Enhancements to the RADAR User Location and Tracking System

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Outline

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- The RADAR System
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Introduction

- Computing is increasingly ubiquitous
  - Lightweight
  - Portable
  - Networking capable
- High-speed wireless LANs are more accessible
- RADAR leverages on the above to provide user location and tracking abilities

Introduction (cont'd)

- To enable location of people and devices so users can effectively interact with their surroundings e.g.
  - Printing a document
  - Locating another mobile user
  - Displaying position on a map
- To propose enhancements to the basic system built

User Location Systems (Background)

Four broad categories:

- IR-based systems
  - ***Active Badge***

    Merits: accurate location information

    Demerits: poor performance, limited range, specialised hardware requirements
- Indoor RF-based systems
  - Duress Alarm Location System
  - Daedalus Project
  - ***3D-iD RF Tag System***

    Merits: increased range

    Demerits: Advertised best resolution of 10 ft, no data networking capacity, also requires specialised hardware

User Location Systems

- Wide-area cellular-based systems
  - ***Cellular Telephones***

    Merits: Work well outdoors

    Demerits: reduced effectiveness indoors from reflections suffered by signals, lack of tight time synchronisation
- Others
  - GPS
  - Ultrasound
  - Pulsed DC magnetic field

Disadvantages

The drawbacks of these systems include

- Cost prohibitive in installation and maintenance - specialized hardware requirements
- Poor scaling due to limited range
- Poor and limited performance
- Lack of data networking capabilities

Features of the RADAR System

- Implemented purely in software
- Uses widely available RF-based wireless LANs (802.11)
- Location-aware services enabled by RADAR complement the data networking capability of RF WLANs
- Suitable for large-scale deployment
- Lower maintenance costs

The RADAR System

- Structure
  - Access Points (APs) are located to provide overlapping coverage
  - W-LAN capable mobile device
- Fundamental idea
  - Signal strength is a function of user location
  - Use signal strength(SS) of beacons in RF network to infer mobile user's position
  - *Radio Map* is created with entries of the form:

$$(x, y, ss_{i\ (i=1..n)})$$

How it works

- Locating the User
  - Measures signal strength of APs within range
  - Search Radio Map database to find best match
  - Estimates corresponding co-ordinates to be mobile location
- Search methods
  - Nearest Neighbor in Signal Space (NNSS) algorithm
  - NNSS-Avg.
- Creating the Radio Map
  - Explicit measurement
  - Mathematical modelling
- Error distance

Table 1: Highlights of testbeds

	Testbed 1	Testbed 2
Hardware	Digital Equip. Corp. WaveLAN	Aironet Wireless Inc 4800 series
MAC	CSMA/CA [27]	IEEE 802.11b [28]
Modulation	Spread-spectrum DQPSK	Spread-spectrum CCK
Output Power	50 mW	100 mW
Data Rate	2 Mbps	11 Mbps
Number of APs	3	5
Floor Dimensions	43.2 m x 22.5 m	42.9 m x 21.8 m
OS	FreeBSD 3.0	Windows 2000

