stored.
- Validation of signal strength and location certainty: Once a signal strength map is interpolated this map should be validated.

## 4. ADDING VALUE TO A WIFI NETWORK

The University of Saskatchewan (U of S) provides a dense publicly available WiFi network on a compact campus that consists of extensive indoor and outdoor spaces. In fact, the core area of campus is covered by a dense array of APs offering more than two visible routers from most locations, indoors and outdoors. As a relatively traditional university campus there are many multi-floor buildings and the main area of campus is not integrated with the surrounding urban environment. One characteristic of the router environment that results from this latter feature is the relative lack of inclusion of campus routers on public sites such as Wigle.net. However, the campus does provide router location information to Skyhook; unfortunately, this information appears to be limited to street address information or clicking on a web map of campus, requiring Skyhook to geocode addresses, resulting in additional uncertainty in locations based on the router network. Therefore, in order to create a foundation for WiFi-based EPS several steps are necessary.

### 4.1 Accurately map router location

There are more than 700 wireless APs currently installed (winter, 2010) on the U of S campus. Already installed and newer APs have been set up by university's Information Technology Services (ITS) in a consistent manner and those APs' spatial information is maintained by university's Facility Management Department (FMD). Both base map and CAD-drawn blueprints (Figure 2) were used in our AP mapping process. Informational of this spatial information was integrated with detailed AP information all provided by ITS (Figures 3). This AP data did not initially contain precise geographical information, hence the need for blueprints, maps, and installation information.

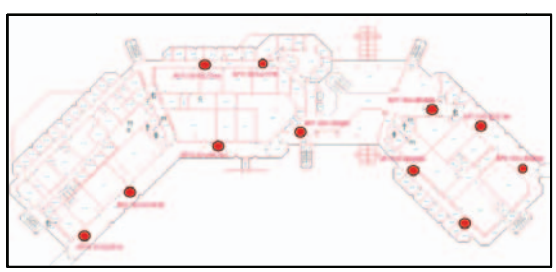

Figure 2. A blueprint for Agriculture building second floor

| Radio Address | Ethernet Address | System Name | Location |
|---|---|---|---|
| 00:17:0f:e6:60:e0 | 00:17:e0:98:61:ac | AP1130-9861ac | Arts 5th Fl South |
| 00:17:ef:e6:6b:d0 | 00:17:e0:98:63:0e | AP1130-98630e | Arts 5th Fl North |
| 00:17:0f:e6:75:30 | 00:17:e0:98:64:32 | AP1130-986432 | Arts 6th Fl South |
| 00:17:0f:e6:71:c0 | 00:17:e0:98:63:c6 | AP1130-9863c6 | Arts 6th Fl North |
| 00:1a:e3:77:d0:00 | 00:1b:53:02:1f:c6 | AP1130-021fc6 | Arts 7th Fl South |
| 00:1f:ca:cd:5a:10 | 00:1d:e5:56:7b:dc | AP1130-567bdc | Arts 7th Fl North |
| 00:1f:ca:84:8b:c0 | 00:1d:e5:56:7a:c0 | AP1130-567ac0 | Arts 8th Fl South |
| 00:1f:ca:84:88:10 | 00:1d:e5:56:7a:24 | AP1130-567a24 | Arts 8th Fl North |
| 00:23:5e:4a:d9:20 | 00:21:d8:48:27:78 | AP1130-482778 | Arts 9th Fl South |
| 00:21:a0:02:b7:50 | 00:21:d8:48:58:18 | AP1130-485818 | Arts 9th Fl North |
| 00.17.0f.e6.70.00 | 00.17.e0.98.63.9a | AP1130-98639a | Arts 10th Fl South |
| 00.17.0f.e6.6e.60 | 00.17.e0.98.63.5e | AP1130-98635e | Arts 10th Fl North |
| 00.17.0f.e6.6c.c0 | 00.17.e0.98.63.2c | AP1130-98632c | Arts 11th Fl South |
| 00.17.0f.e6.6f.70 | 00.17.e0.98.63.7e | AP1130-98637e | Arts 11th Fl North |
| 00.1a:e3:d3:15:80 | 00:1b:53:c8:52:64 | AP1130-c85264 | Athabasca Hall 126 |
| 00:12:43:b9:7d:c0 | 00:12:43:85:5e:a8 | AP1200-855ea8 | Athabasca Hall 149 Hallway |
| 00:1a:e3:d0:10:40 | 00:1b:53:02:27:d8 | AP1130-0227d8 | Athabasca Hall 170 |
| 00:1a:e3:d3:14:d0 | 00:1b:53:c8:52:4e | AP1130-c8524e | Athabasca Hall 226 |
| 00:1a:e3:d2:ac:00 | 00:1b:53:c8:45:34 | AP1130-c84534 | Athabasca Hall 326 |

