RADAR: An In-Building RF-Based User Location and Tracking system

Paramvir Bahl and Venkata N. Padmanabhan
Microsoft Research

Presented in CS 407

Overview

- *Introduction*
- *Related Work*
- *Methodology*
  - *The RADAR System*
  - *The RADAR Testbed*
- *Algorithm and Experimental Analysis*
  - *Empirical Method*
  - *Radio Propagation Model*
- *Enhancements to the Basic system*
  - *Continuous User Tracking*
  - *Profiling the Environment*
  - *Effects of Multiple Floors*
- *Conclusion*

Introduction

- *User Location and Tracking (ULT)*
  - *User location problem*
  - *User Tracking problem*
- *Issues in general*
  - *Scalability*
  - *Response Time*
  - *Granularity*
  - *Relocation*
  - *Accuracy*
- *Approach used in RADAR*

Related Work

- *Location Tracking Systems Type:*

  IR-Based Systems

    Active Badge

  Indoor RF Based

    Duress Alarm Location System

    3D-iD RF tag System

  Global Positioning System (GPS)

  Others

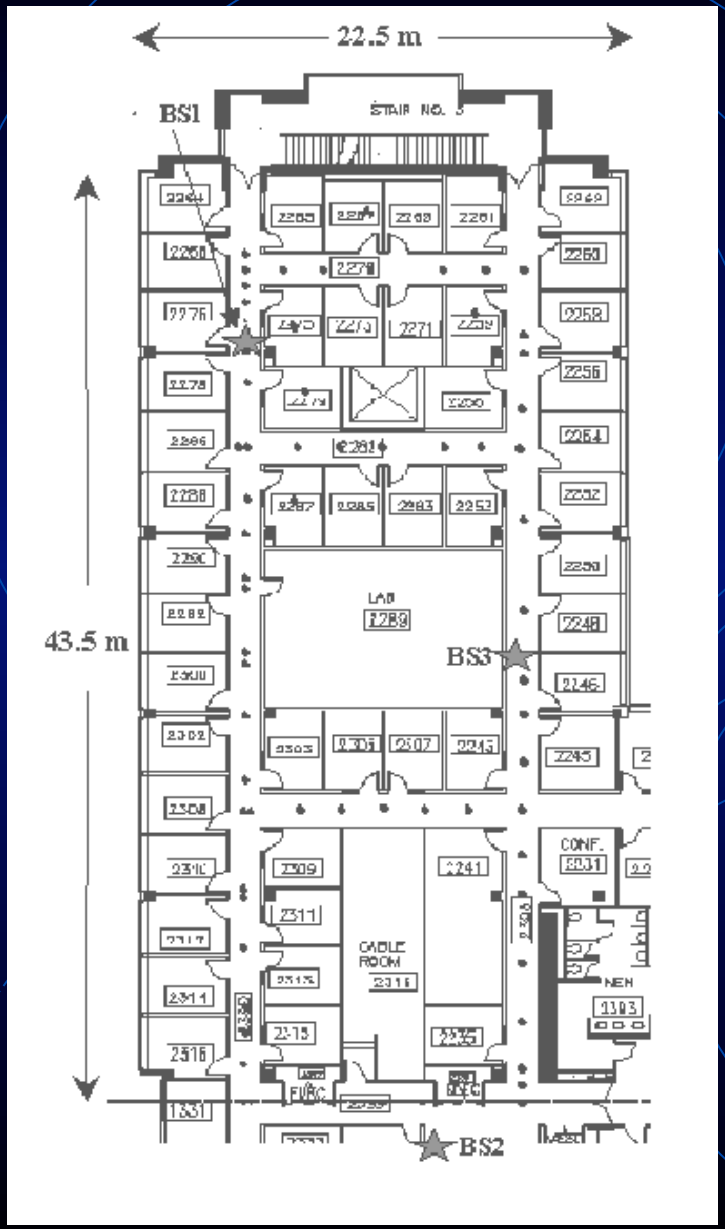
    Pulsed Magnetic Fields Based

    Ultra Sound Signals

The RADAR System

- *Implemented purely in software*
- *Functional Components*
  - *Base Stations (Access Points)*
  - *Mobile Users*
- *Fundamental Idea in RADAR*
  - *Signal Strength is a function of the receiver's location*
  - *Road Maps*
- *Techniques to build the Road Maps*
  - *Empirical Method*
  - *Radio Propagation Model*
- *Search Techniques*
  - *Nearest Neighbor in Signal Space (NNSS)*
  - *NNSS Avg.*
  - *Viterbi-like Algorithm*