The RADAR Testbed

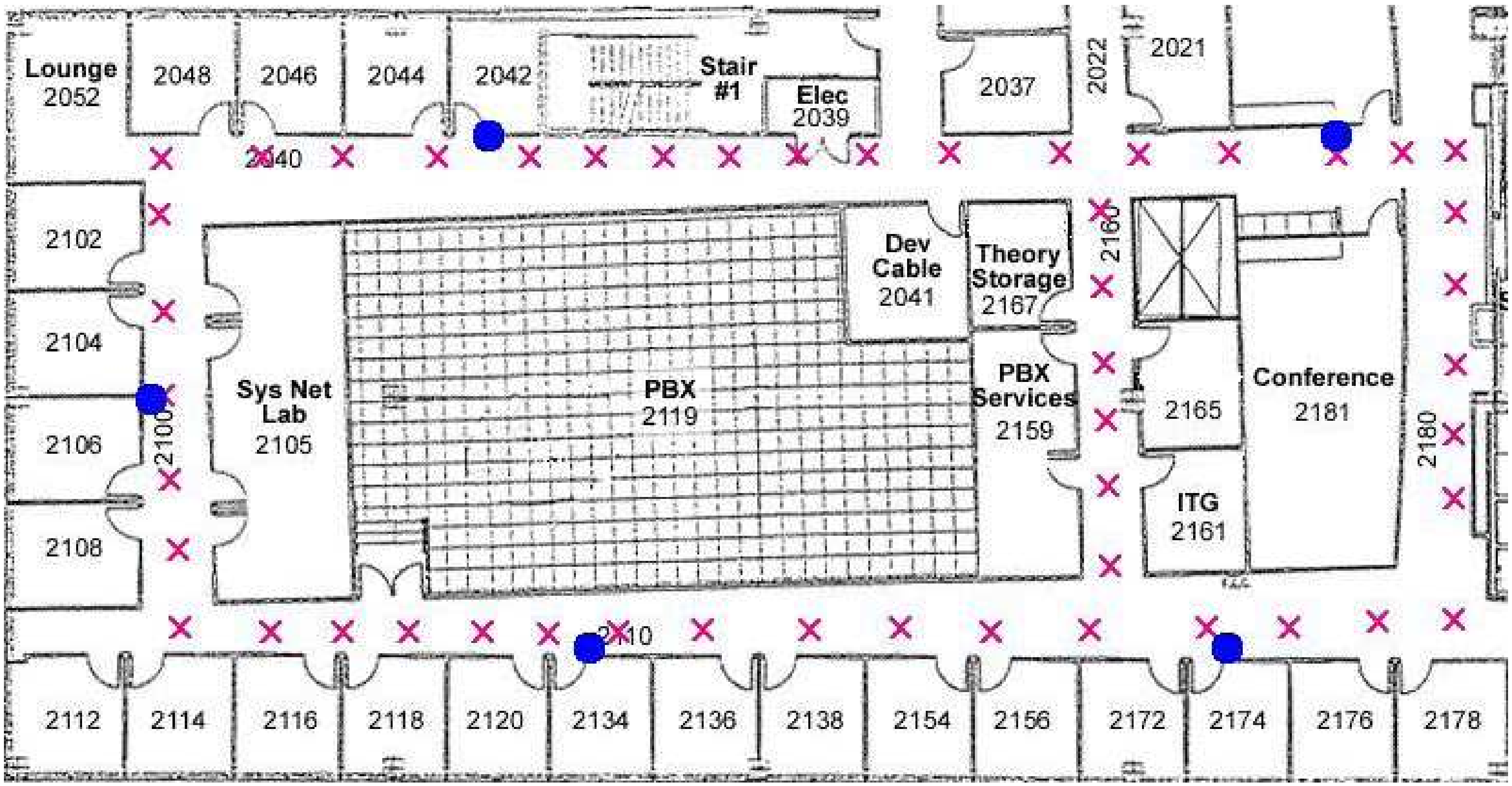

Figure 1: Map of the floor where the new experiments were conducted. The crosses denote the locations where signal strength from beacon packets were recorded. The filled dots show the locations of the 5 access points.

