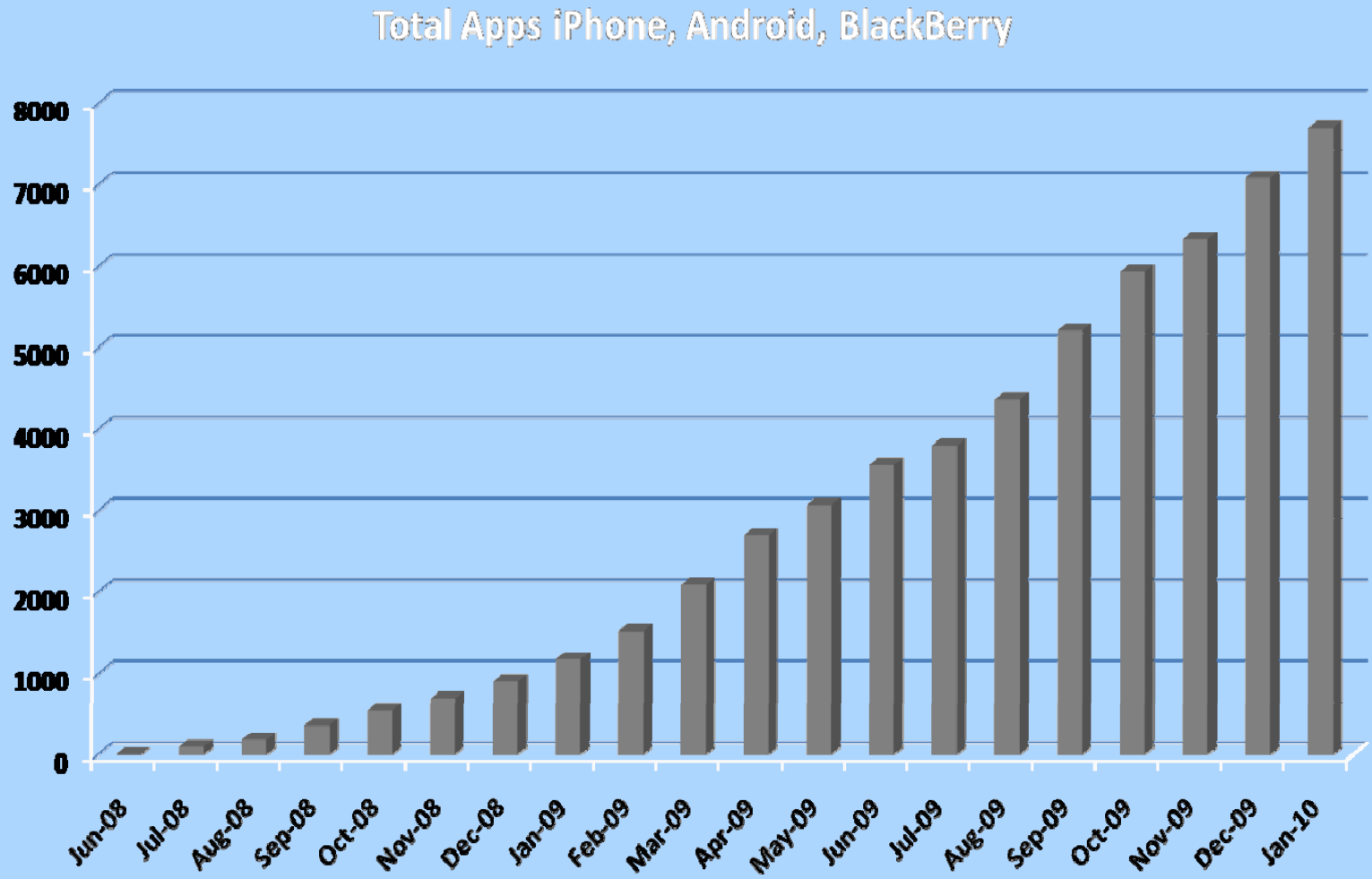
Stanford's 2010 PNT Challenges and Opportunities Symposium

# Wi-Fi Localization and its Emerging Applications

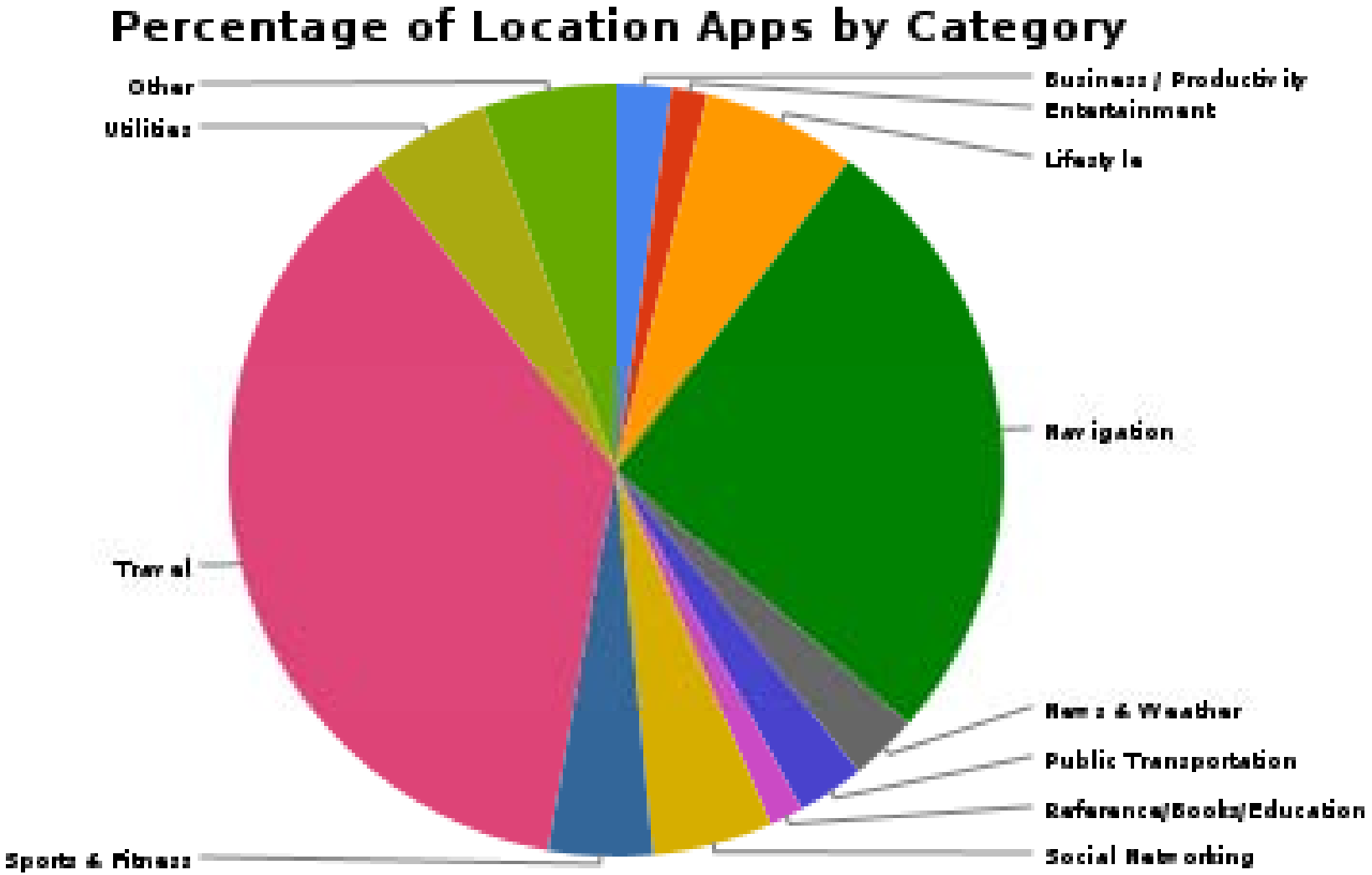
*Kaveh Pahlavan,*
*CWINS/WPI & Skyhook Wireless*