The RADAR Testbed



- *Base Station*
  - *Pentium-based PC*
  - *FreeBSD 3.0*
- *Mobile Host*
  - *Pentium Based laptop*
  - *Windows 95*
- *Enhanced RADAR*
  - *Multiple Floors*

Data Collection

- *Key Step in their approach*
- *Records the Radio Signal as a function of the user location*
- *Off-Line Phase*
- *Real-Time Phase*
- *Every packet received by the base station, the WiLIB extracts*
  - *Signal Strength*
  - *Noise floor at the transmitter*
  - *Noise floor at the receiver*
  - *MAC address of the transmitter*

Data Processing

- *Traces collected from the off-line phase are unified into a table consisting of tuples of the format*

  [x,y,d,ss(i),snr(i)] I € {1,2,3}

- *Search Algorithm*
  - *NNSS*
  - *NNSS – Avg.*
  - *Viterbi-like Algorithm*

- *Layout Information*

Algorithm and Experimental Analysis

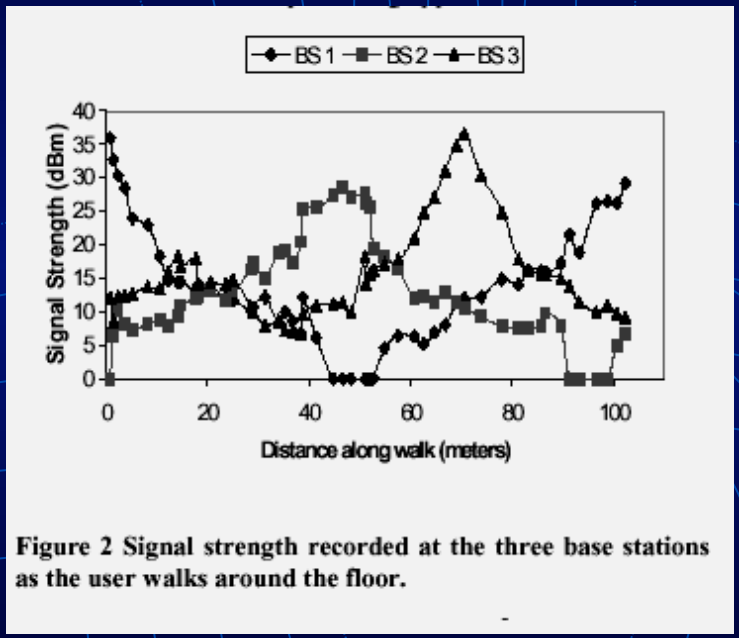


Figure 2 Signal strength recorded at the three base stations as the user walks around the floor.

Empirical Method

- *280 combinations of user location and orientation (70 distinct points, 4 orientations on each point)*

- *Uses the above empirical data recorded in the off-line phase to construct the search space for the NNSS Algorithm*

- *Algorithm (Emulates the user location problem)*

  1. Picks one location and orientation randomly

  2. Searches for a corresponding match in the rest of the 69 points and orientations

- *Comparison with*

  - Strongest Base Station

  - Random Selection

Error Distance Values

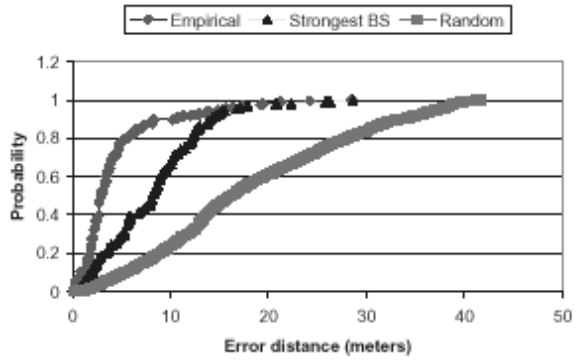


Figure 3 CDF of the error in location estimation.