Basic System Performance

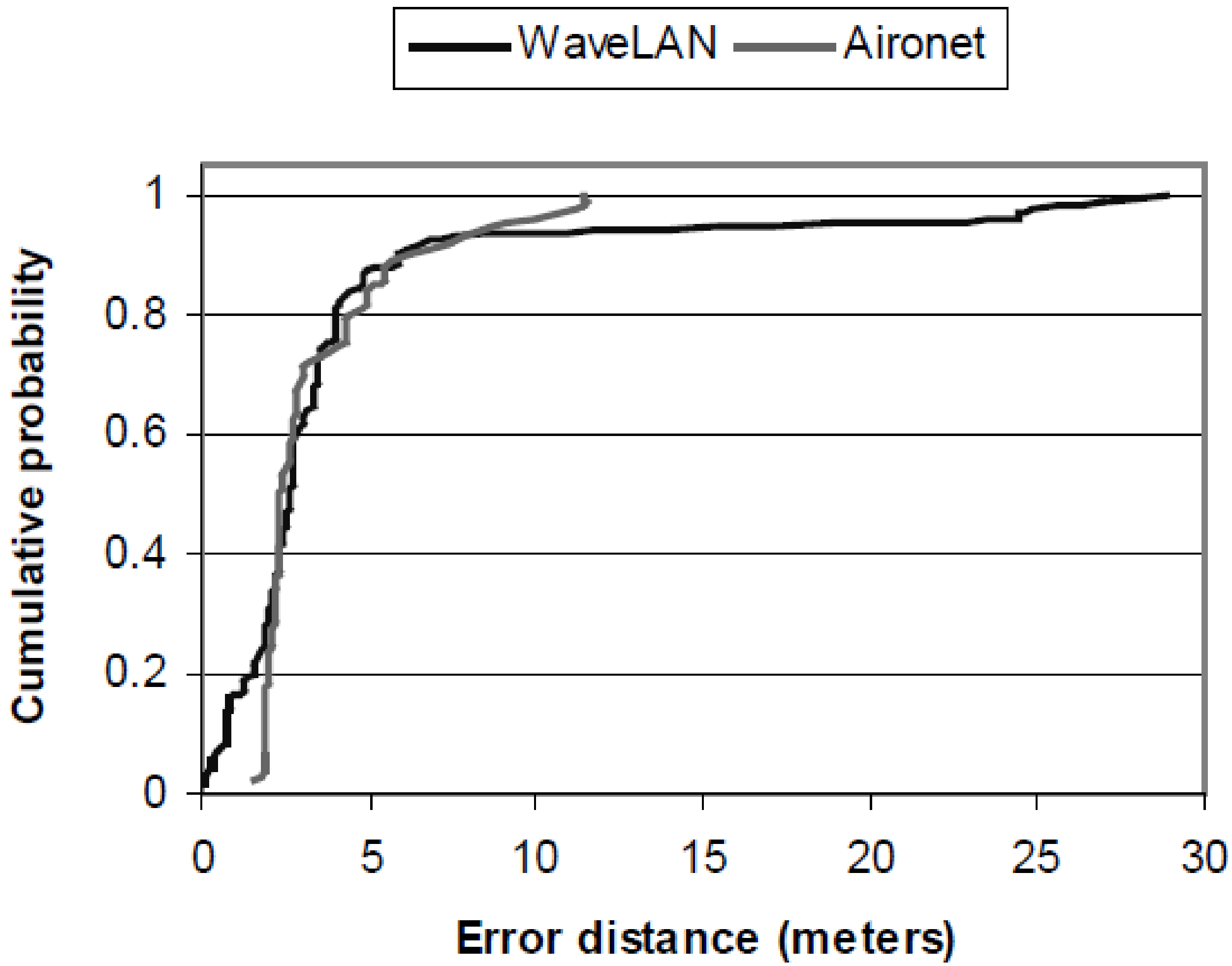

Figure 2: CDF of the Error Distance

Effect of Number of Access Points

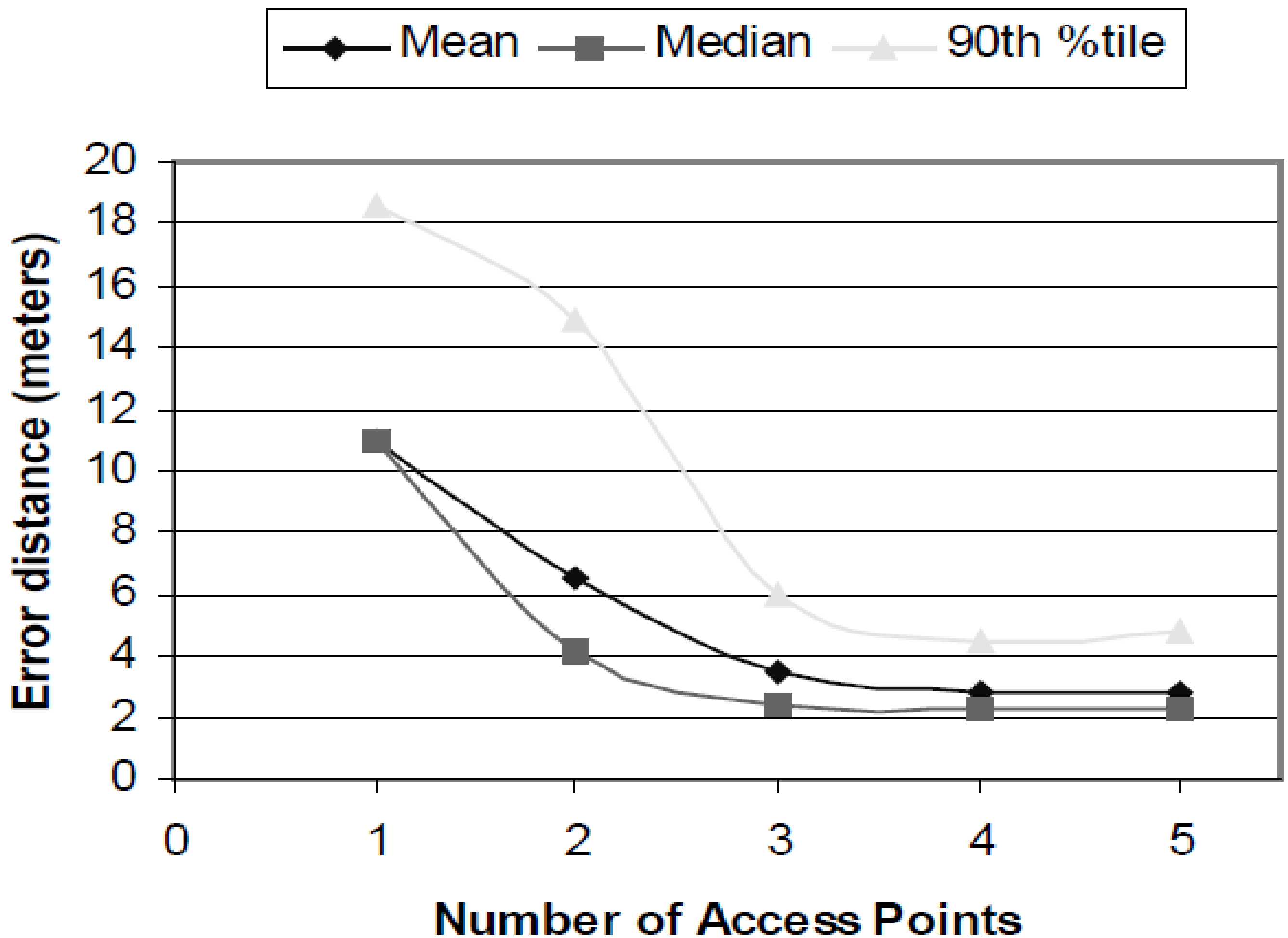

Figure 3: Impact of the number of APs on the error distance.

