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

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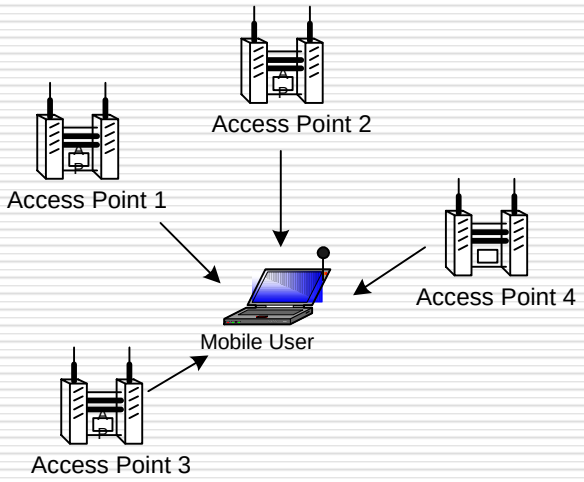
Algorithmic Components

- 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?

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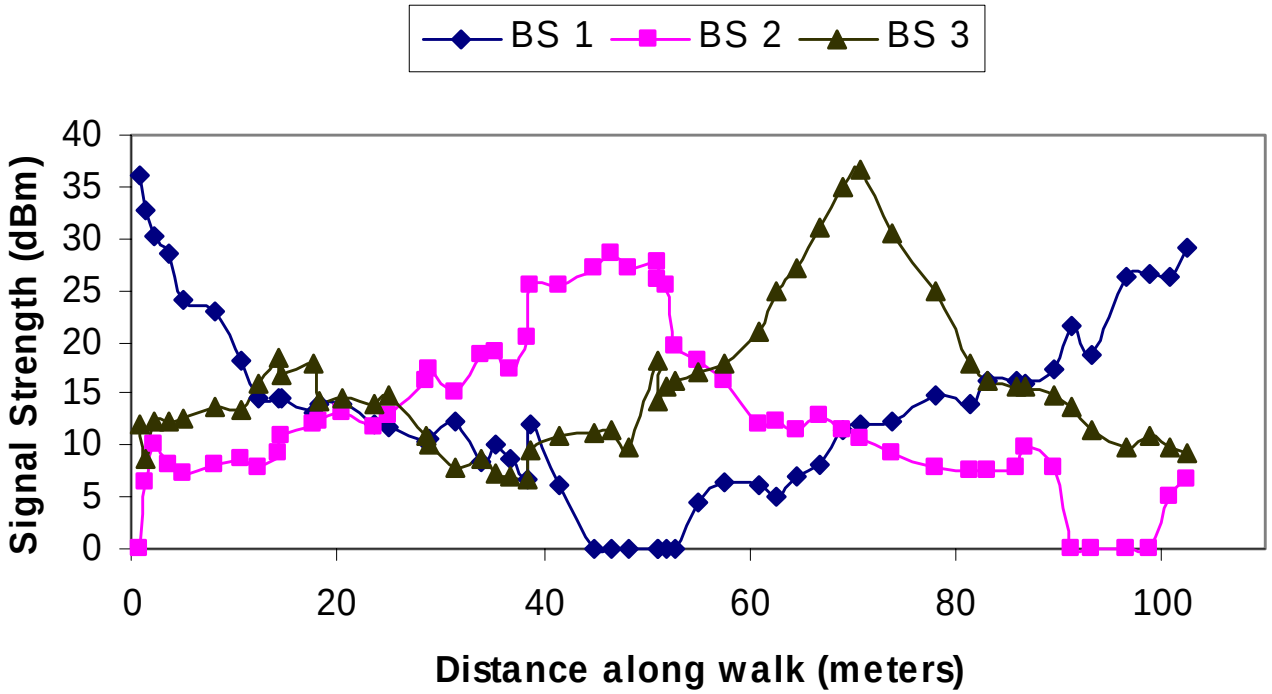

Signal strength correlates well with distance

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

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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 $(x,y,z,d,s_1,\ldots,s_n)$
- 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

