Location-Aware Services in an In-Building Environment

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The RADAR System

Research Goal

Leverage the *existing infrastructure* of an *indoor* RF wireless LAN to build applications that take advantage of location information.
Related Work in Positioning System

Outdoor (Cellular) Systems
- GPS, DGPS, etc. (QualComm/SnapTrack, ...)
- Time Difference of Arrival (TruePosition System...)
- Angle of Arrival (KSI, ...)

Solutions designed for the outdoors are either ineffective or too costly indoors
Related Work in Indoor Positioning Systems

Infrared-based systems
- AT&T Research’s Active Badge System
  - Accurate due to short range and line-of-sight property
  - Scales poorly, limited by LoS, requires specialized infrastructure

Radio Frequency-based systems
- Cell-level granularity [HKSR97]
- Duress Alarm Location System, PinPoint

Alternative technologies: magnetic, optical, acoustic
- MIT’s Cricket System (MobiCom ‘99, ‘00), AT&T’s Bat
  - Very accurate (cm resolution)
  - Requires dedicated infrastructure
  - Targeted at specialized applications, e.g. head tracking, Orientation etc.

Traditional approach has been based on dedicated technology and infrastructure
The RADAR System

Our Approach

- Leverage *existing* infrastructure
- Use off-the-shelf RF wireless LAN
- Several advantages
  - WLAN deployed primarily to provide data connectivity
  - Software adds value to wireless hardware
  - Better scalability and lower cost than all available solutions
  - Not too hard to install and easy to manage
    - One-time cost for building signal-strength database
    - One-time cost for building the location hierarchy

Three Components

- User Location and Tracking
- Location Information Management
- Programmability
Location Determination

Algorithmic Components

- RF fingerprinting and matching
- RF environment profiling and matching
- Trajectory prediction
- Scanning and channel switching
- Location databases and location services
How good an indicator of location is signal strength?

Signal strength correlates well with distance.
Signal Processing in RADAR

Key idea:
- Map signal strengths to physical locations (*Radio Fingerprinting*)

Inputs:
- signal strength of access point beacons
- building geometry

Offline phase: Construct a **Radio Map**
- tabulate <location, SS> information

Real-time phase:
- extract SS from base station beacons
- find Radio Map entry that best matches the measured SS
Radio Map Construction

Empirical method
- Access Points emit beacons periodically
- measure SS at various locations
- record SS along with corresponding coordinates
  - user orientation needs to be included too!
  - tuples of the form \((x, y, z, d, s_1, ..., s_n)\)
- accurate but laborious

Mathematical method
- compute SS using a simple propagation model
  - factor in free space loss and wall attenuation
  - Cohen-Sutherland line clipping algorithm
- more convenient but less accurate
Demo

RADAR Demo

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Baseline Performance

Median error distance is 2.94 meters
Neighbor Averaging

- Find nearest neighbor in signal space (NNSS)
  - default metric is Euclidean distance
- Phys. coordinates of NNSS ⇒ user location
- Refinement: $k$-NNSS
  - average the coordinates of $k$ nearest neighbors

$N_1, N_2, N_3$: neighbors
$T$: true location of user
$G$: guess based on averaging

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Performance with Averaging

Median error distance is 2.13 meters when averaging is done over 3 neighbors

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How extensive does the Radio Map have to be?

Diminishing returns as the number of physical points mapped increases
Radio Map Construction with RF Modeling

Signal Propagation Measurements

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

Model parameters: \( P(d_o) = 28 \text{ dBm}, \ n = 1.53, \ \text{WAF} = 3.1 \text{ dBm}, \ C = 4 \text{ walls} \)
How well does WAF work?

Median error distance is 4.94 m compared to 2.94 m with empirically constructed radio map and 8.16 m with nearest base station method.

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Are User Trajectory and Speed Predictable?

Signal processing, and pattern recognition allow mobility management

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Mobility Modeling and Prediction

User’s previous locations can provide a good hint of her next location

number of signal strength samples

mean Median 90th %tile

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Environmental Profiling

RF propagation characteristics change all the time

Calculate location of known AP using different Radio Maps. Select the one that produces best result.