Enhancements to the Basic System

Three main improvements:

- Continuous user tracking
- Environmental profiling
- Extension of basic NNSS algorithm to a 3D space, i.e. to multiple floors in a building

Continuous user tracking

- Idea of continuous tracking
  - Use past information to have a better guess of current location, i.e. user cannot “jump around”, follows a path
  - Physical constraints limit possible movements
- Aliasing problem may be alleviated
  - Physically distant points *A* and *B* could be very close together in signal space due to aliasing
  - “Recent past signal strength information” + “the physical contiguity constraint” to unambiguously pick one between *A* and *B*

Viterbi-like Algorithm

- Mobile host obtains signal strength tuple
- NNSS search to have *k* nearest neighbours in signal space (*k*-NNSS)
- History of depth *h* of such *k*-NNSS sets kept
- *h* updated by adding most recent *k*-NNSS set and removing oldest set
- Shortest path between vertices in newest and oldest *k*-NNSS set computed
- Guess user location as the start of the path

Continuous user tracking (cont'd)

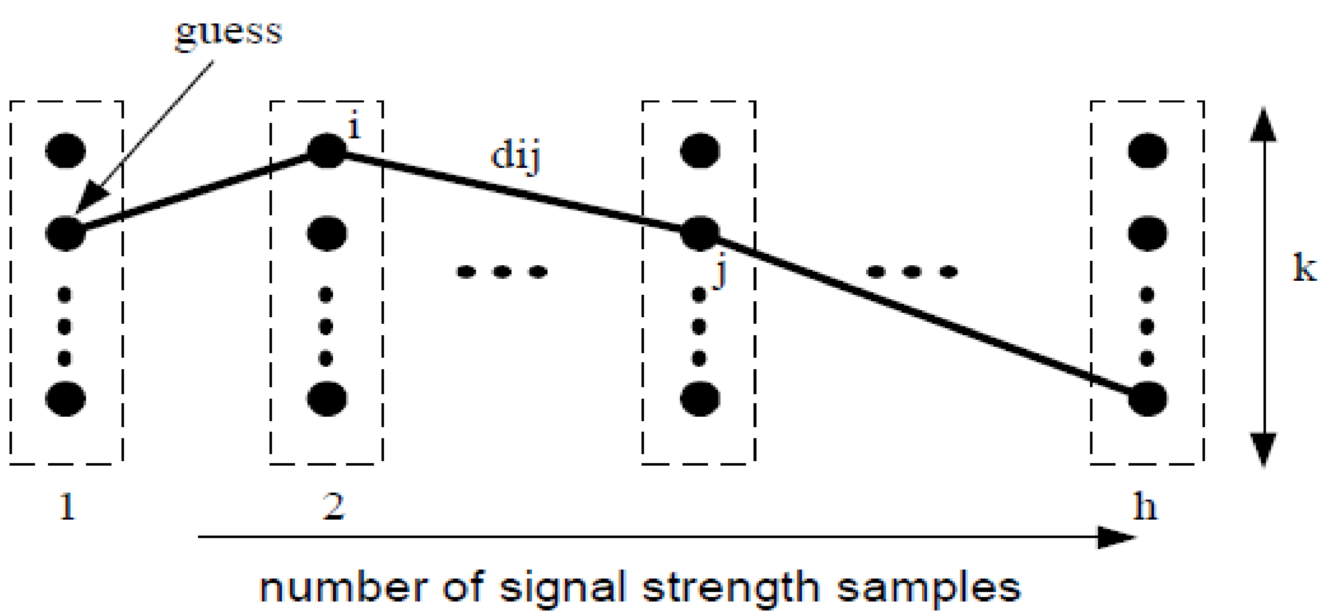

Figure 4: A depiction of the state maintained by the Viterbi-like continuous tracking algorithm. The shortest path is shown in bold. The location corresponding to the mid-point of the path is guessed to be the user's location. The weight of an edge between vertices i and j is d_{ij}, the Eucledian distance between the corresponding locations.