Figure 3. A Spreadsheet for Access Points Information

**Access Points Location Mapping**

All base maps and CAD-drawn blueprints for all campus buildings from FMD were georeferenced to 'NAD 84 UTM Zone 13 North coordinate system with ArcGIS$^{TM}$. Once a georeferenced image was produced it was used to locate APs on the campus map. Individual APs in blueprints were digitized as point features and digitized points were compared with spreadsheet information. There were several missing APs and some APs location descriptions were different. Visual inspection of APs was performed to ensure that digitized APs were correct and placed in the correct location. While visual inspection was performed, AP MAC addresses were also validated for all sources (spreadsheet and georeferenced and digitized maps).

### 4.2 Signal Strength Transects

Raw signal strength data was collected for the campus core area and was performed along transects in four orthogonal paths starting from each AP location (Figure 4). Signal strength collected from hallways, bridges, and tunnels from indoors and along paths as dictated by plotted transects. The Panasonic CF-T5 personal laptop running with 'Windows XP$^{TM}$ Professional Service Pack 3' was used for the data collection. The laptop's an Intel® Wireless WiFi Link 4965 ABG (802.11 a/b/g) wireless card.


Figure 4. Warwalking Path

Netstumbler 0.4.0 was used for detecting available WLAN service and collecting WiFi signal strength data (Figure 5). Netstumbler observes all APs within the wireless card's visible range (Li et al., 2007). It does this by "pinging" nearby APs and "listening" to the return message from the router to find the signal strength and of the surrounding WLAN.

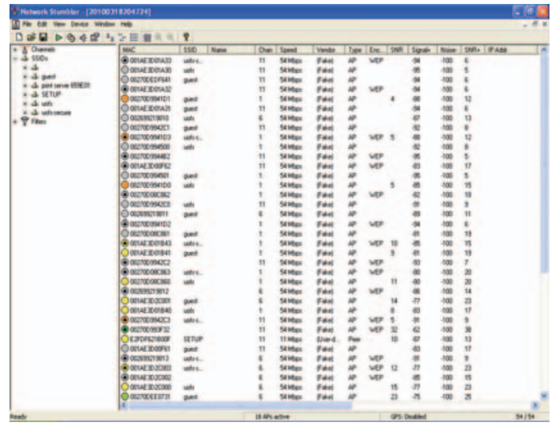

Figure 5. NetStumbler Windows

**Data Collection**

Signal strength data was collected continuously along each transect from all visible APs to the laptop. However, the raw data, which was recorded by Netstumbler didn't contain spatial information. Spatial and signal strength data were integrated after data was collected: Starting and ending points for each transect were determined then X-Y coordinates were digitized for each point in ArcGIS. This allowed for the conversion of Netstumbler data into a mappable GIS format. All collected data was converted to point data for each transect. A Python scripts was used for converting text file from Netstumbler into a shape file.

### 4.3 Interpolate campus signal strength to 1 meter grids

Data collection resulted in more than 100 reference points for each AP. These points only showed the WiFi signal strength changes along the experimental path.

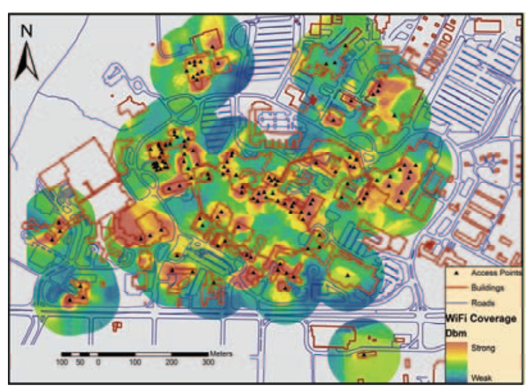


Figure 6. WiFi Availability

From this raw data the estimated WiFi coverage was established through spatial interpolation. Inverse Distance Weight (IDW) was used as a method of interpolation to estimate signal strength across campus. IDW estimates each cell's values by averaging the values of collected data points in the neighbourhood of each cell (McCoy and Johnston, 2002). The closer cells have more influence or weight (higher average value) than more distant cells (see figure 6 for the resulting signal strength map).