November 9, 2010

# LBS Apps from 10s to 10s of Thousands




Source: Skyhook Wireless



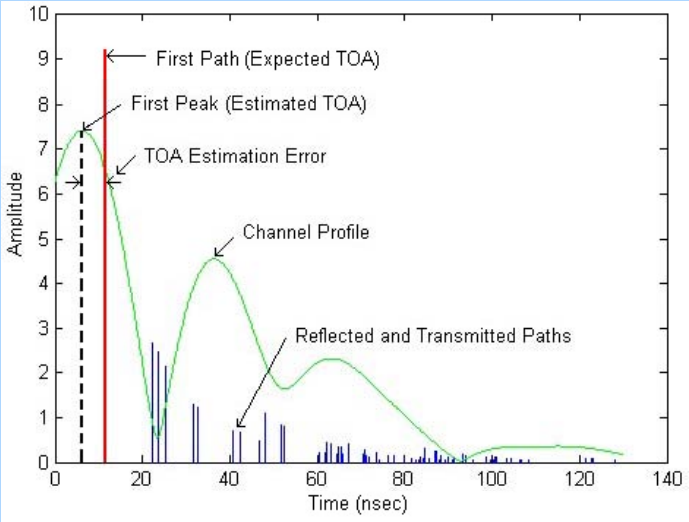

Source: Skyhook Wireless

# WiFi Pos Moved to the Core

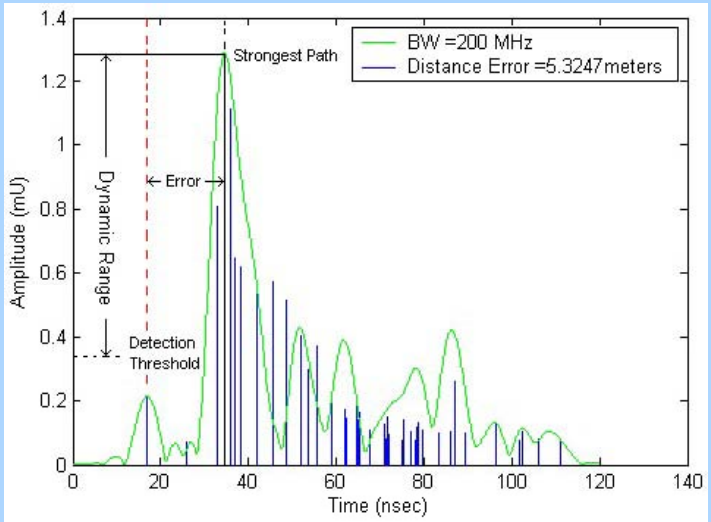

Source: Skyhook Wireless

# Challenges for TOA systems

- The first path is not detectable by measurement system - Undetected Direct Path (UDP) [Pah98]
- Measurement bandwidth is not wide enough to distinguish the first few paths from each other [Ala03]




Limitations on Bandwidth

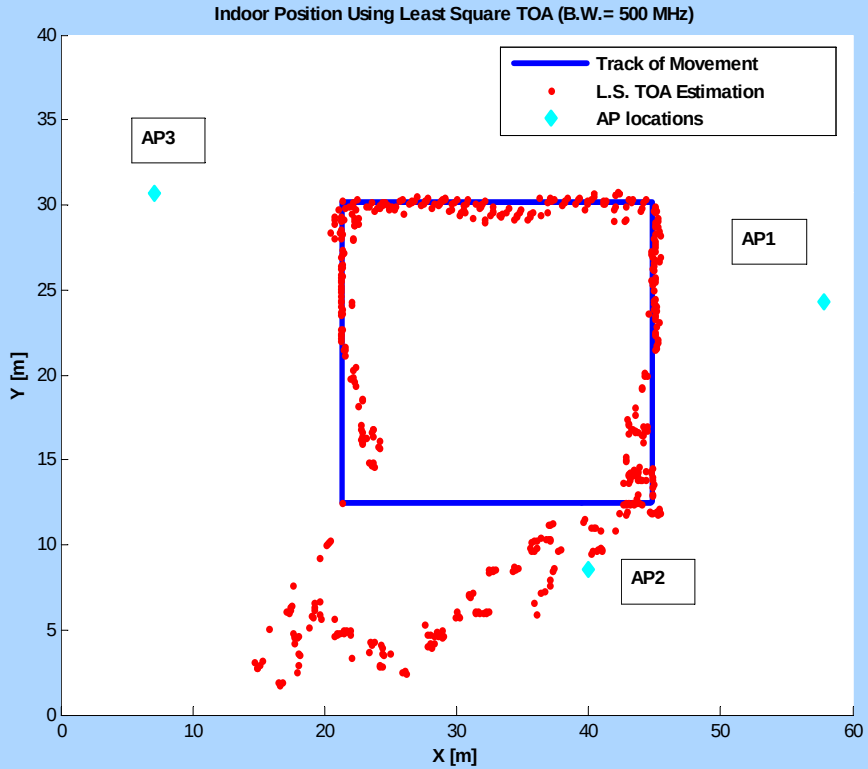


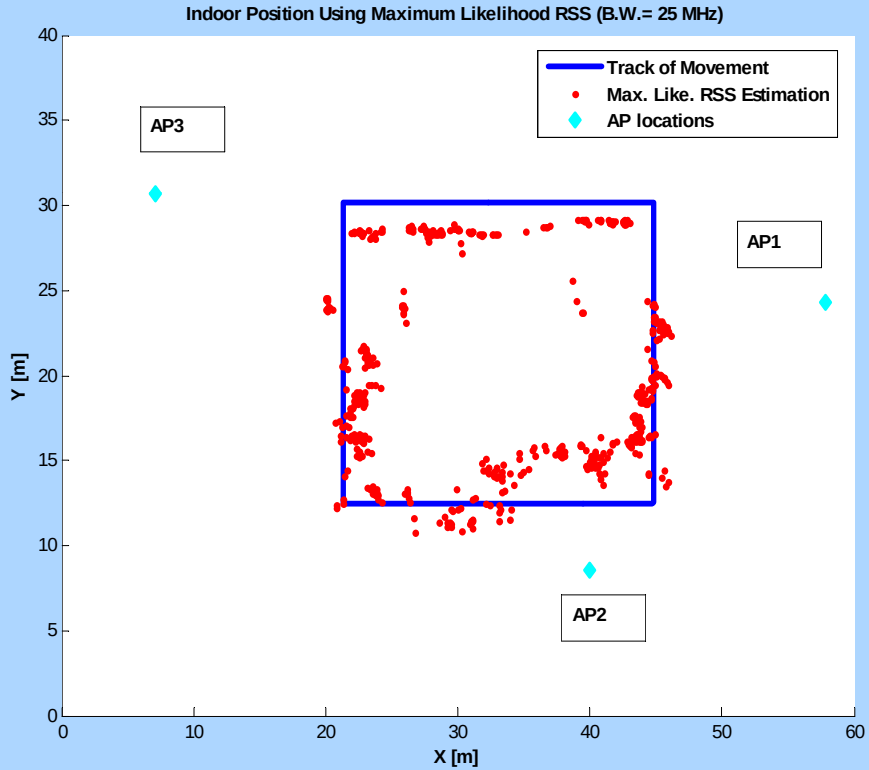

Undetected Direct Path

[Pah98] K. Pahlavan, P. Krishnamurthy and J. Beneat, "Wideband Radio Propagation Modeling for Indoor Geolocation Applications", IEEE Communications Magazine, April 1998.

[Ala03] B. Alavi and K. Pahlavan, "Bandwidth Effect on Distance Error Modeling for Indoor Geolocation," 14th Annual IEEE International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC'03), Beijing, China, September 7-10, 2003.

# TOA vs RSS




A. Hatami, and Kaveh Pahlavan, " Comparative statistical analysis of indoor positioning using empirical data and indoor radio channel models," *Consumer communications and networking conference*, 2006

# RSS-Based Wi-Fi Localization

- RSS is the most popular metrics for WiFi localization
- Average power can be easily measured without any specific knowledge of the transmitted pulse shape
- Effects of multipath fading is eliminated when we use average power for localization but shadow fading will remain as the main source of error.
- The CRLB for performance shows large errors which are proportional to the distance [1]