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RADAR Demo

Baseline Performance

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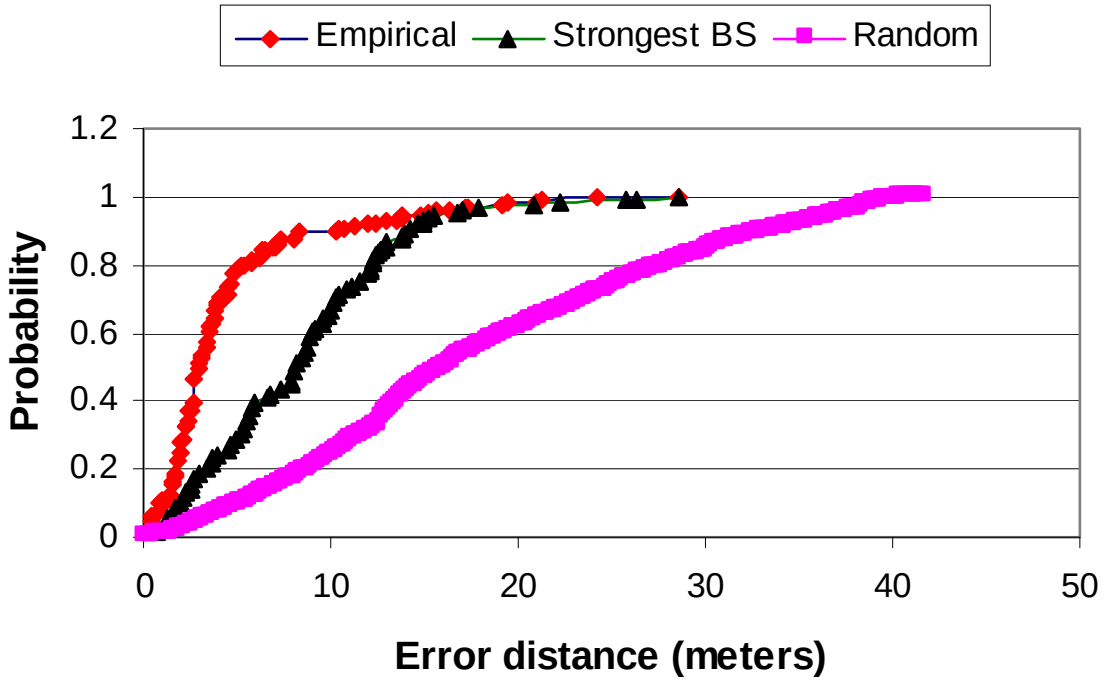

Median error distance is 2.94 meters

Neighbor Averaging

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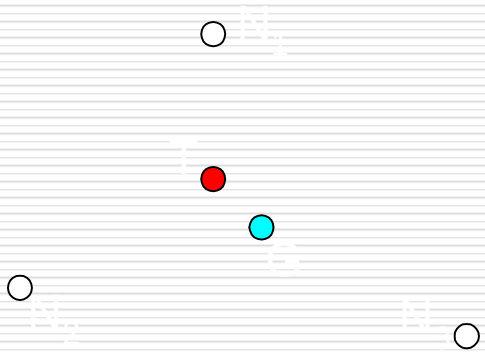
- Find nearest neighbor in signal space (NNSS)
  - default metric is Euclidean distance
- Phys. coordinates of NNSS $\Rightarrow$ user location
- Refinement: *k*-NNSS
  - average the coordinates of *k* nearest neighbors



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

Performance with Averaging

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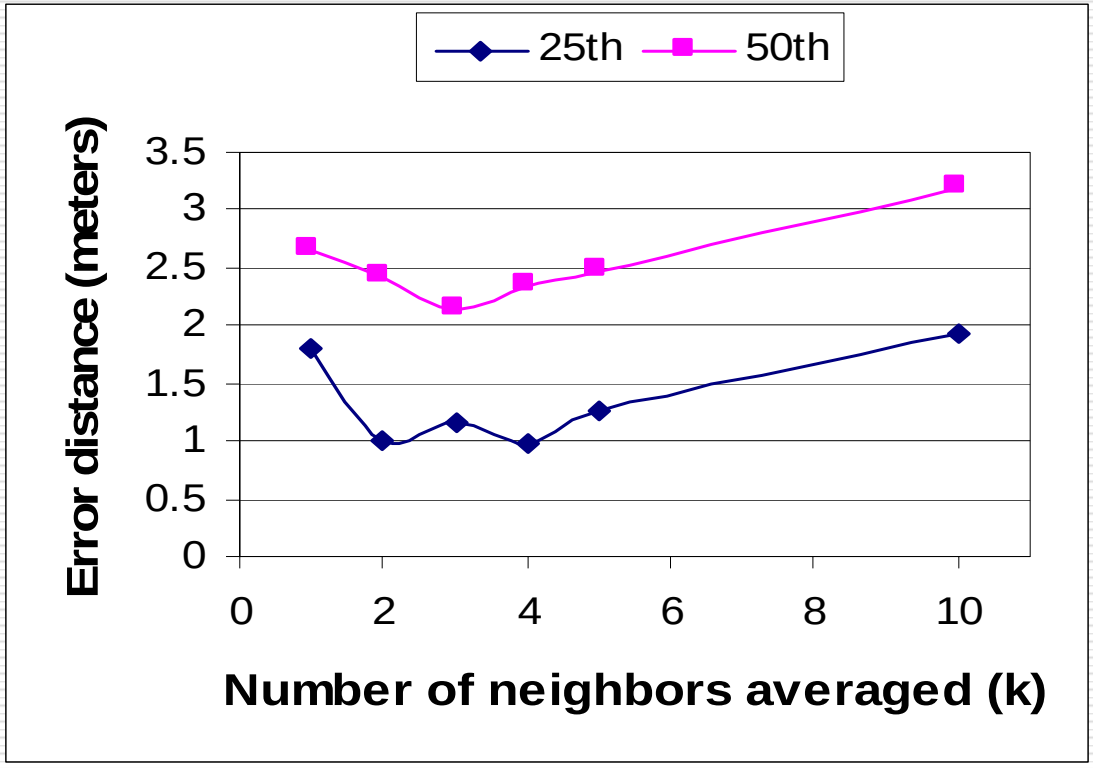