## 5. RESULTS

The purpose of producing a WiFi coverage map is to validate the distribution and consistency of the WiFi network on campus. Measurements were made across the campus to allow for a comparison with interpolated WiFi signal strength in the core area of wireless coverage. A set of measurements collected with the same device used on transects was used for validation. A total of thirteen measurements were collected from twelve different positions in both outdoor and indoor settings (Figure 7).

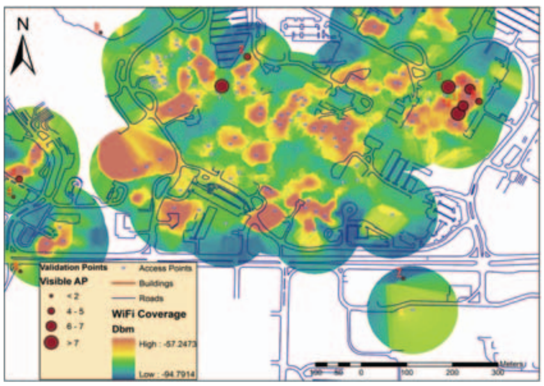


Figure 7. Validation Points Location

Seven measurements were collected outside of buildings around campus and five measurements were collected from inside a single campus building where we anticipated interference from its structural complexity. Each validation position received signals from 2 to 11 APs. Each set of measurements consists of 30 seconds of data collected at a 1 second sampling interval.

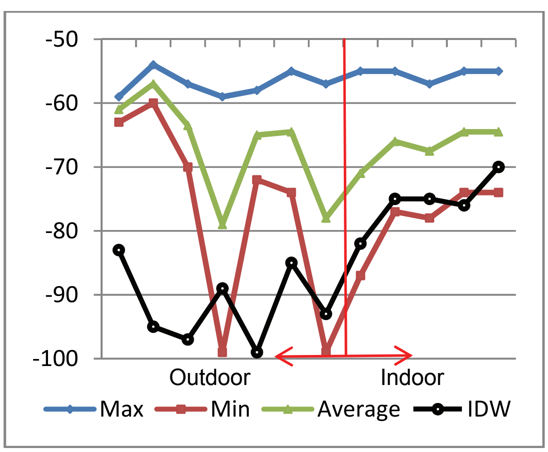


Figure 8. Comparison signal strength between validation points and IDW map. (Max, Min, & Average: reading from validation points, IDW: reading from IDW map)

After analyzing all validation points, there were some interesting differences between the actual reading of signal strength and estimated signal strength (IDW) (Figure 8). For indoor validation points, the values in IDW maps and the values from reference points matched quite well. IDW appeared to provide quite good estimation for indoor environments but was less accurate for outdoor spaces. Furthermore, our software and data collection methods appeared to generate more outliers in outdoor settings. WiFi measurements in outdoor environments could be affected by signal interference or the presence of other wireless devices that are not part of the formal campus network. Validation of the coverage map is important to the development of optimized algorithms for EPS with high efficiency and certainty.

## 6. CONCLUSIONS AND FUTURE WORK

EPS is designed for spaces in which GPS cannot provide reliable location information. EPS has the potential to provide seamless positioning service in indoor and outdoor environments. The evolution of mobile devices places high demand on new functionality; the proposed system can be used as an additional feature on WiFi enabled smartphones. One of the criteria for a system based on our research is that the navigation device with EPS communicates with an external server in order to access spatial and non-spatial information regarding APs. A design that accesses an external database reduces demand on a device's processor. The obvious drawback is that the application requires a connection to the server to determine current location based on employed positioning algorithms (however, this latter task could also be performed off-device at the server).

WiFi-based EPS has many potential benefits for developing indoor location aware services. First, EPS doesn't need to employ any special infrastructure for its service. Once EPS is successfully deployed, it may trigger the proliferation of EPS related services and software because of the extensive availability of WiFi and flexibility of software-based applications. Furthermore, EPS can provide location aware service without requiring additional hardware; the user simply downloads the software-based application to their mobile devices. Finally, EPS can deliver location information to the user with certainty and consistency both indoors and outdoors.

An interesting result of the WiFi validation process is the difference between indoor and outdoor locations. Reduced accuracy outdoors is likely the result of interference from buildings and other structures. Fortunately these are the environments in which GPS can provide reliable and accurate location information. Future work should help explain the differences in location in different types of environments. Such research can help move EPS from limited implementation with questionable accuracy to one which can be seamlessly integrated with GPS.

## 7. References

Bluetooth, 2010. Bluetooth Basics. http://bluetooth.com/English/Pages/Default.aspx.

