Enhancements to the RADAR User Location and Tracking System

Paramvir Bahl, Venkata Padmanabhan and Anand Balachandran

by
Pandurang Kamat
4/24/2003

About the Authors

- Paramvir ("Victor") Bahl (Microsoft Research)
  - Ph.D. from University of Massachusetts Amherst
  - senior researcher and a manager in the Systems and Networking Research Group.
  - wide interests in mobile computing and wireless networking : low-power RF comm.; ubiquitous wireless Internet access/services; indoor location determination; self organizing, self configuring multi-hop wireless networks; and real-time audio-visual wireless communications.
  - founder of ACM SIGMOBILE, ACM Mobile Computing and Communications Review and MobiSys
  - Over 50 papers and 34 patents in the wireless, communications and DSP domains
- Venkata Padmanabhan (Microsoft Research)
  - Ph.D. from UC Berkeley.
  - wide-area and wireless networking, Web performance, and mobile computing.
  - involved in projects on network performance measurement, network tomography, Internet geography, peer-to-peer networking, and wireless user tracking.
- Anand Balachandran (UCSD)
  - Computer Science Ph.D. student. (background in Chemical Engineering)
  - research interests : wireless networking; wireless Internet; infrastructure and ad-hoc networks; and mobile computing.

Outline

- The problem of locating users inside buildings
- Related Work
- The RADAR system
- Performance of the basic RADAR system
- Enhancements to the RADAR system.
- Implementation Insights
- Concluding Remarks

Introduction

- The goal is to enable the mobile user to interact effectively with his/her surroundings
- Granularity of the required location information varies for applications
  - coarse grained : nearby printer
  - fine grained : book in a library

Related Work

- IR-based
  - *Active Badge* system
  - badge emits unique IR signal every 10 seconds
  - sensors placed at known locations in the building pick up the unique Ids and relay to centralized *location manager* software
  - Pros: provides accurate information
  - Cons:
    - Scales poorly due to limited IR range
    - Installation and maintenance costs for special hardware
    - Poor performance in presence of sunlight (rooms with windows)
- RF based
  - 3D-iD system by Pinpoint Corp.
  - Antennas emit RF signals at 2.4 GHz, tags respond with the ID code.
  - Location is triangulated based on multiple antennas
  - Cons:
    - High cost
    - Specialized hardware

Related Work

- Wide-area cellular based
  - signal attenuation, Angle of Arrival (AOA), Time Difference of Arrival (TDOA)
  - indoor effectiveness reduced due to multiple reflections suffered by the RF signal and inability of hardware to provide fine-grain time synchronization
- Others
  - using ultrasound signals, magnetic fields etc.
  - drawbacks: specialized hardware, high cost and range limited

The RADAR system

- Software system built on a deployment of off-the-shelf wireless LAN technology.
- In an RF network, the energy level or signal strength (*SS*) of a packet is a function of the receiver's (mobile user's) location and hence can be used to infer the user location with respect to the Access Points (APs).
- A *Radio Map* of the building is created. This is a database of marked locations in the building and the observed (or estimated) signal strength of the beacons signal strength of the beacons emanating from the APs as recorded at these locations.
- Example entry in Radio Map : $(x, y, z, ss_i\ (i = 1..n))$
  - where (x, y, z) is the physical coordinates of the location where the signal is recorded and ss_i is the signal strength of the beacon signal emanating from the i_{th} AP.

Creating the Radio Map

Method 1 :

- A mobile user walks around the building and at different locations records the physical co-ordinates and signal strengths of the beacon packets from each AP within range.

Method 2 :

- The radio map is constructed using a mathematical model of indoor RF propogation
- Method 1 is more accurate.

Locating the User

- The mobile measures the signal strength of each of the APs within range. It then searches through the Radio Map database to determine the signal strength tuple that best matches the signal strengths it has measured.
- Nearest Neighbor in Signal Space (NNSS) algorithm is the search technique.
- The *NNSS* algorithm computes the *Euclidean distance* (in signal space) between each SS tuple in the Radio Map (*ss1,ss2,ss3*) and the measured *SS* tuple (*ss'1,ss'2,ss'3*). The tuple minimizing the Euclidean distance is the winner.
- NNSS-Avg. picks *k* neighbors and averages the locations.
  - better estimate

New RADAR Testbed

- Hardware (APs and NICs) from Aironet Communications.
- Operates in 2.4 Ghz ISM band.
- IEEE802.11b network with data rate up to 11Mbps.

Basic system performance

- new (Aironet) vs. old (WaveLAN) Testbed
- 3 APs considered.
- Long Tail – due to *Signal Aliasing.*

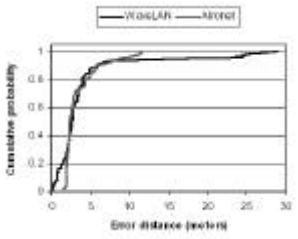


Fig: CDF of the Error Distance

Effect of Number of Access Points

- Little benefit beyond 3 APs
- Noise in *SS* limits accuracy.