Median error distance is 2.13 meters when averaging is done over 3 neighbors

How extensive does the Radio Map have to be?

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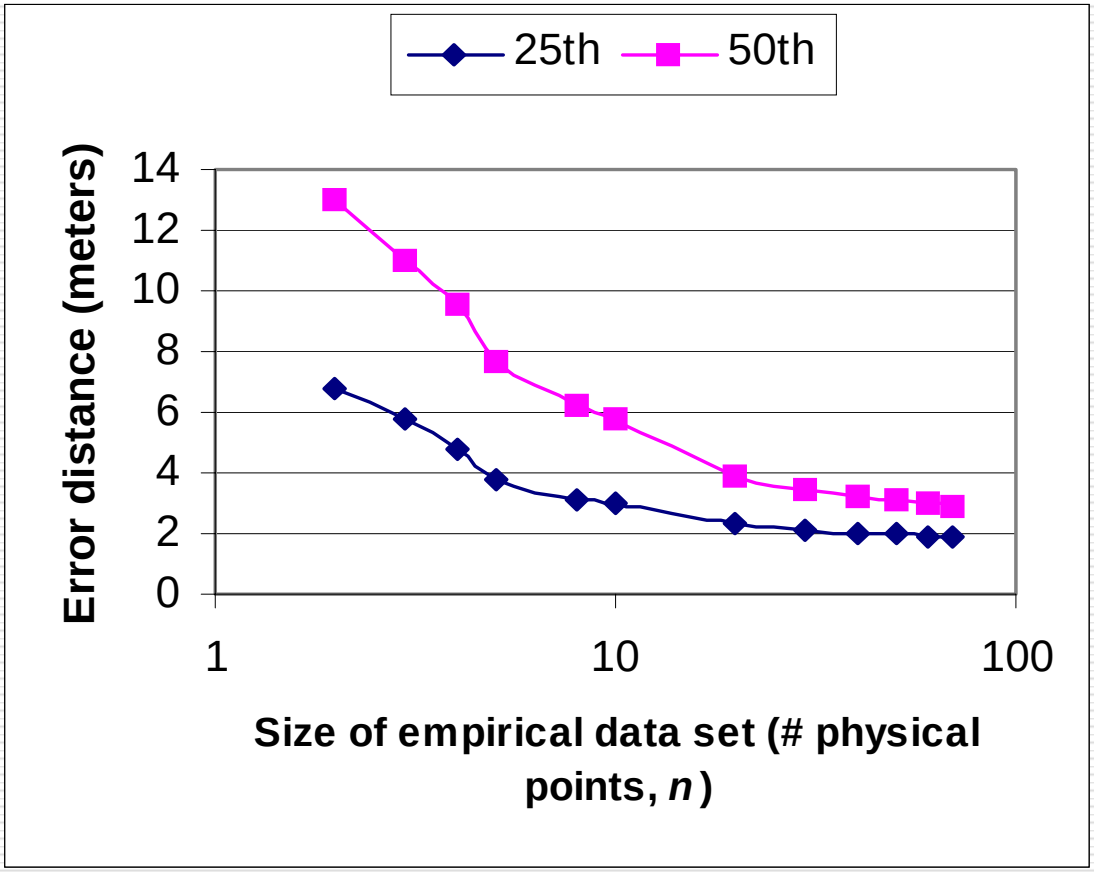