Borriello, G., Chalmers, M., LaMarca, A. and Nixon, P., 2005. Delivering real-world ubiquitous location systems. Communication of the ACM, 48(3): 36-41.

Clinton, W., 2000. Statement by the President Regarding the United States' Decision to Stop Degrading Global Positioning System Accuracy. Office the the Press Secretary, The White House.

Gallagher, T., Li, B., Kealy, A. and Dempster, A., 2009. Trials of commercial Wi-Fi positioning systems for indoor and urban canyons, IGNSS symposium 2009, Gold Coast, Australia.

Golledge, R.G., 1999. Human wayfinding and cognitive maps. Wayfinding behavior: Cognitive mapping and other spatial processes. Johns Hopkins University Press, Baltimore, 5-45 pp.

Goodchild, M., 2007. Citizens as sensors: the world of volunteered geography. GeoJournal, 69(4): 211-221.

Jones, K., Liu, L. and Alizadeh-Shabdiz, F., 2007. Improving Wireless Positioning with Look-ahead Map-Matching, The Annual International Conference on Mobile and Ubiqutous System: Networking and Services. Citeseer, Philadelphia, PA, pp. 1-8.

Kaemarungsi, K. and Krishnamurthy, P., 2004. Properties of indoor received signal strength for WLAN location fingerprinting, Annual International Conference on Mobile and Ubiqutous System: Networking and Services, Boston, MA, pp. 14?3.

Kim, M., Fielding, J. and Kotz, D., 2006. Risks of using AP locations discovered through war driving. Lecture Notes in Computer Science, 3968: 67-82.

Li, B., Kam, J., Lui, J. and Dempster, A., 2007. Use of Directional Information in Wireless LAN based indoor positioning, International Symposium on GPS/GNSS. Citeseer, Sydney, Australia.

Li, B., Salter, J., Dempster, A. and Rizos, C., 2006. Indoor positioning techniques based on wireless LAN, IEEE International Conference on Wireless Boradband and Ultra Wideband Communication. Citeseer, Sydney, Australia, pp. 13-16.

Madhavapeddy, A. and Tse, A., 2005. A study of bluetooth propagation using accurate indoor location mapping. UbiComp 2005: Ubiquitous Computing: 105-122.

McCoy, J. and Johnston, K., 2002. Using ArcGIS spatial analyst. ESRI Press.

Montello, D., 2005. Navigation. In: P. Shah and A. Miyake (Editors), The Cambridge handbook of visuospatial thinking. Cambridge University Press, Cambridge, pp. 257-294.

Morgan, E., Shean, M., Alizadeh-Shabdiz, F. and Jones, R., 2006. Continuous data optimization by filtering and positioning systems. Google Patents.

Muthukrishnan, K., Lijding, M. and Havinga, P., 2005. Towards smart surroundings: Enabling techniques and technologies for localization, The First International Workshop on Location- and Context-Awareness. Springer, Munich, Germany, pp. 34.

Prasithsangaree, P., Krishnamurthy, P. and Chrysanthis, P., 2002. On indoor position location with wireless LANs, The 13th IEEE PIMRC Conference. Citeseer.

SkyhookWireless, 2010. How It Works. www.skyhookwireless.com.

Steiniger, S., Neun, M. and Edwardes, A., 2006. Foundations of location based services. CartouCHe-Lecture notes on LBS, 1.

Tippenhauer, N., Rasmussen, K., Poper, C. and Capkun, S., 2009. Attacks on public WLAN-based positioning systems, The ACM/Usenix International Conference on Mobile Systems, Applications and Services. ACM New York, NY, USA, Krakow, Poland, pp. 29-40.

Weyn, M. and Klepal, M., 2009. Adaptive Motion Model for a Smart Phone Based Opportunistic Localization System. Mobile Entity Localization and Tracking in GPS-less Environnments: 50-65.

Weyn, M. and Schrooyen, F., 2008. A Wi-Fi Assisted GPS Positioning Concept., ECUMICT, Gent, Belgium.

Zandbergen, P., 2009. Accuracy of iPhone Locations: A Comparison of Assisted GPS, WiFi and Cellular Positioning. Transactions in GIS, 13(s1): 5-25.

Zhou, R., 2006. Wireless indoor tracking system (WITS). Aktuelle Trends in der Softwareforschung, Tagungsband zum doIT Software-Forschungtag. dpunkt. verlag Heidelberg, Germany. To appear.

## 8. ACKNOWLEDGEMENTS

This research was kindly supported by the GEOIDE NCE as part of PIV03, Multi-sensor Systems for Tracking an Mobility Application