Continuous user tracking Performance

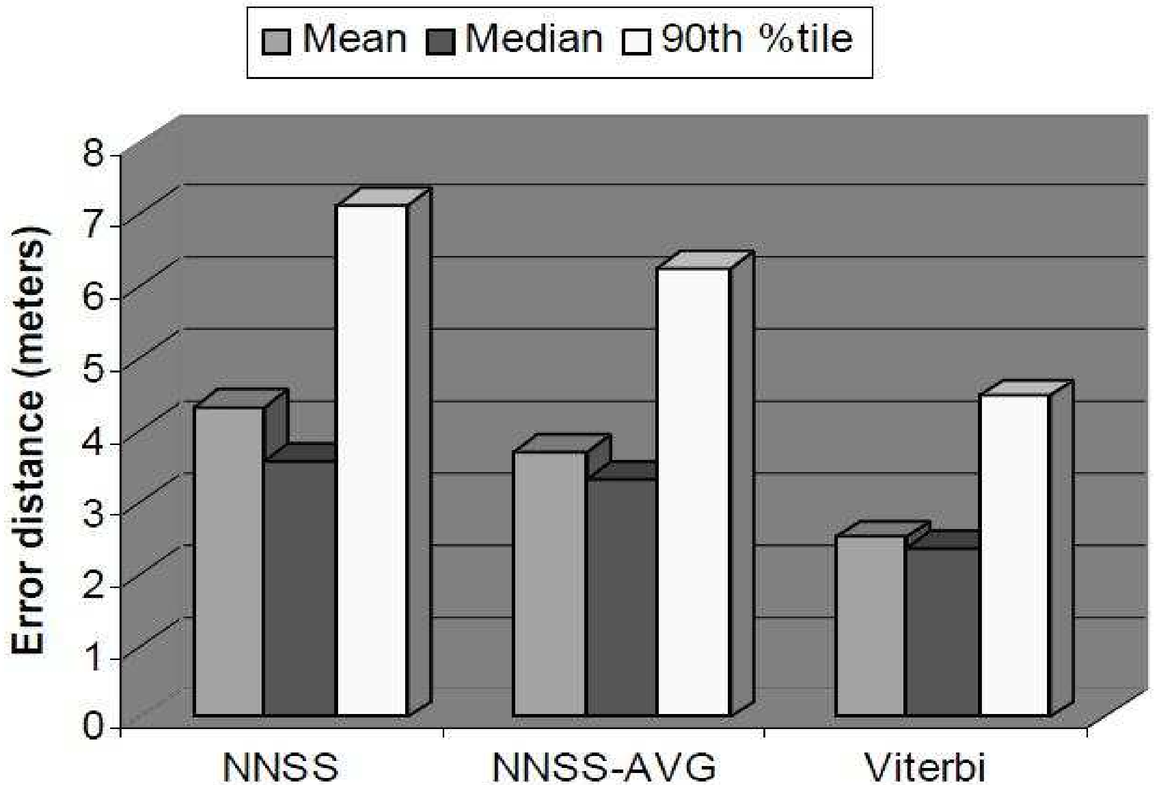

Figure 5: Performance of the various algorithms in tracking a user who is walking.

Profiling the Environment

- RF environment is hostile environment
  - Signal reflected, absorbed, multipath effect
  - Human body influences signal, by as much as 3.5dBm
  - Different times of day, different numbers of humans, signal varies
- Radio Map created at a particular time may not accurately reflect the environment at a different time

Profiling the Environment (cont'd)

- Solution
  - Use multiple Radio Maps
- How to dynamically choose the Radio Map that best represents the environment?
  - APs at fixed known locations
  - Use RADAR to guess AP location, as if the AP was a mobile user
  - Compare AP location to each Radio Map estimate
  - Radio Map with the closest estimate for AP location is used to determine the user location

Profiling the Environment (cont'd)

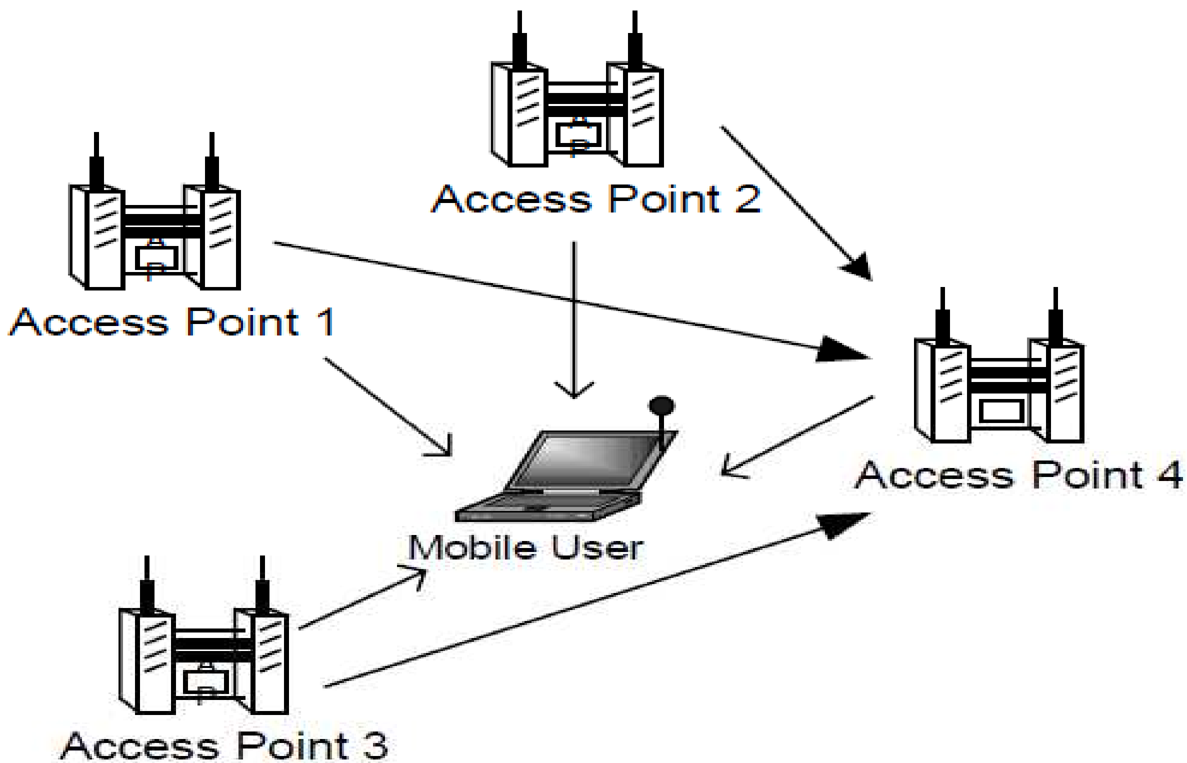

Figure 6: Access point-based environmental profiling: Beacon packets from neighboring APs are used to estimate (known) location of the target AP (AP4) using different Radio Maps.