Diminishing returns as the number of physical points mapped increases

Radio Map Construction with RF Modeling

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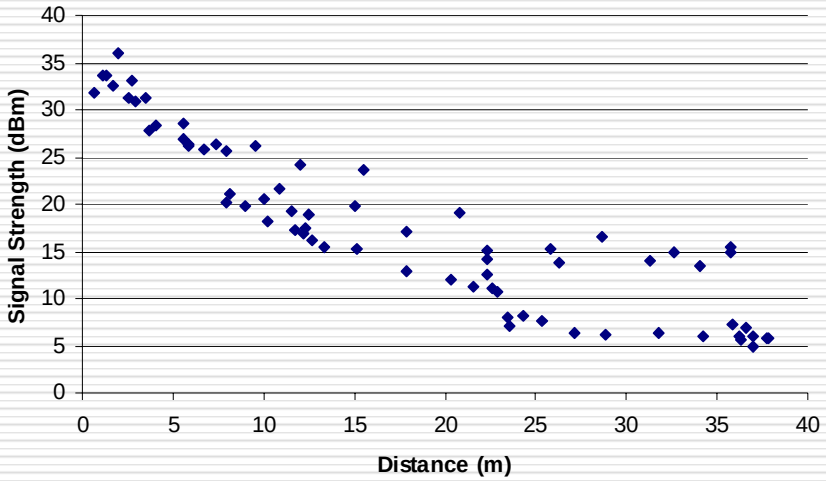
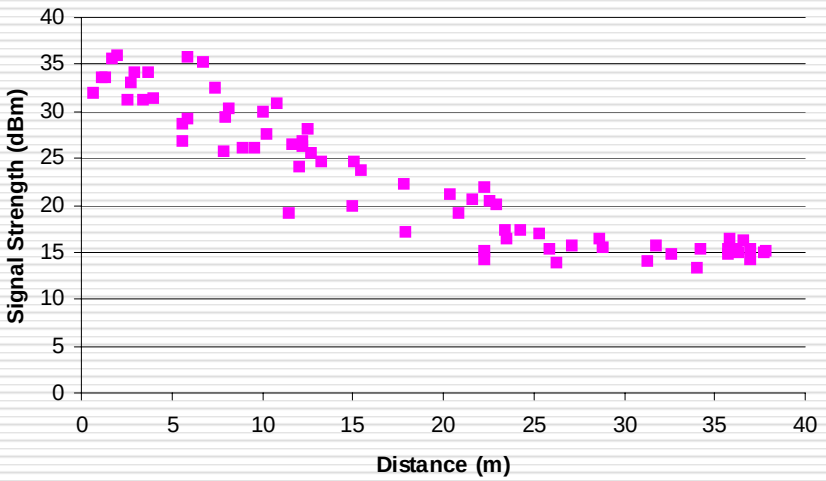
Signal Propagation Measurements





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

Model parameters: $P(d_0)$ = 28 dBm, n = 1.53, WAF = 3.1 dBm, C = 4 walls

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How well does WAF work?

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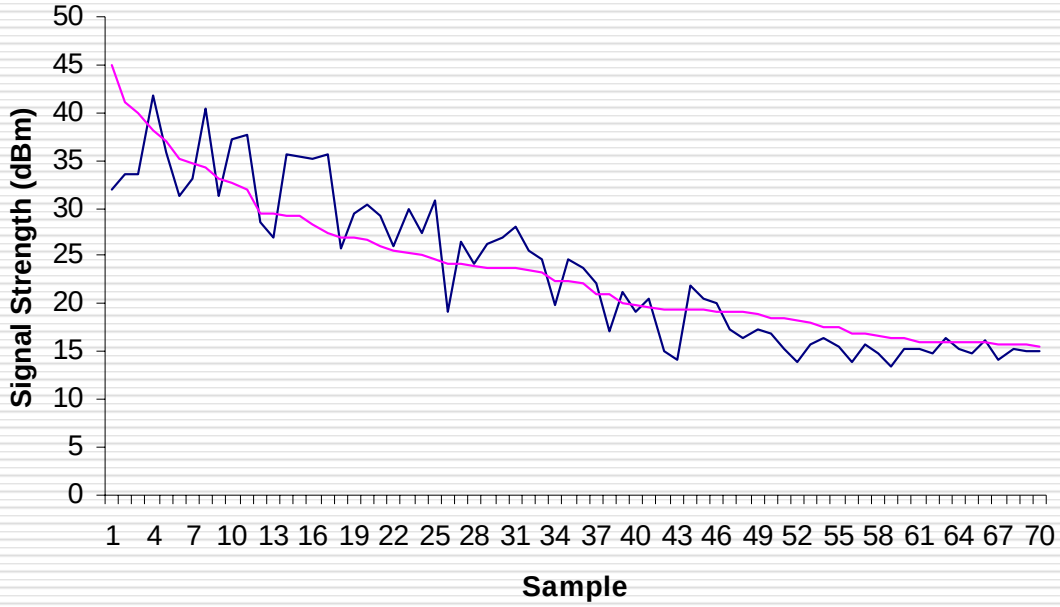

Median error distance is 4.94 m compared to 2.94 m with empirically constructed radio map and 8.16 m with nearest base station method

Are User Trajectory and Speed Predictable?