$$\sigma_D^{\,2} \geq \frac{(\ln 10)^2}{100} \frac{\sigma_{sh}^{\,2}}{n_p} d$$

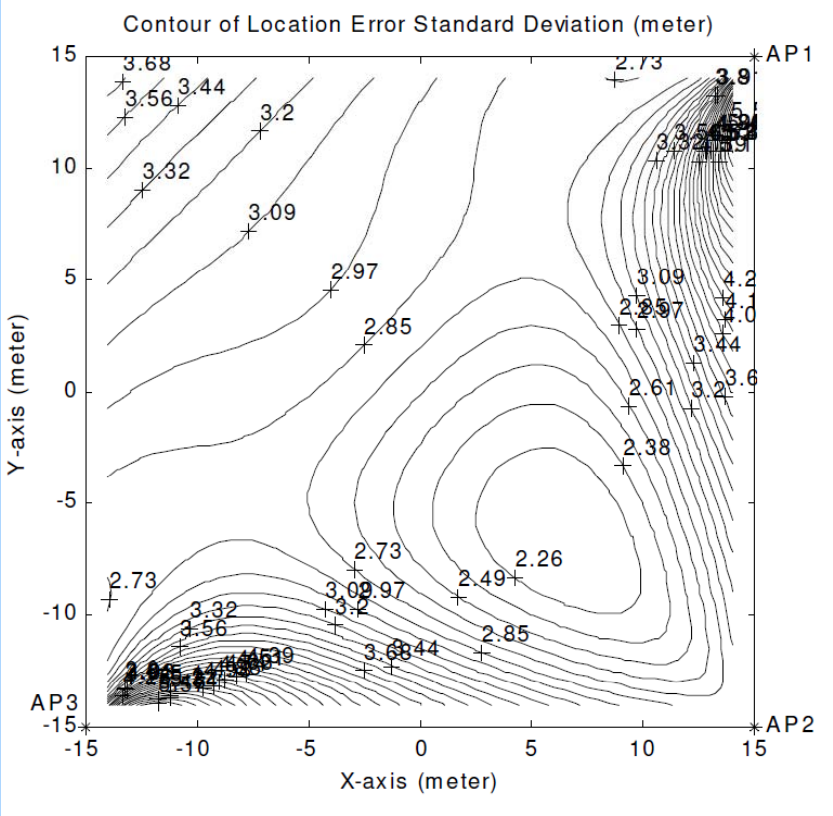
$\sigma_{sh}$ : standard deviation of zero mean gaussian random variable representing log-normal shadowing

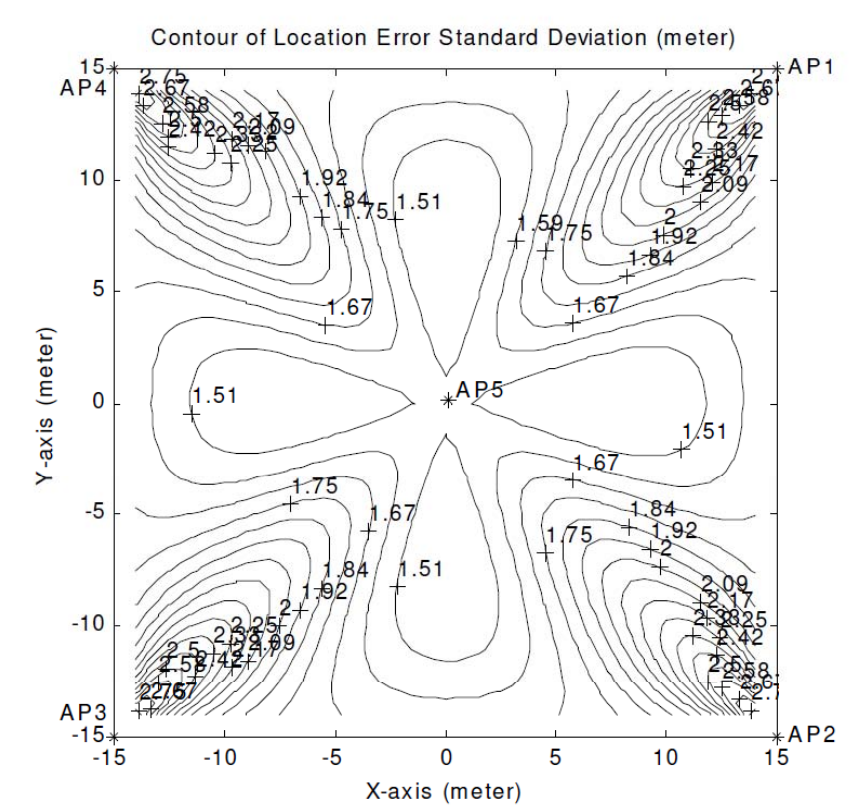
$n_p$ : path loss factor

$d$ : distance between two nodes

[1] Y. Qi and H. Kobayashi, On relation among time delay and signal strength based geolocation methods, in Proc. IEEE Global Telecommunications Conf. (GLOBECOM03), San Francisco, CA, Dec. 2003, vol. 7, pp. 40794083.

# Examples of bounds for RSS

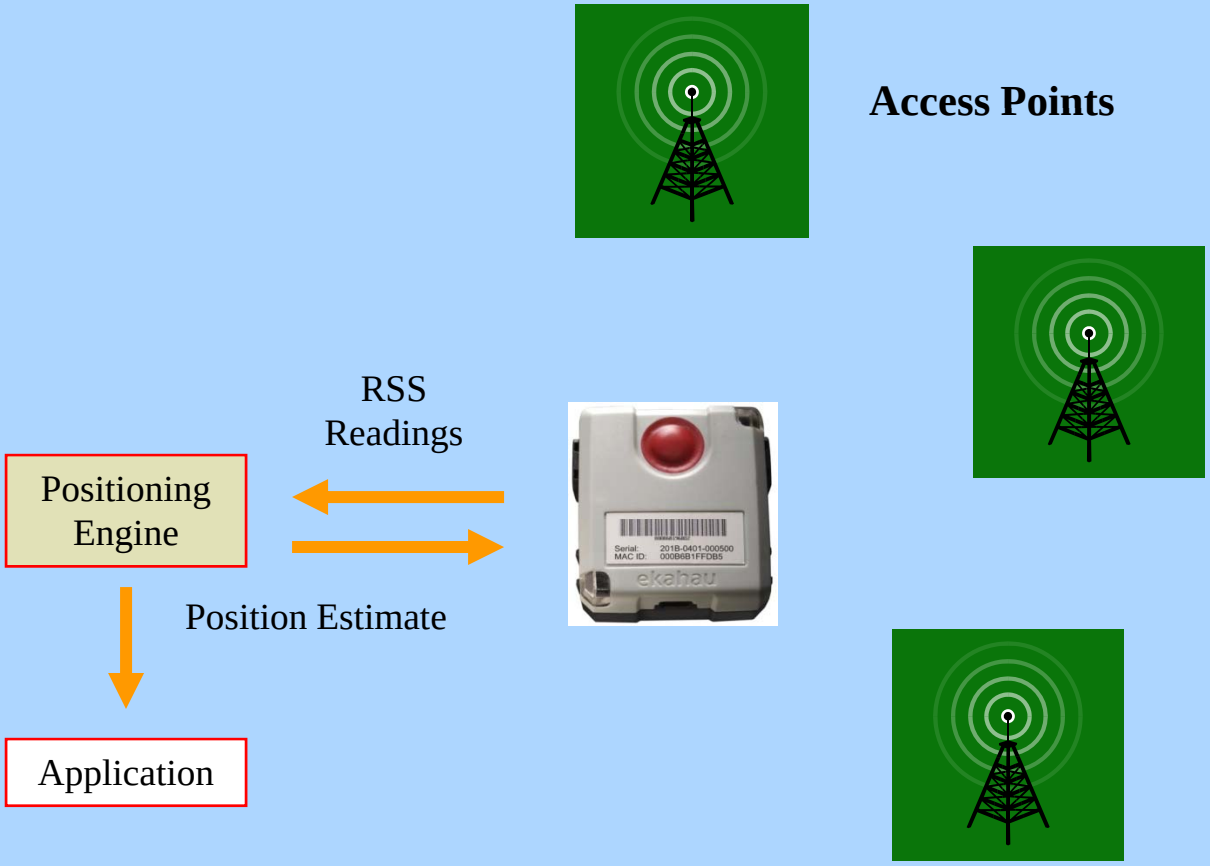



Chen, Y. & Kobayashi, H. (2002). Signal Strength Based Indoor Geolocation. Proceedings of the IEEE International Conference on Communications. pp 436-439. 28 April – 2 May 2002. New York.