Profiling the Environment (cont'd)

How it works

- APs record SS samples over sliding window *w*
- Compute the mean m_i of SS samples for every AP*i*
- Use m_i together with pre-computed (μ_e) and standard deviation (σ_e) of the SS crresponding to each environmental state, *e*
- Assume Normal distribution, N(μ_e, σ_e) for SS
- Use PDF for Normal distribution to quantify the likelihood that the mean, m_i, conforms with the distribution
- Multiply the likelihood of each environmental state *e*, to obtain an overall estimate of the likelihood for environment *e*
- The environment e_{max} with the highest likelihood of match is guessed to be the true environment state
- Move sliding window forward

Profiling the Environment (cont'd)

- Experiment 1
  - Place a pair of laptops in the campus cafeteria (in corners)
  - Periodically broadcast 4-byte UDP packets from one
  - Second laptop in different corner records signal strength from broadcasts
  - Experiment performed during two periods of the day
    - *busy period* (lunch time)
    - *lean period* (end of business day)

	Mean	Std. Deviation
Busy hour	46.07	2.41
Non-busy hour	50.05	1.19

Table 2: Characteristics of received signal strength in two different environments

Profiling the Environment (cont'd)

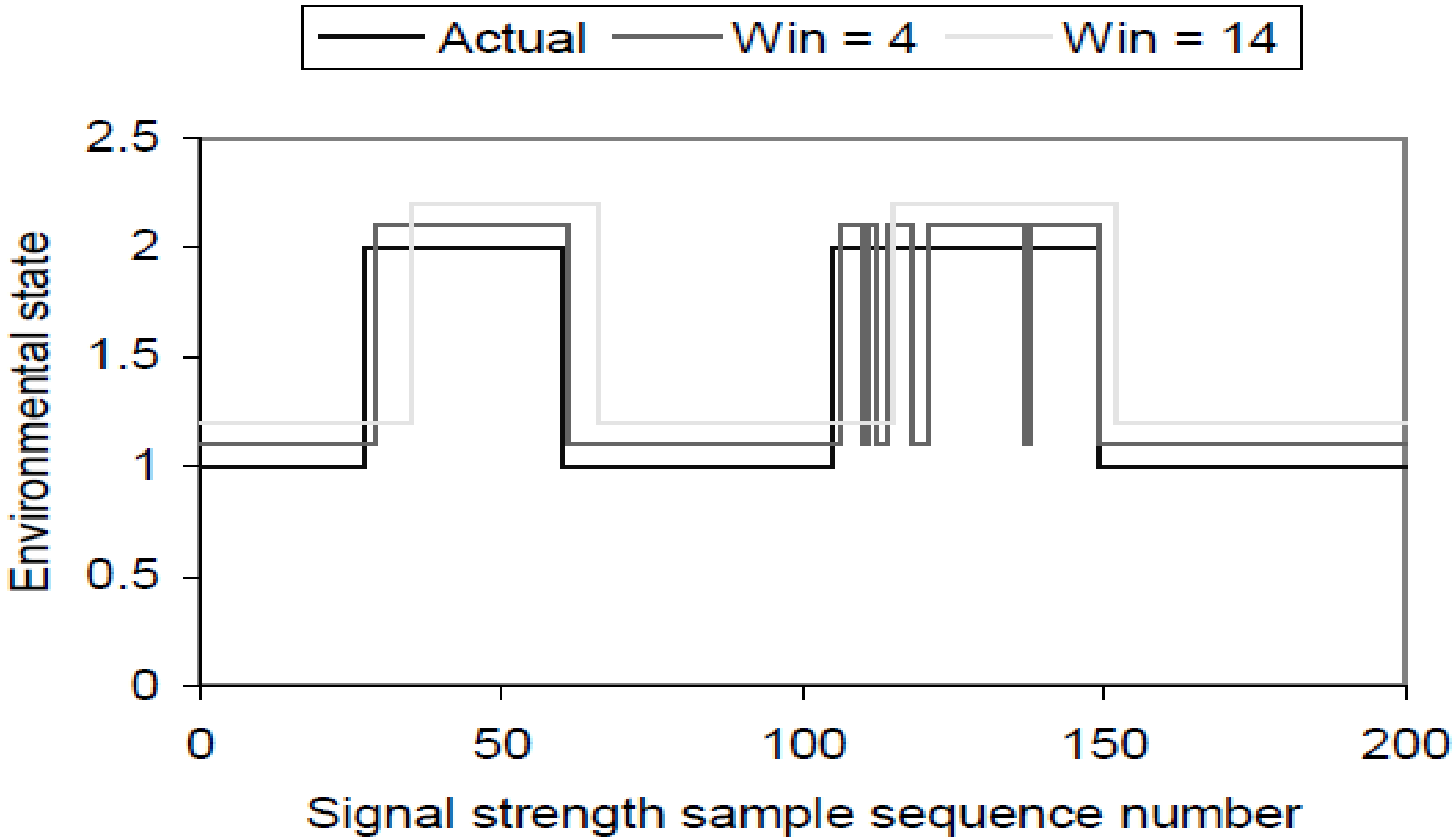

Figure 7: The transitions, both actual and inferred, between two different environmental states.