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Channel Switching

For the mobile to “hear” neighboring APs – all APs must be on the same channel

Effects overall system cost

Switching channels to listen to AP beacons is possible

- Degrades performance considerably

Mobile on Ch.1

Aquiring beacons

AP1 on Ch. 1

AP2 on Ch. 6

AP3 on Ch. 11

Channel Switching Time = 10 msec
Beacons Interval = 100 msec
Programming Requirements for RADAR

Ability of the wireless NIC to scan specified channels

For every incoming packet from a specified MAC address, ability to retrieve the packet’s
- received signal strength,
- noise floor at the transmitter, and
- noise floor at the receiver.
AP Monitor in WinXP

Windows XP contains the necessary support to enable RADAR
# Experimental Testbeds

<table>
<thead>
<tr>
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<th>Testbed 1 (Bldg. 31/2)</th>
<th>Testbed 2 (Bldg. 112/2)</th>
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</thead>
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<tr>
<td><strong>Hardware</strong></td>
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<td>Aironet/Cisco</td>
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<tr>
<td><strong>MAC</strong></td>
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<tr>
<td><strong>Modulation</strong></td>
<td>SS DQPSK</td>
<td>SS CCK</td>
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<td><strong>Power</strong></td>
<td>50 mW</td>
<td>30 mW</td>
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<tr>
<td><strong>Raw Date Rate</strong></td>
<td>1, 2 Mbps</td>
<td>1,2, 5.5, 11 Mbps</td>
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<tr>
<td><strong># of APs</strong></td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td><strong>Floor</strong></td>
<td>43.2 m x 22.5 m</td>
<td>42.9 m x 21.8 m</td>
</tr>
<tr>
<td><strong>OS</strong></td>
<td>FreeBSD 3.0</td>
<td>Windows 2000</td>
</tr>
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</table>
Exploiting Location

Subscription based:
- Location Information Service
- Location Alert Service
- Location based Buddy List Service
- OnSale Mall Buddy Service

Network Improvements
- AP Load balancing
- Node-level QoS
Location Information Service

WISH (Where IS Harry?)
"I wish I knew where Harry is."

User location system that works with Wireless LANs

Usage scenarios
- Locate people and devices
- Discover nearby resources (printers, offices, restrooms, etc.)
Location Information Service Architecture

WISH Client

WiLIB

Device Driver

http://wish

Eventing Infrastructure

WISH Server

Every 2 minutes

Every 30 seconds

Every 30 seconds

Access Point

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Where IS Harry Service
Location Alert Service

When I can’t find Harry...

“Alert me when you find Harry.”

Soft-state eventing infrastructure to trigger alerts when event matches are found.

Personalized alert delivery through Instant Messaging, emails, cell phone SMS
Location Alert Service Architecture

- WISH Client
- WISH Server
- WISH Alert Service
- Eventing Infrastructure
- SIMBA Library
- MyAlertBuddy

Alert Subscription Page

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Location-Based Buddy List Service

When Harry is my buddy..

"Alert me if Harry happens to be close by."

Subject-based publish/subscribe eventing based on user profiles

Integrated tightly with MSN buddy list
Location-Based Buddy List Service Architecture

“Victor is in the mall.”

“Wilf is in the mall.”

http://www.mschoice.com
http://choice
OnSale Mall Buddy Service

Personalized sales announcements

“Alert me when electronics are on sale.”

Subject-based publish/subscribe eventing based on product categories and user profiles

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OnSale Mall Buddy Service Architecture

Profile

S

Shopping Profiles

Mall Buddy Client

Wilf

Mall Buddy Server

OnSale Server

Eventing Infrastructure

“Electronics are on sale.”

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Summary

Takes advantage of existing Wireless LAN infrastructure

Easy to install and manage
- one-time cost for building signal-strength database
- one-time cost for building the location hierarchy

System does not require line-of-site communication

Provides security, replication, partitioning for scalability, and back-up and restore

RADAR: a software solution to indoor location determination

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Thanks!

http://research.microsoft.com/~bahl