# RTLS for Asset Tracking

# How does RTLS work?




**Two steps: (1) Sight survey to create a reference data base**
**(2) use the data base to locate a users**

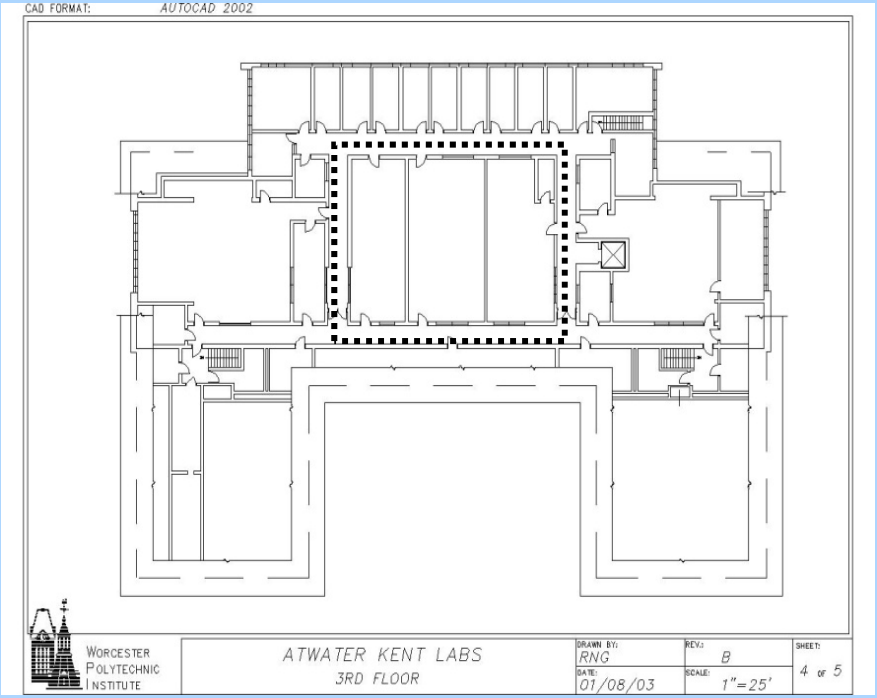
# RTLS for Asset Tracking

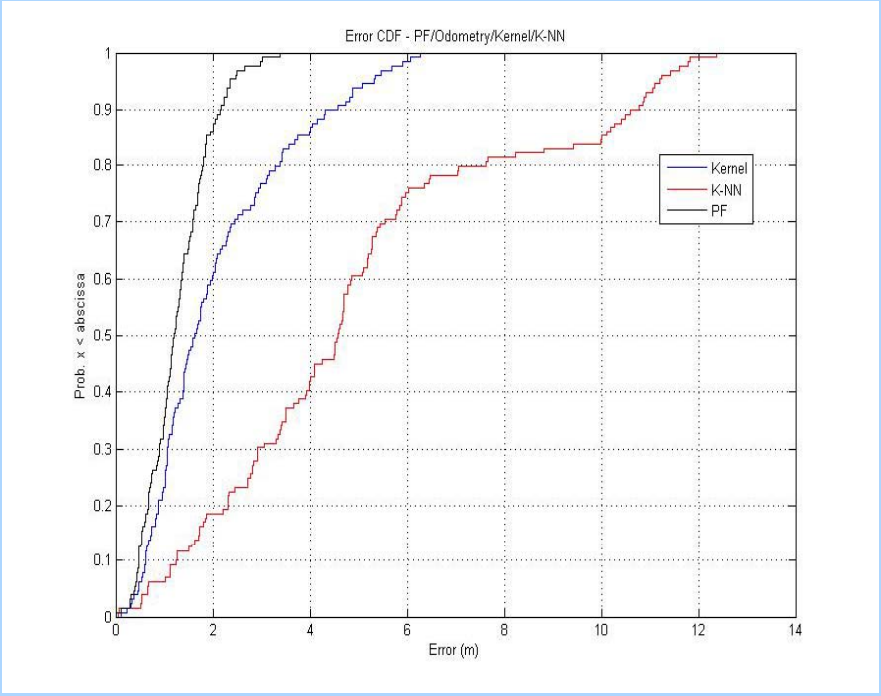
**Customer corporate is responsible for the site survey and it has access to exact location of the APs the product and the algorithm is developed by a company**

Source: Supply Insight website

# Inertial Systems in Robotics


# Simulation Results



# Challenges

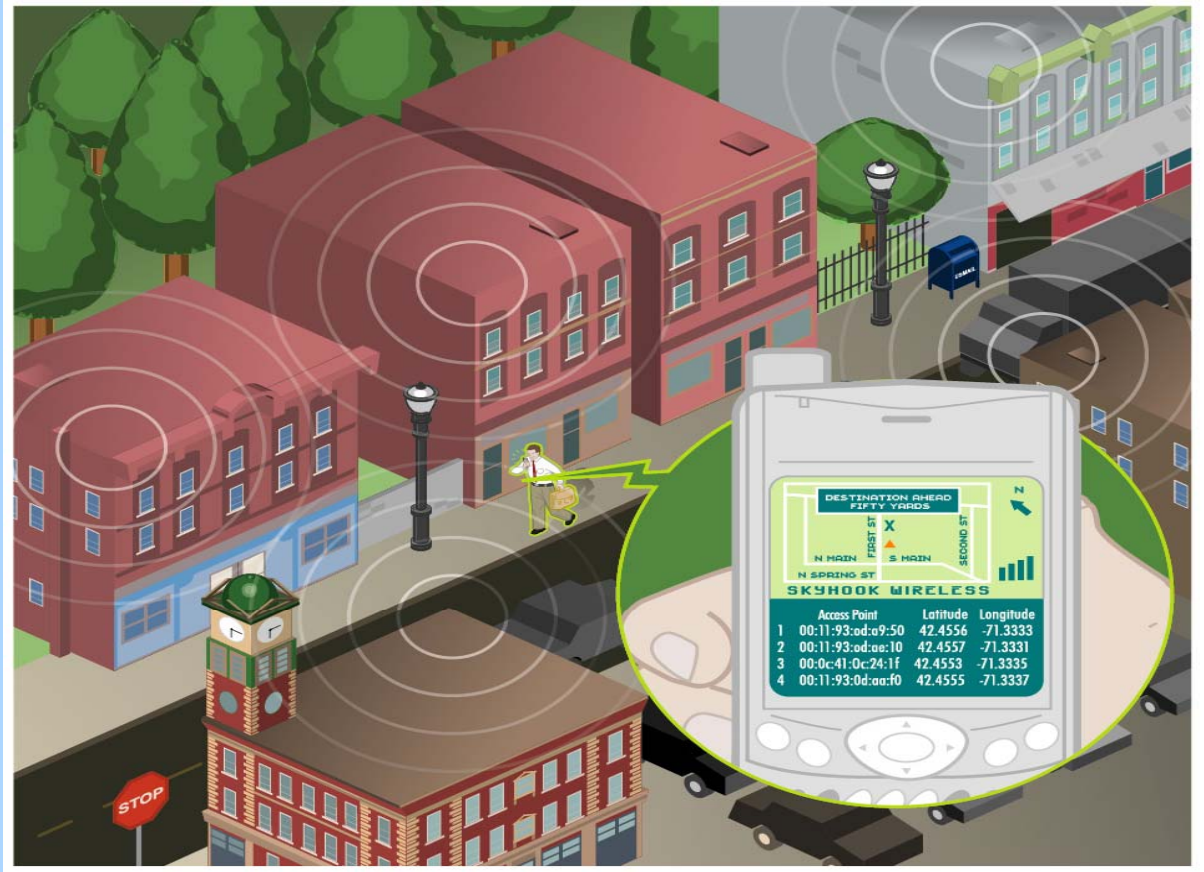
- Database Collection
  - Find more efficient geo-tagging techniques
- Algorithms
  - Improve accuracy by fusion of Wi-Fi and inertial systems
- Business
  - Expand the market to increase revenue

# WPS: a Software GPS

# Wi-Fi Localization and GPS

- Wi-Fi localization first appeared in the literature in 2000
  - P. Bahl and V. Padmanabhan, “RADAR: an in-building RF-based user location and tracking system,” *IEEE INFOCOM*, Israel, March 2000.
  - X. Li and K. Pahlavan, M. Latva-aho, and M. Ylianttila, "Indoor Geolocation using OFDM Signals in HIPERLAN/2 Wireless LANs," *In proc. IEEE PIMRC*, vol.2, pp. 1449-1453, London, Sep. 2000.
- GPS is not designed for indoor Wi-Fi localization complements it by
  - Support of robust indoor coverage
  - Reduction in time to fix
  - Reduction in power consumption
  - Resistance to interference
- GPS complements WiFi localization in
  - Outdoor coverage
  - Universal coordinate reference frame