Profiling the Environment (cont'd)

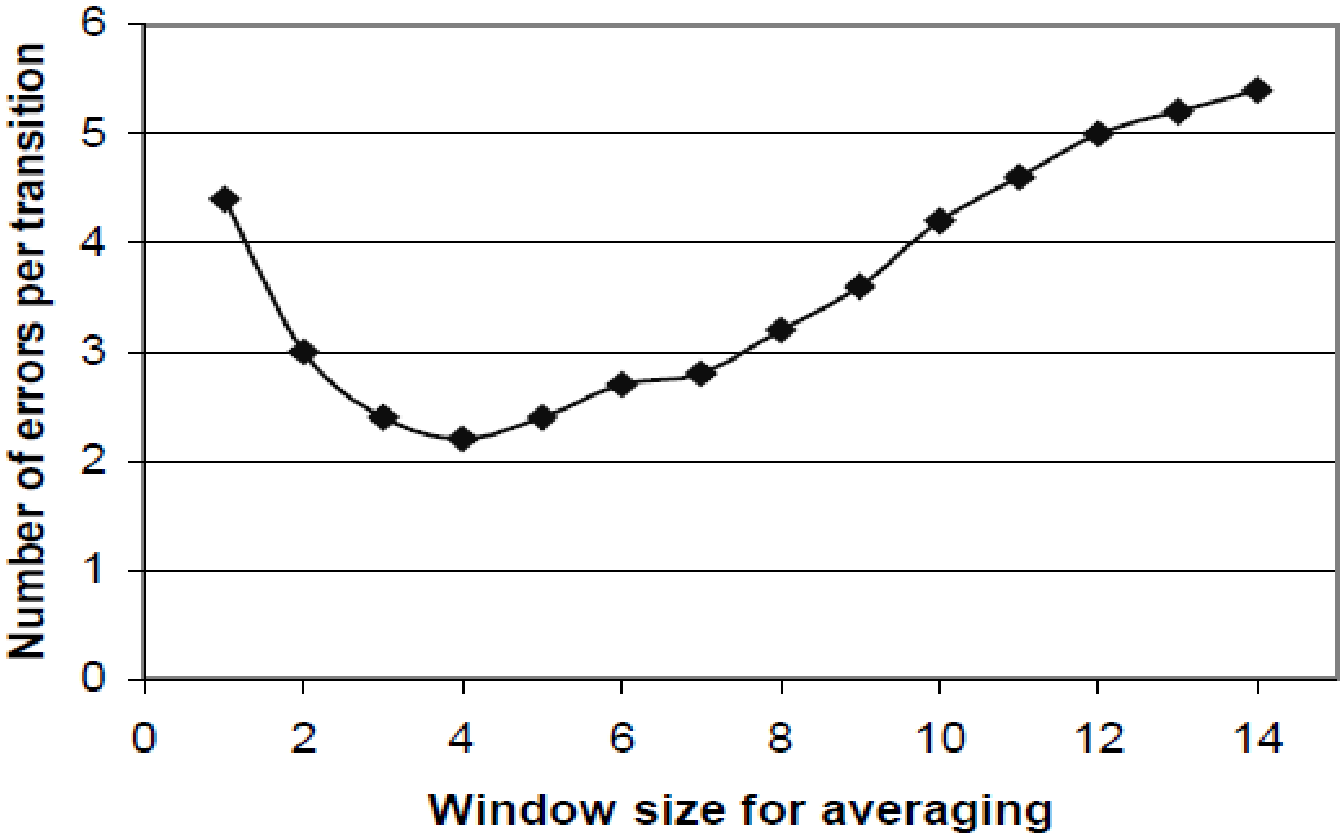

Figure 8: The error in inferring the environmental state as a function of the window size used for averaging signal strength samples.

Profiling the Environment (cont'd)

- Experiment 2
  - Simulate variations of the environment by introducing artificial obstructions (why not perform it in real environment?)
  - Construct two Radio Maps, busy and non-busy
  - Use the non-busy map to simulate the case where environmental profiling is not performed
  - Selecting correct map (non-busy or busy map) to simulate the case where environmental profiling is used
  - What if there is more dynamic environment?