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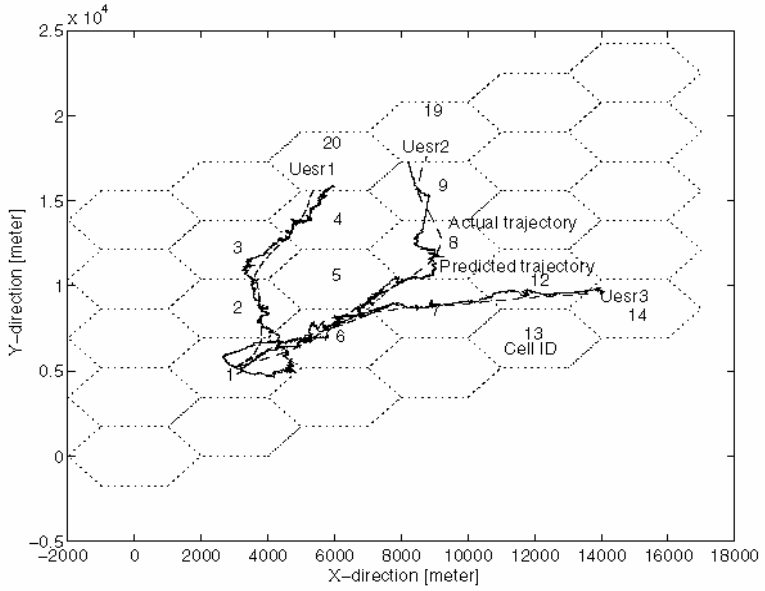

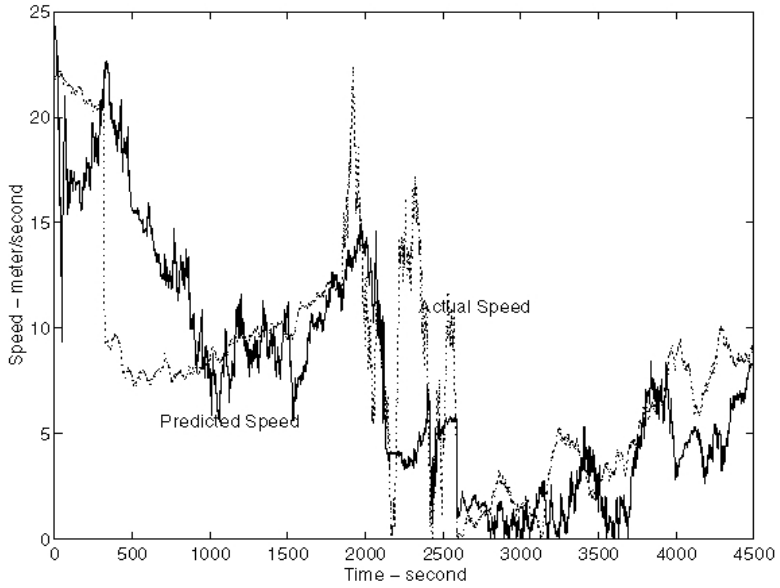

Signal processing, and pattern recognition allow mobility management

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Mobility Modeling and Prediction

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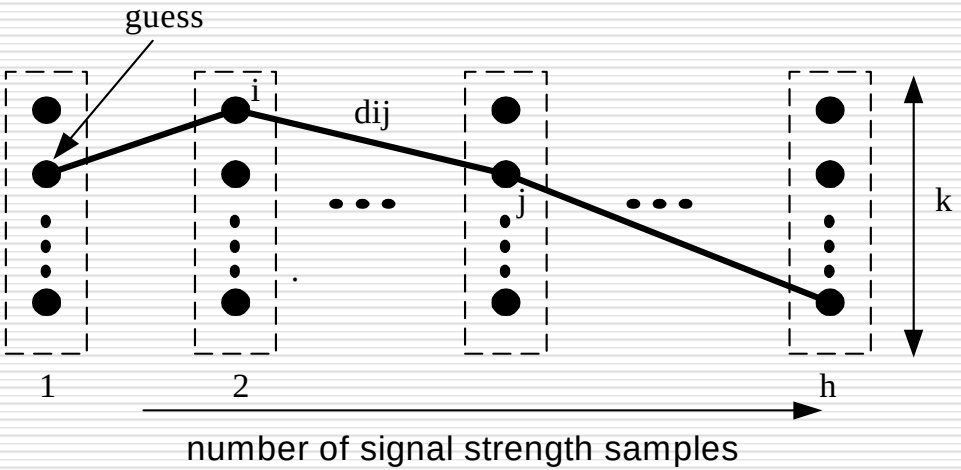
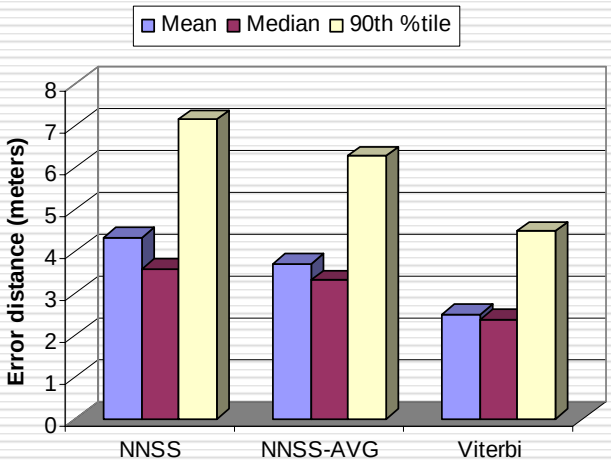
User's previous locations can provide a good hint of her next location