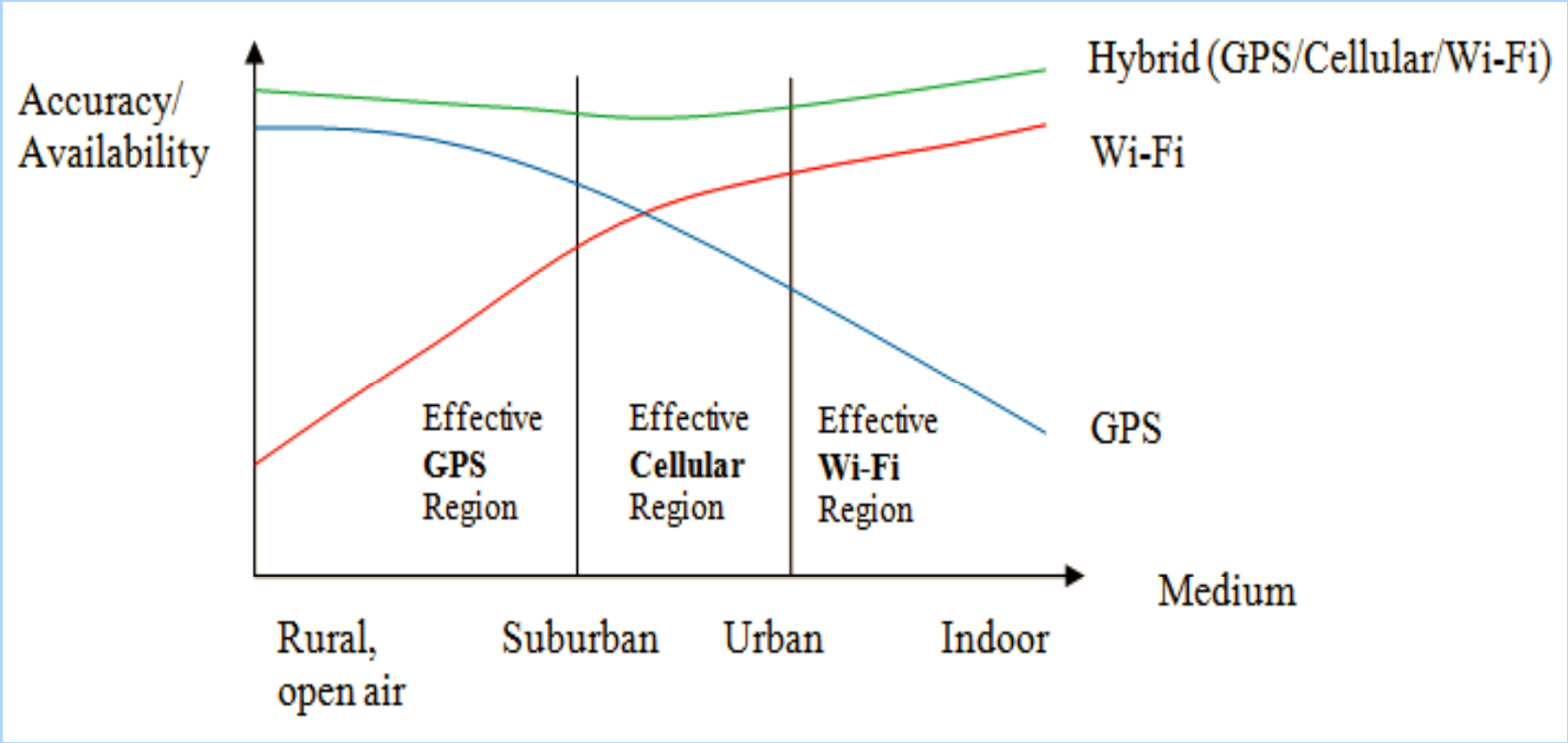
# WPS Application Scenario




**A service provider is in charge of surveying and algorithm development and that company does not know the exact location of APs**

Source: Skyhook Wireless

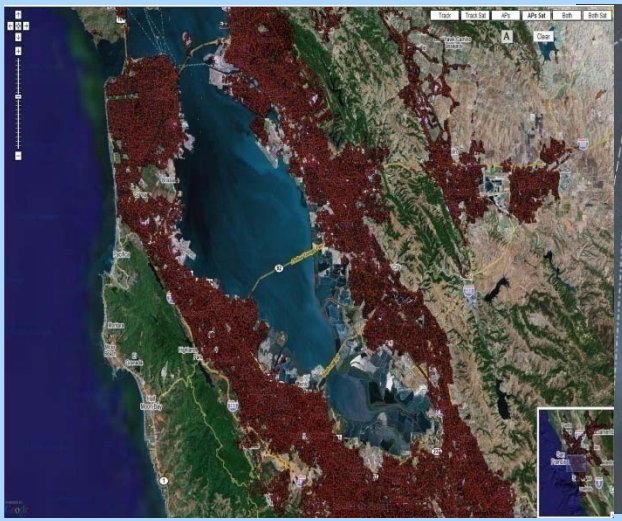
# Performance and Environment



# Smart Devices

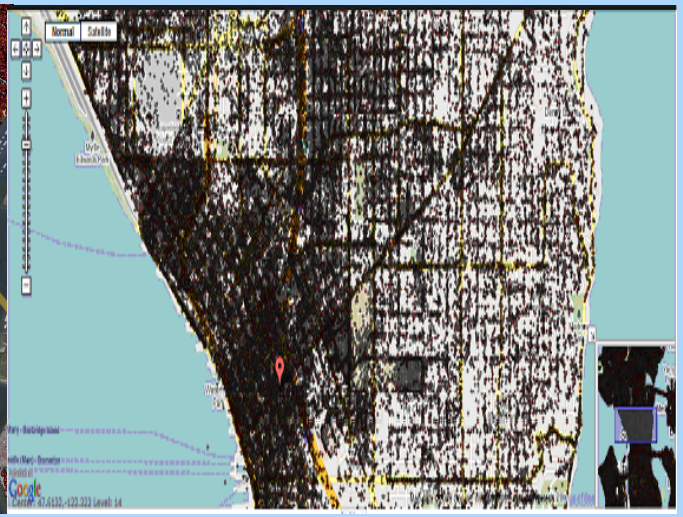



# Wi-Fi Location Data Base



Bay Area

Manhattan

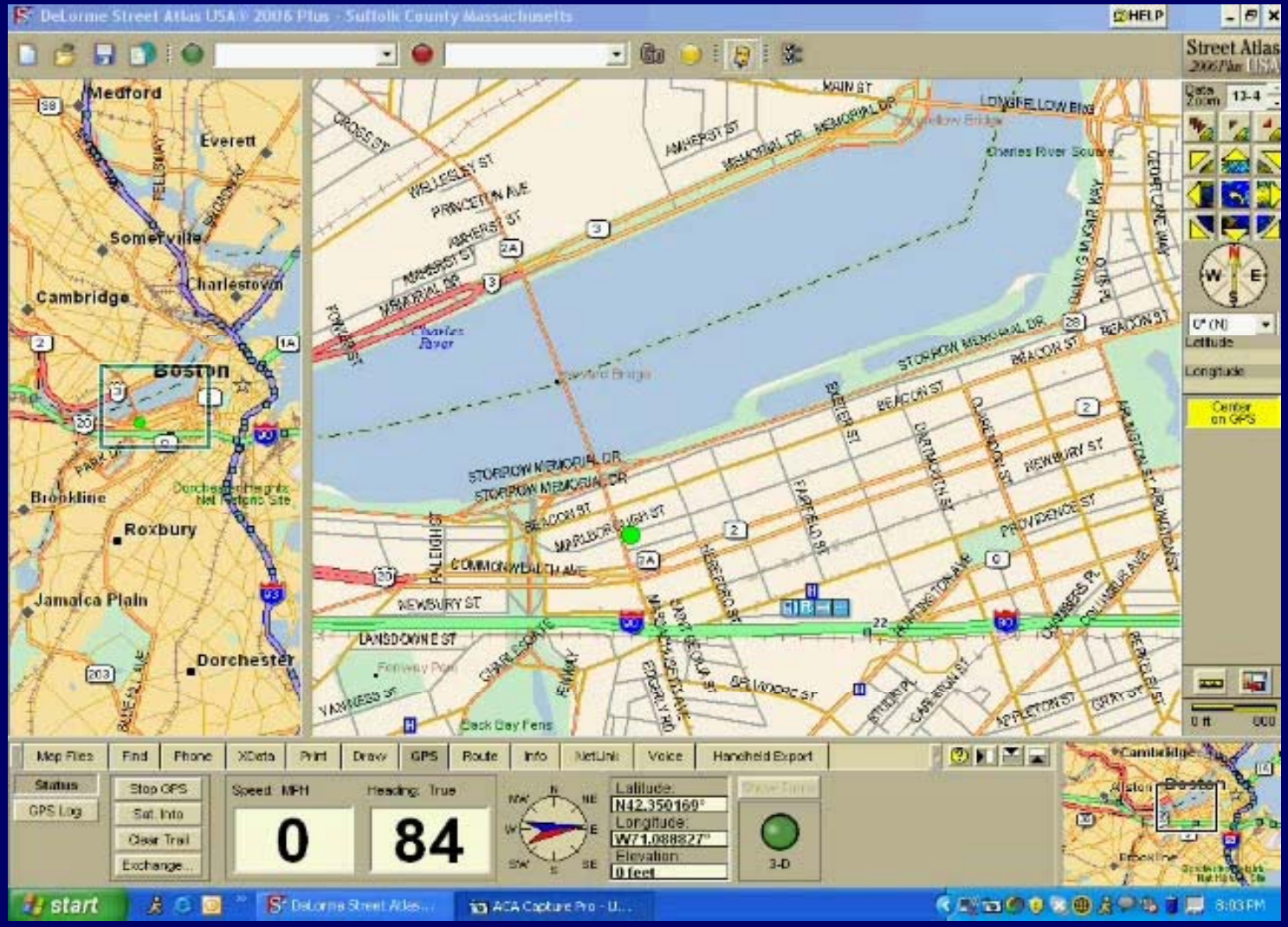


Seattle

- Skyhook data base has over 200 million APs on top cities around the world
- Client software calculates location using reference database and Skyhook algorithms