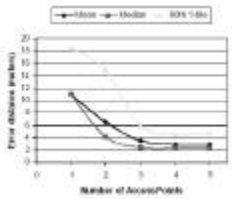


Fig: Impact of the number of APs on the error distance.

RADAR Enhancements

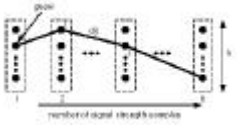
- Continuous user tracking
- Profiling the environment
- Testing for multiple floors

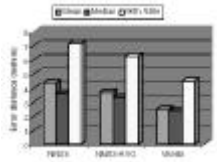
Continuous User Tracking

- Use past-location information to improve accuracy of future guesses.
- Physical contiguity constraint
  - Also used to anticipate handoffs in cellular networks.
- Positive side effect: problem of aliasing is alleviated.
- Viterbi-like algorithm
  - Original Viterbi algorithm is used by receivers to determine the most likely message transmitted over noisy channel.

Viterbi-like algorithm

- Each time *ss* tuple is obtained by mobile host, NNSS is run to determine *k* neighbors.
- A history of depth *h* (latest h entries) of such *k*-sets is maintained.
- This collection can be viewed as a graph shown in fig.; with edges only between vertices in consecutive sets.
- Edges weighted using Euclidean distance (physical) as metric.
- The shortest path (using least weighted edges) is user's most likely trajectory.
- Lag of h *ss* samples before guessing.





Viterbi with k=3 and h=6

Profiling the environment

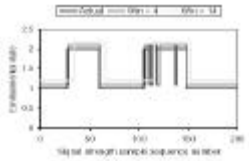
- The problem :
  - RF signal reflections, diffractions and scattering create a hostile environment for *SS* based location systems.
  - The Multipath phenomenon
  - The *People* factor.
- The solution :
  - Multiple *Radio Maps* for multiple environments.
  - Use APs to calibrate the environment
  - Question: how do we chose the right map in real-time ?

"The Answer is far from "elementary" my dear Watson !"

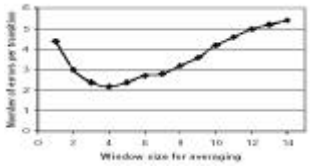
Profiling the environment (contd.)

- Each AP records signal strength samples extracted from beacons and packets received from other APs within range.
- For each other AP, say *AP-i*, it computes the mean, *m-i*, of the received signal strength samples over a sliding window *w* samples.
- It uses *m-i* together with the pre-computed mean (µ-*e*) and standard deviation (ó-*e*) of the signal strength corresponding to each environmental state, *e*, to estimate the likelihood that the received signal strength samples are in conformance with that environmental state.
- Assume Gaussian (Normal) distribution, N(µ-*e*, ó-*e*), for the signal strength.
- For each environmental state, *e*, the likelihood of match determined by each pair of APs are multiplied together to obtain an overall estimate of the likelihood of the environmental state being *e*.
- The environment *e-max* with the highest likelihood of match is then guessed to be the true environmental state.

Profiling the environment (contd.)

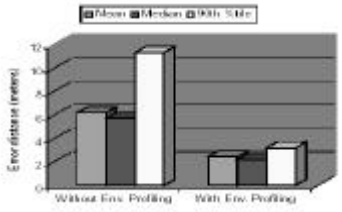


	Mean	Std. Deviation
Busy hour	46.07	2.41
Non-busy hour	50.85	1.19



Profiling the environment (contd.)

- Performance :
  - Experiment done for “busy” and “non-busy” hours.
  - Marked improvement in “error distance”.

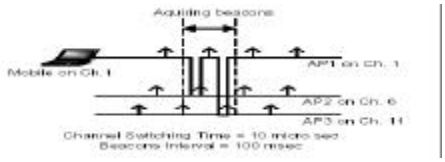


RADAR on Multiple Floors

- 3 floor experiment
- Took points with same (x,y) on each floor.
- RADAR works well in multi-floor environment.
- Found that aliasing is not that big an issue in vertical space.

Implementation Insights

- Effects of Multiple Channels
  - Neighboring APs are on different channels (frequency re-use requirements)
  - Mobile has to scan all channels in “active-scan” mode for beacons.
  - The overhead for switching and waiting can be significant.
- Solution :
  - Synchronize the mobile with APs and do “just-in-time” channel switching



Implementation Insights

- WiLIB
  - Created WiLIB, a software library to provide user-level access to underlying wireless hardware.
  - Access signal strength, noise floor at Tx and Rx, MAC address of Tx
  - Provides list of APs from where beacon can be heard by WNIC.
  - WNIC can be configured for a specific channel.

Concluding Remarks

- Identified limitations of basic RADAR system.
- A continuous user tracking technique using a viterbi-like algorithm to disambiguate user locations and alleviate signal aliasing.
- An Access Point based environmental profiling scheme that’s resilient to variations in radio propagation environment.
- Experimental validation in multi-floor environment.
- Real world :
  - Highly variable RF propagation environment
  - Cost of APs -> “light” APs