Method	25th (meter)	50th (meter)	75th (meter)
Empirical	1.92	2.94	4.69
Strongest	4.54 (2.4x)	8.16 (2.8x)	11.5 (2.5x)
Random	10.37 (5.4x)	16.26 (5.5x)	25.63 (5.5x)

Table 1 The 25th, 50th, and 75th percentile values of the error distance. The numbers in parentheses indicate the degradation of the strongest BS and random methods compared to the empirical method.

Empirical Method (Cntd.)

- *Multiple Nearest Neighbor*
  - *Increases the accuracy of the Location Estimation*

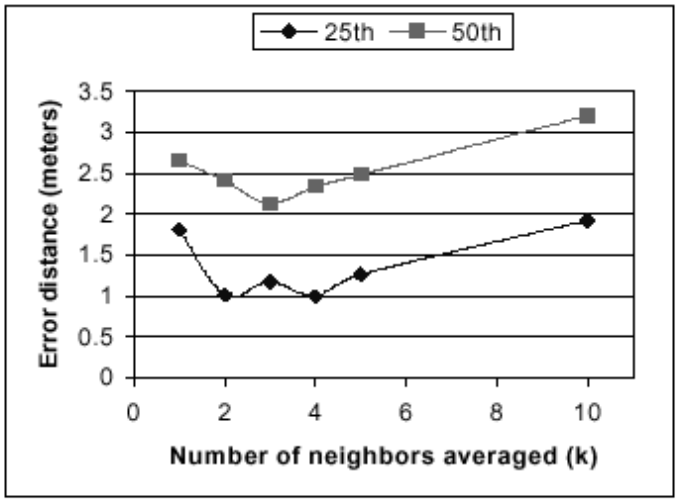


Figure 5 The error distance for the empirical method with averaging on the data set containing the max signal strength measurement for each location.

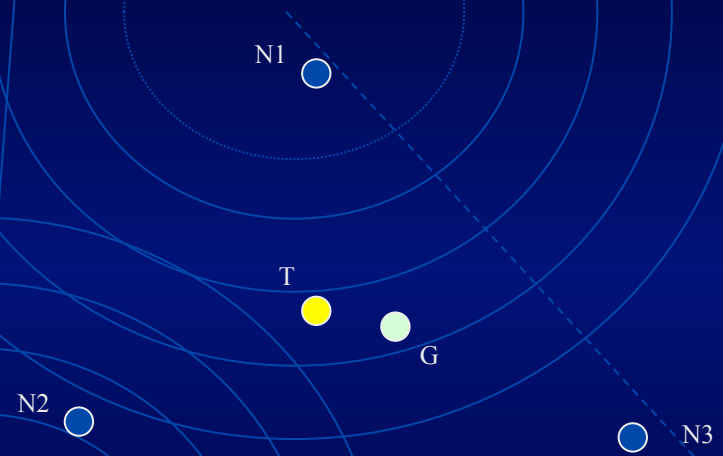


Figure : Multiple Nearest Neighbors
T – True Location
G – Guess
N1,N2,N3 - Neighbors

Empirical Method (Cntd.)

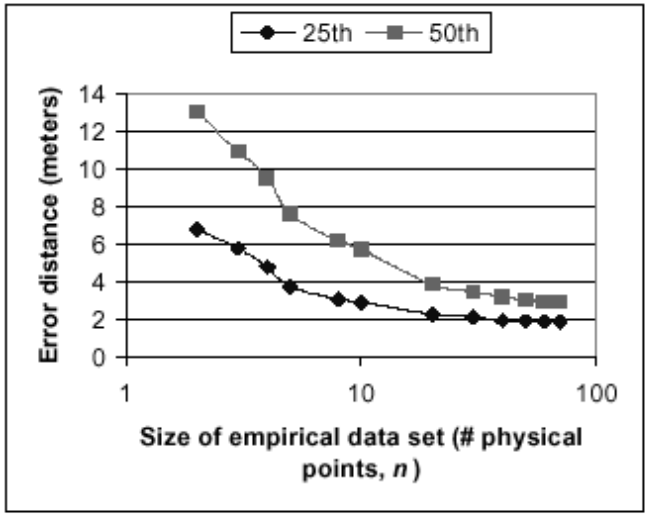


Figure 6 The error distance versus the size of the empirical data set (on a log scale).