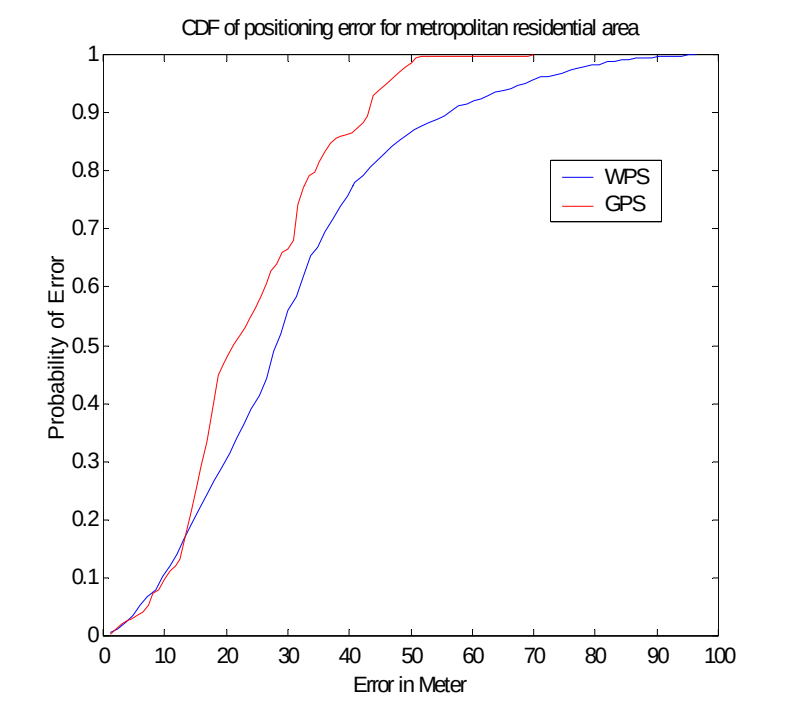
Source: Skyhook Wireless

# WPS: A Software GPS

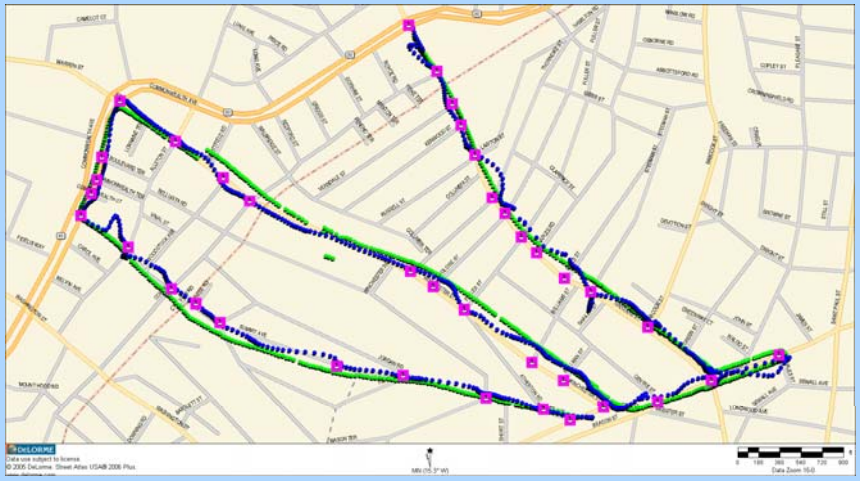



Source: Skyhook Wireless

# Boston Metro Residential

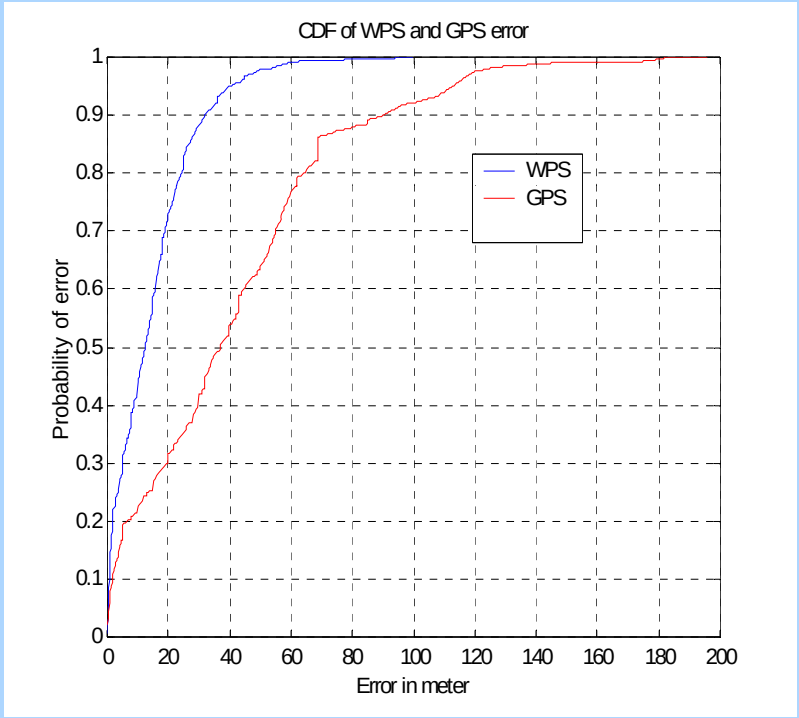


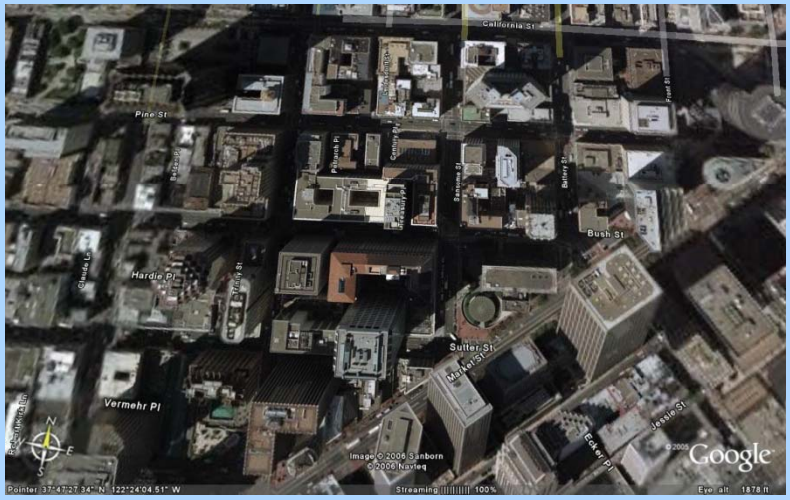


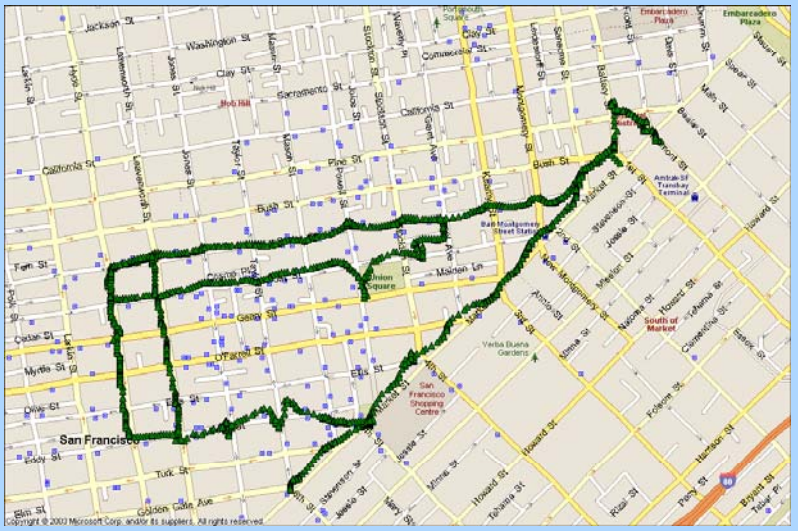


Source: Skyhook Wireless

# San Francisco Downtown



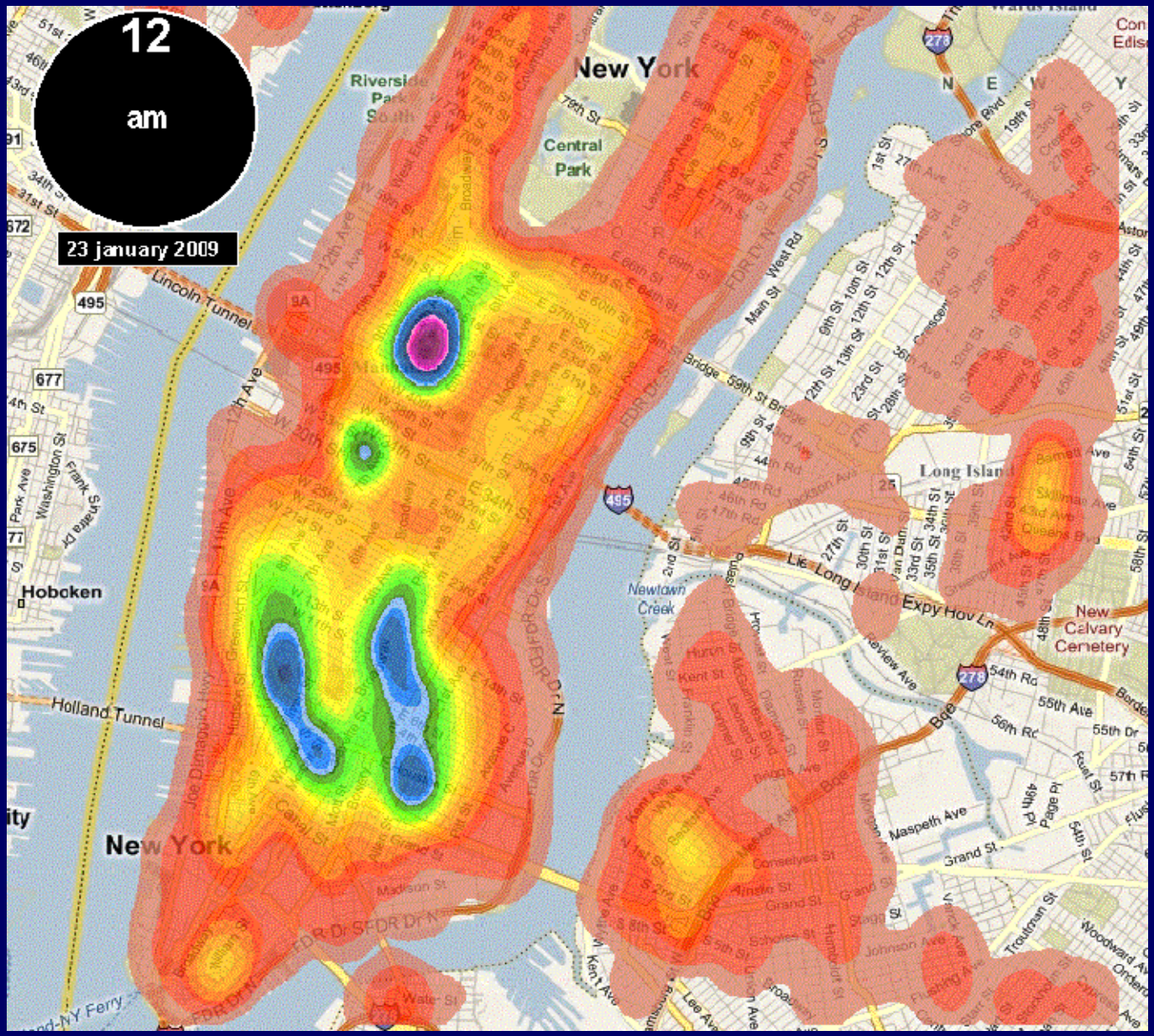




Source: Skyhook Wireless

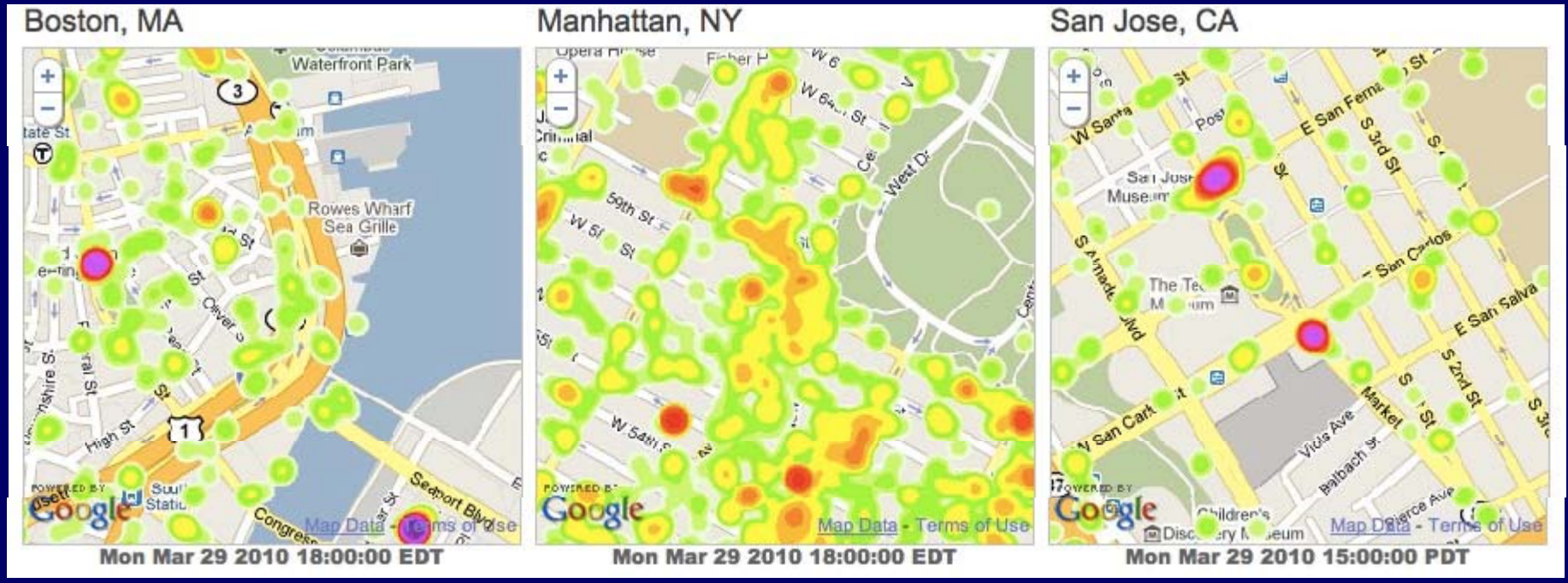
# Next phases of location technology


Source: Skyhook Wireless




Source: Skyhook Wireless

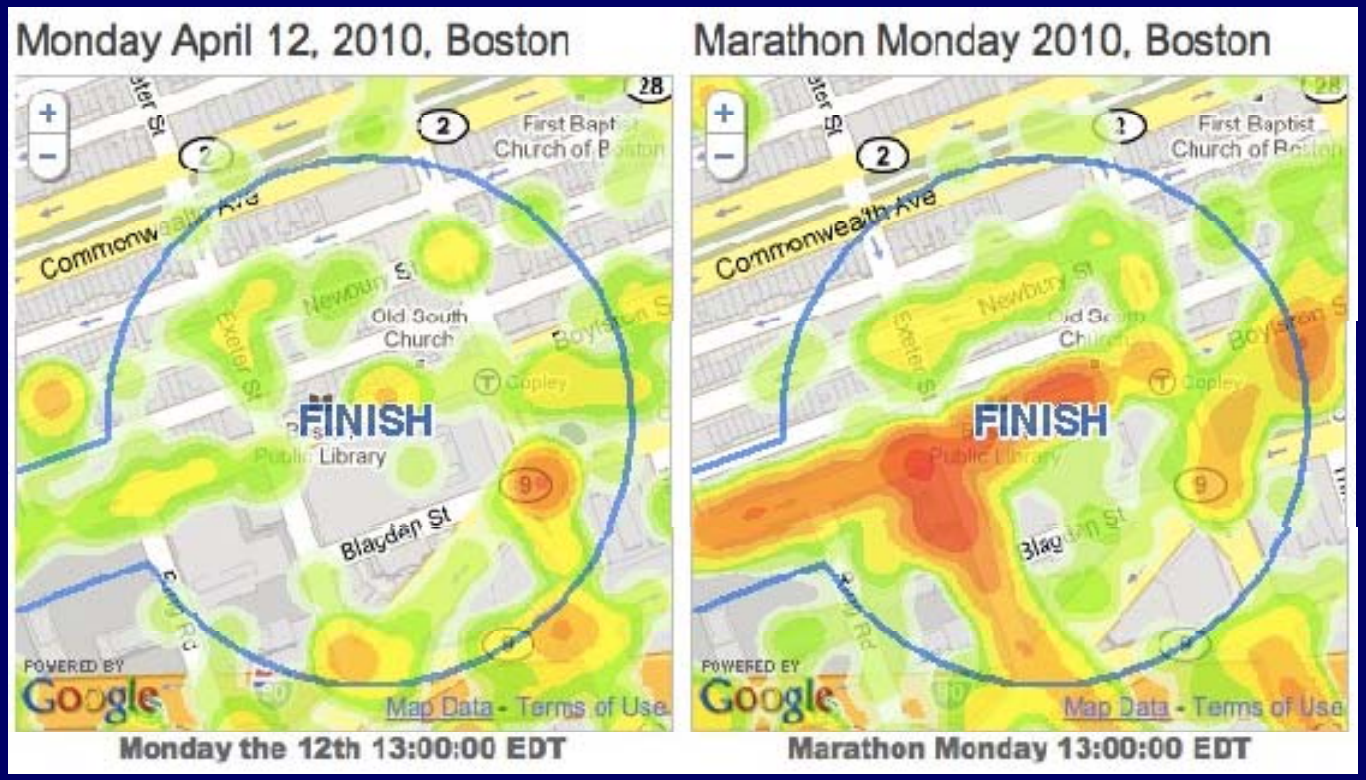
# SpotRank Data Intelligence Service




Source: Skyhook Wireless

# Location Intelligence – SpotRank

- Real-time population density based on location requests
- Sample data from 1pm the day of the Boston Marathon and one week prior shows the day-to-day difference in pop. density




Source: Skyhook Wireless

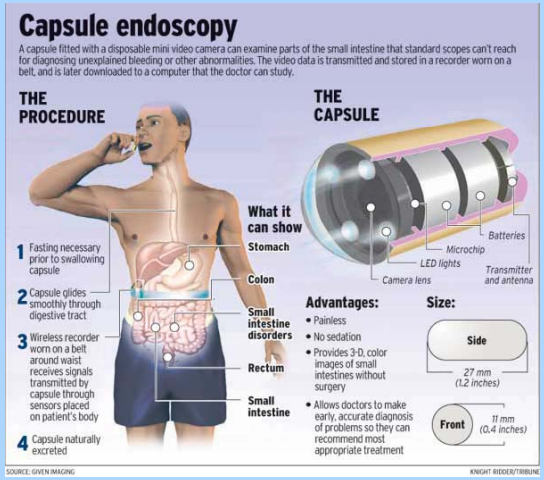
# Skyhook Predictive Demographics

- Trace aggregate groups of people that leave a neighborhood at night (home) and determine daytime location (work, school)
- Never seen before data creates new options for targeting

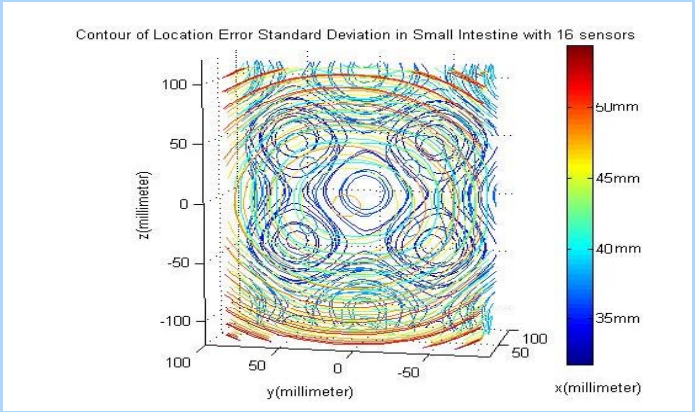
# Challenges

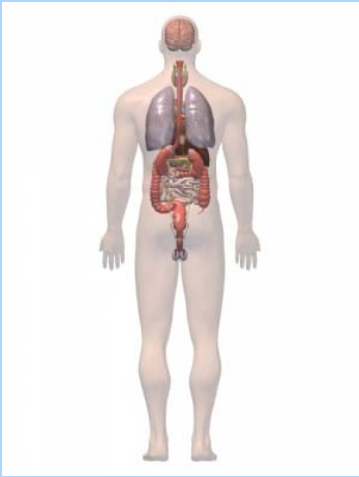
- Database Collection
  - Cost efficient wardriving
  - Data mining in organic data
- Algorithms
  - Handling GPS errors and AP displacements
- Business
  - New applications in social networking and human mobility pattern