Environmental Profiling

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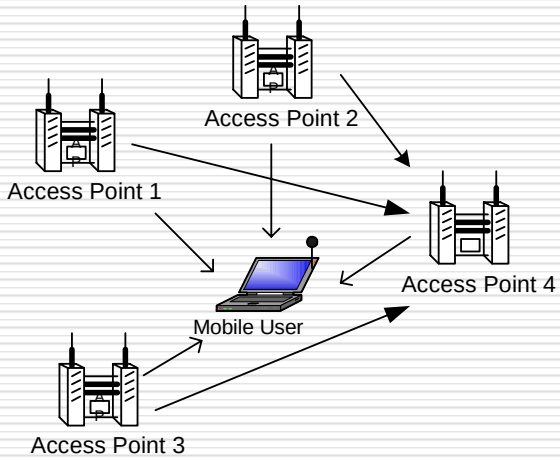
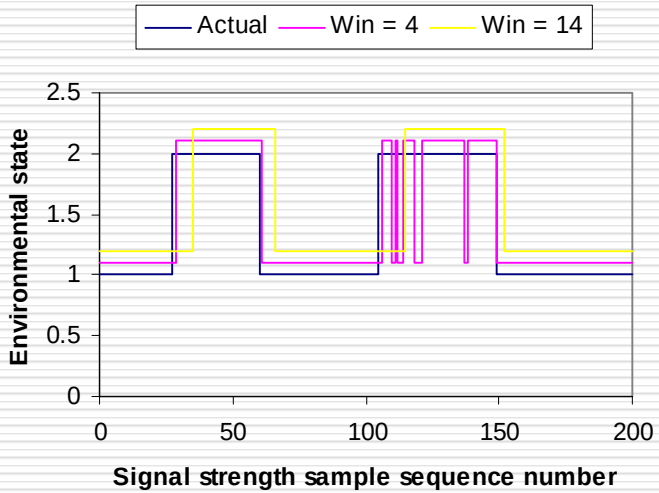
RF propagation characteristics change all the time





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

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Channel Switching

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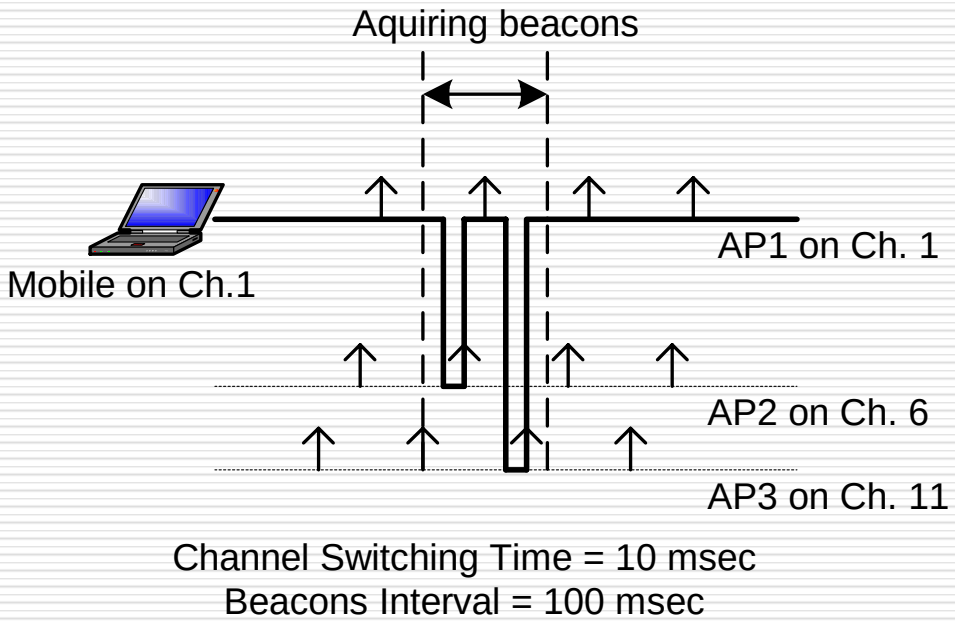
For the mobile to "hear" neighboring APs – all APs must be on the same channel