Impact of Number of Data Points

Empirical Method (Cntd.)

- *Impact of Number of Number of Samples*

  - Accuracy obtained by all the samples can be obtained if only a few samples are taken

No. Of Real-Time Samples	Error Distance degradation
1	30%
2	11%
3	4%

- *Impact of User Orientation*

  - Off-line readings for all orientations is not feasible

  - Work around is to calculate the error distance for all combinations

Empirical Method (Cntd.)

- *Tracking a Mobile User*
  - *Analogous to the user location problem*
  - *New Signal Strength data set*
  - *Window size of 10 samples*
  - *4 Signal Strength Samples every second*
- *Limitation of Empirical Method*
  - *To start off with needs an initial signal strength data set*
  - *Relocation requires re-initialization of the initial data set.*

Radio Propagation Model

- *Introduction*
  - *Alternative method for extracting signal strength information*
  - *Based on a mathematical model of indoor signal propagation*
- *Issues*
  - *Reflection, scattering and diffraction of radio waves*
  - *Needs some model to compensate for attenuation due to obstructions*
- *Models*
  - *Rayleigh Fading Model : Infeasible*
  - *Rician Distribution Model : Complex*
  - *Wall Attenuation Factor*

Wall Attenuation Factor

$$P(d)[dBm] = P(d_o)[dBm] - 10n\log\left(\frac{d}{d_o}\right) - \begin{cases} nW * WAF & nW < C \\ C * WAF & nW \geq C \end{cases}$$

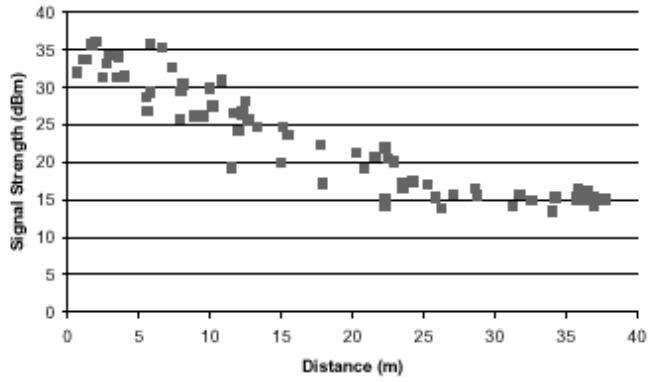


Figure 8 Effect of applying correction for intervening walls between the base station and the mobile user.

Radio Propagation Model (Cntd.)

- *Advantages:*
  - *Cost Effective*
  - *Easily Relocated*

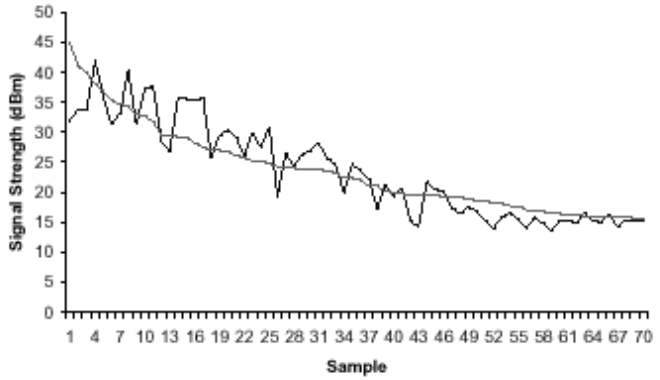
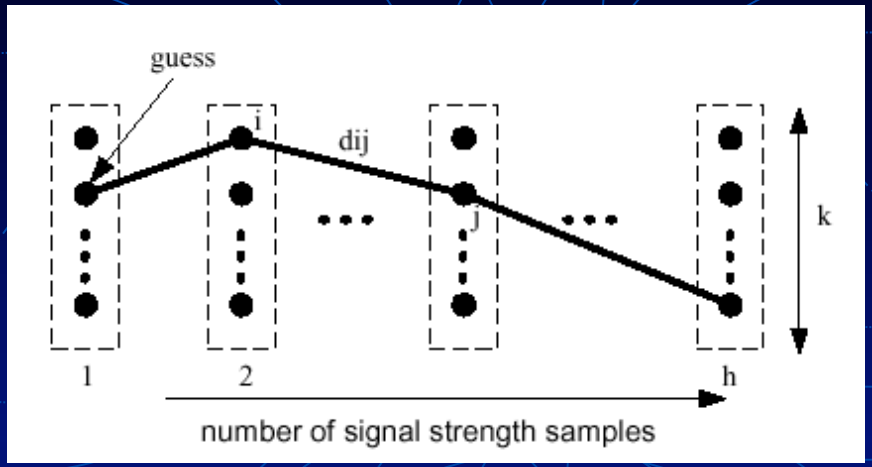


Figure 9 Predicted versus measured signal strength.