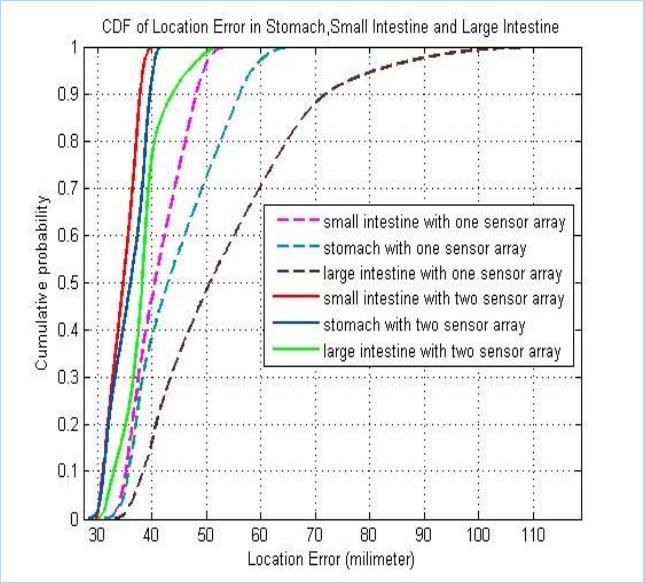
# RSS Localization for the BAN









# Taking Positioning Indoors

## Wi-Fi Localization and GNSS



**Solving the challenge of robust, reliable positioning in GNSS signal-challenged environments has long represented a kind of Holy Grail for product designers, systems integrators, and service providers. One promising approach is to combine GNSS with terrestrial systems exploiting existing wireless infrastructures. This article describes how one company has succeeded using GPS and wireless local area networks — better known as Wi-Fi — and, as a result, seen its technology incorporated into a wide range of mobile "connected" platforms, including smart devices such as Apple's iPhone and iPod.**

KAVEH PAHLAVAN, FERIT AKGUL, AND YUNXING YE
WORCESTER POLYTECHNIC INSTITUTE
TED MORGAN, FARSHID ALIZADEH-SHABDIZ, MOHAMMAD HEIDARI, AND CHRISTOPHER STEGER
SKYHOOK WIRELESS

Wireless local area networks (WLANs), now known more popularly as Wi-Fi, were originally designed for data applications. Over the past decade or so, WLAN infrastructure has been implemented for high-speed wireless Internet access in homes, "hot-spots," university campuses, and corporate buildings. Hundreds of millions of Wi-Fi access points (APs) were deployed in major urban areas worldwide.

Today, on the third floor of the Atwater Kent Laboratory at the Worcester Polytechnic Institute, where the lead author's laboratory resides, we can read the addresses of 48 Wi-Fi access points within range of our Wi-Fi–capable devices.