Profiling the Environment (cont'd)

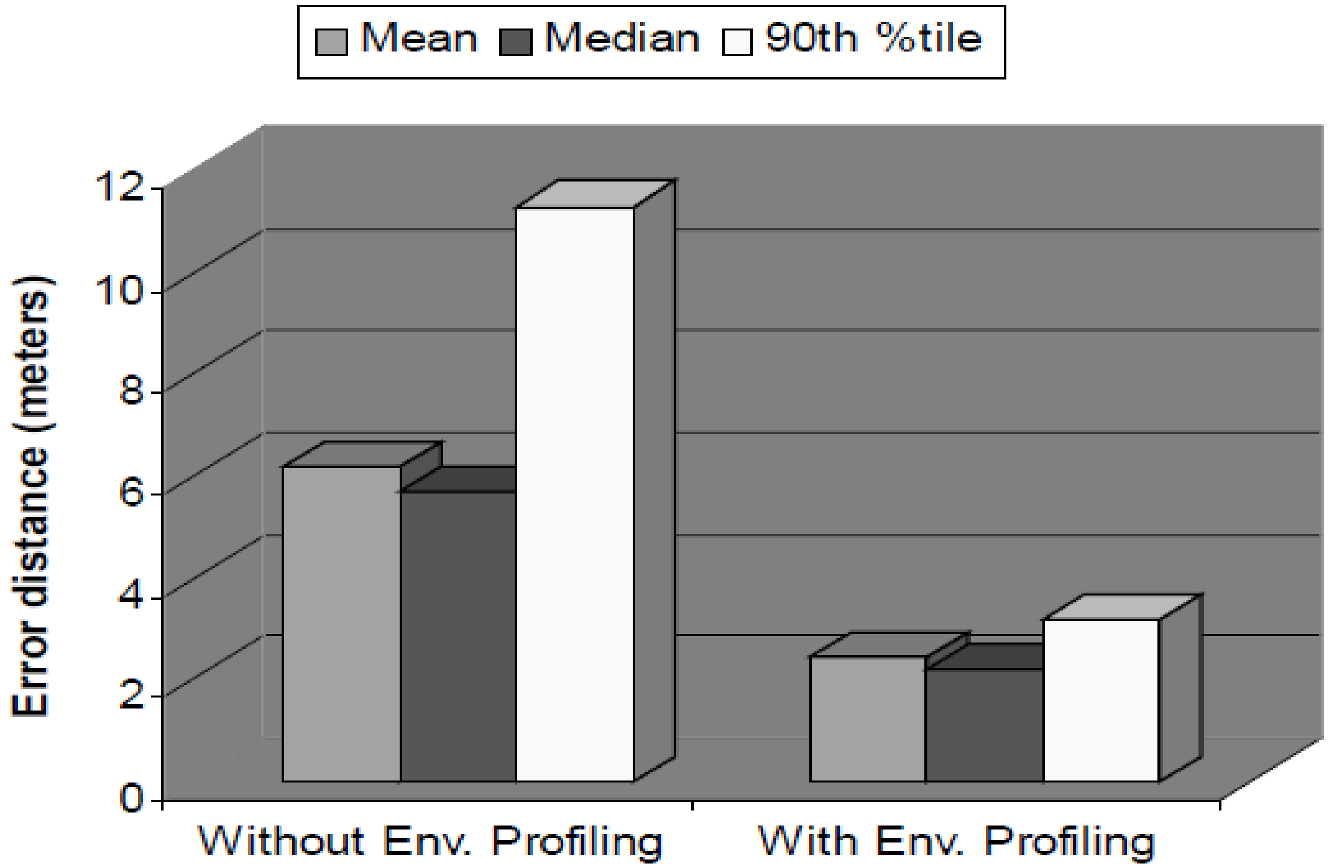

Figure 9: Performance of the NNSS algorithm with and without environmental profiling.

Multiple Floors

- Picked 5 locations with same (x,y) coordinates on each of 3 floors (15 locations in all)
- Placed 3 APs on one of the floors
- Measured beacon signal strength at each location
- RADAR worked in multi-floor environment
  - Floor acts as significant barrier to signal propagation
- Aliasing could be more problematic on multiple floor (can mislead users to wrong floor)
- Extra overhead in multiple floor Radio Mapping

Implementation Insights

- Multiple channel
  - Neighboring APs operate in different channels thus mobile has to scan all channels
  - Leads to switching overheads
  - Solution:
    - Multiple APs on the same channel – increases system cost and complicates network planning and management
    - Synchronise mobiles with APs (e.g. NTP), switch channel at right time to minimize wait for beacons.
- Limited programming support on wireless hardware
  - Extended Window's Network Device Interface Specification (NDIS) by creating WiLIB to enable signal strength information extraction from beacons

Conclusion

- Continuous user tracking using commodity hardware
  - improves user location accuracy by over 33%
  - alleviates aliasing
- Environmental profiling technique tackles variations in RF environment
- Extension of NNSS algorithm enables tracking in 3D space, e.g. multiple floors of a building

Conclusion (cont'd)

- Setup overhead
  - need to physically create Radio Map (even more for environmental profiling),
  - APs must overlap for optimum performance, makes deployment more expensive
- Scalability - what happens with a mix of AP models?
- Response time in operations - vague, only mention of *h lag*
- Performance evaluation in a real-world setting

Question Time!