Future Work

- *User Mobility Profile*
  - *Information about the likelihood of user's current location based on old information*
  - *Aliasing effect gets reduced to a large extent*
- *Based Station based environmental profiling*
  - *Adds robustness to the system*
  - *Reduces inaccuracy*
- *Effects of Multiple Floors*
  - *Works Well*
  - *One map for each floor*
  - *Aliasing problem will increase*

Continuous User Tracking



- *Viterbi-like Algorithm*

  1. NNSS search is done for k nearest neighbors in the signal space

  2. History of depth h of k-NNSS is maintained

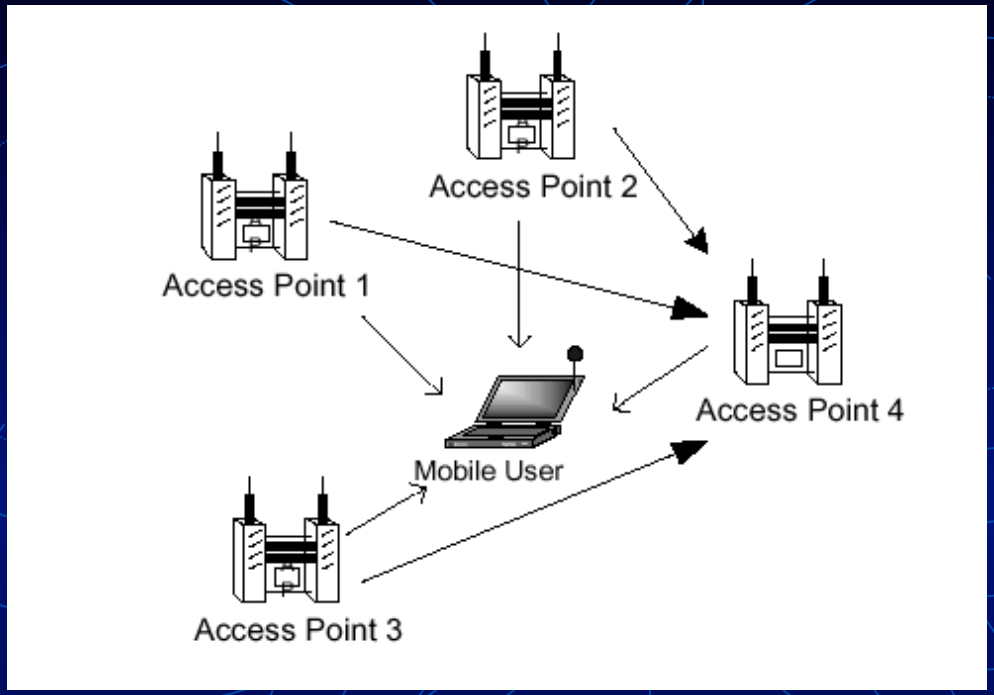
  3. Weights are assigned to the edges, larger the edge weight lesser is the likelihood of the transition

- *Advantage*

  - Outperforms NNSS, NNSS-Avg.

  - Reduces aliasing effect

Profiling the Environment



Uses multiple Radio Maps based on different environments.

Conclusion

- RF-based user location and tracking algorithm is based on
  - Empirically measured signal strength model
    - -- Accurate
  - Radio Propagation Model
    - -- Easily relocated.
- RADAR could locate users with high degree of accuracy.
- Median resolution is 2-3 meters, which is fairly good
- Used to build “Location Services”
  - printing to the nearest printer
  - navigating through a building

Missing Pieces!!

- No mention of the response time of the System
- Not clear how well RADAR would work in a real-world setting
- Unsuitable for rapid development due to the initial infrastructure required
- Security & Privacy Issues associated with localization.


Thanks!!