- Effects overall system cost

Switching channels to listen to AP beacons is possible

- Degrades performance considerably



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

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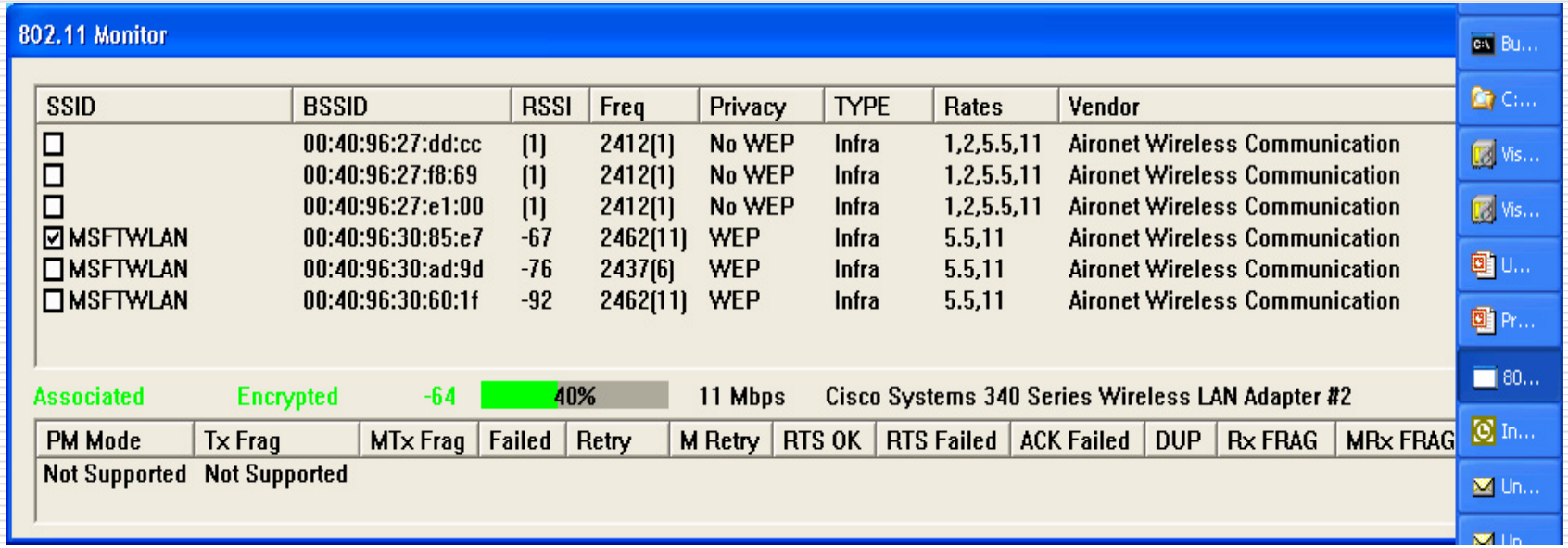
Windows XP contains the necessary support to enable RADAR



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Experimental Testbeds

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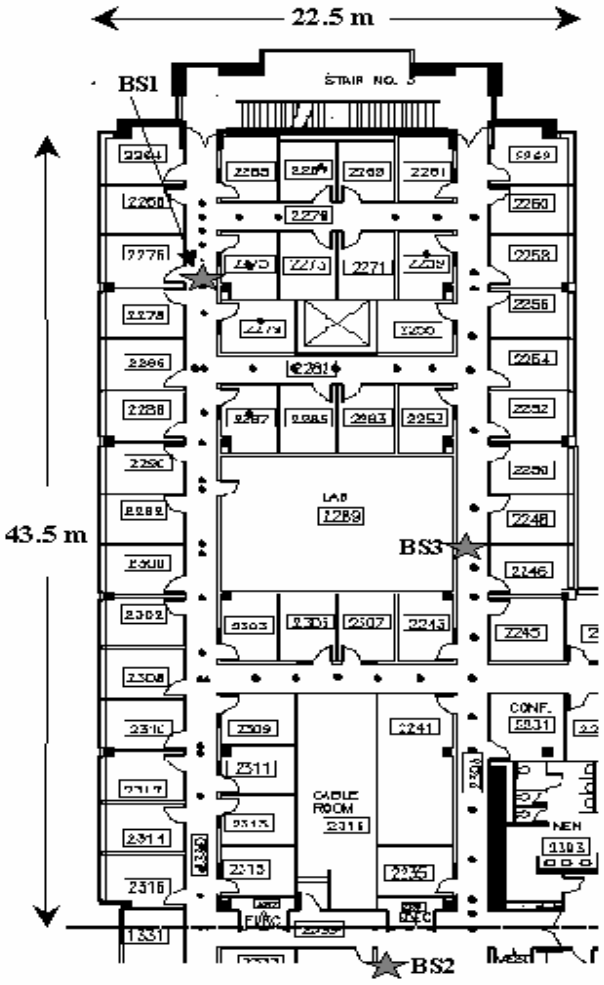
	Testbed 1 (Bldg. 31/2)	Testbed 2 (Bldg. 112/2)
Hardware	RoamAbout	Aironet/Cisco
MAC	CSMA/CA	IEEE 802.11b
Modulation	SS DQPSK	SS CCK
Power	50 mW	30 mW
Raw Date Rate	1, 2 Mbps	1,2, 5.5, 11 Mbps
# of APs	3	5
Floor	**43.2 m x 22.5 m**	**42.9 m x 21. 8 m**
OS	FreeBSD 3.0	Windows 2000