*Wardriving* or access point mapping is a term commonly used for the process of locating Wi-Fi APs while moving around an area, building a database that can be leveraged later for Wi-Fi localization. **Figure 1** shows a map of 1.2 million Wi-Fi access points obtained by wardriving around in the city of Seattle, Washington.

In the year 2000, three years after release of the first IEEE 802.11 WLAN standard, articles describing the use of Wi-Fi signals for indoor geolocation appeared in the research literature. During the past few years, Wi-Fi positioning or localization has found its way in metrowide positioning systems.

GPS was not designed for indoor applications and does not perform well in indoor and dense urban areas. Wi-Fi localization complements GPS positioning by providing robust indoor coverage, reduction in time to fix, reduced power consumption, and resistance to interference. GPS complements Wi-Fi by providing outdoor coverage and a universal coordinate reference frame.

Emerging "smart" devices, such as Apple's iPhone, use Wi-Fi localization technology to complement GPS and cell tower localization in numerous everyday consumer applications, particularly in metropolitan areas. Applications range



K. Pahlavan, F. Akgul, Y. Ye, T. Morgan, F. A.-Shabdiz, M. Heidari, C. Steger, "Taking Positioning Indoors: Wi-Fi Localization and GNSS", InsideGNSS, vol. 5, no. 3, May, 2010.