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Exploiting Location

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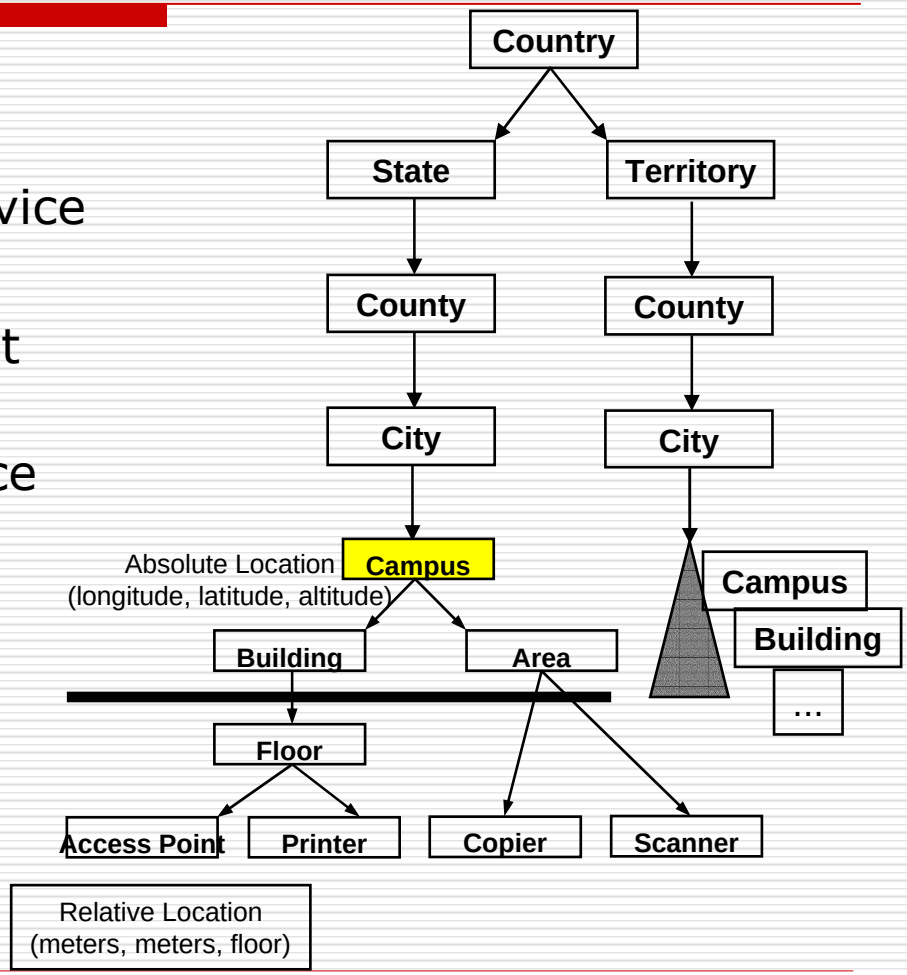
Subscription based:

- 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

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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

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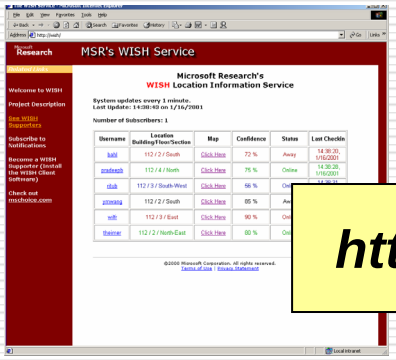

http://wish

Eventing Infrastructure

WISH Client

WiLIB

Device Driver

Every 2 minutes

Every 30 seconds

Every 30 seconds

WISH Server

Every 30 seconds

Access Point

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Where IS Harry Service

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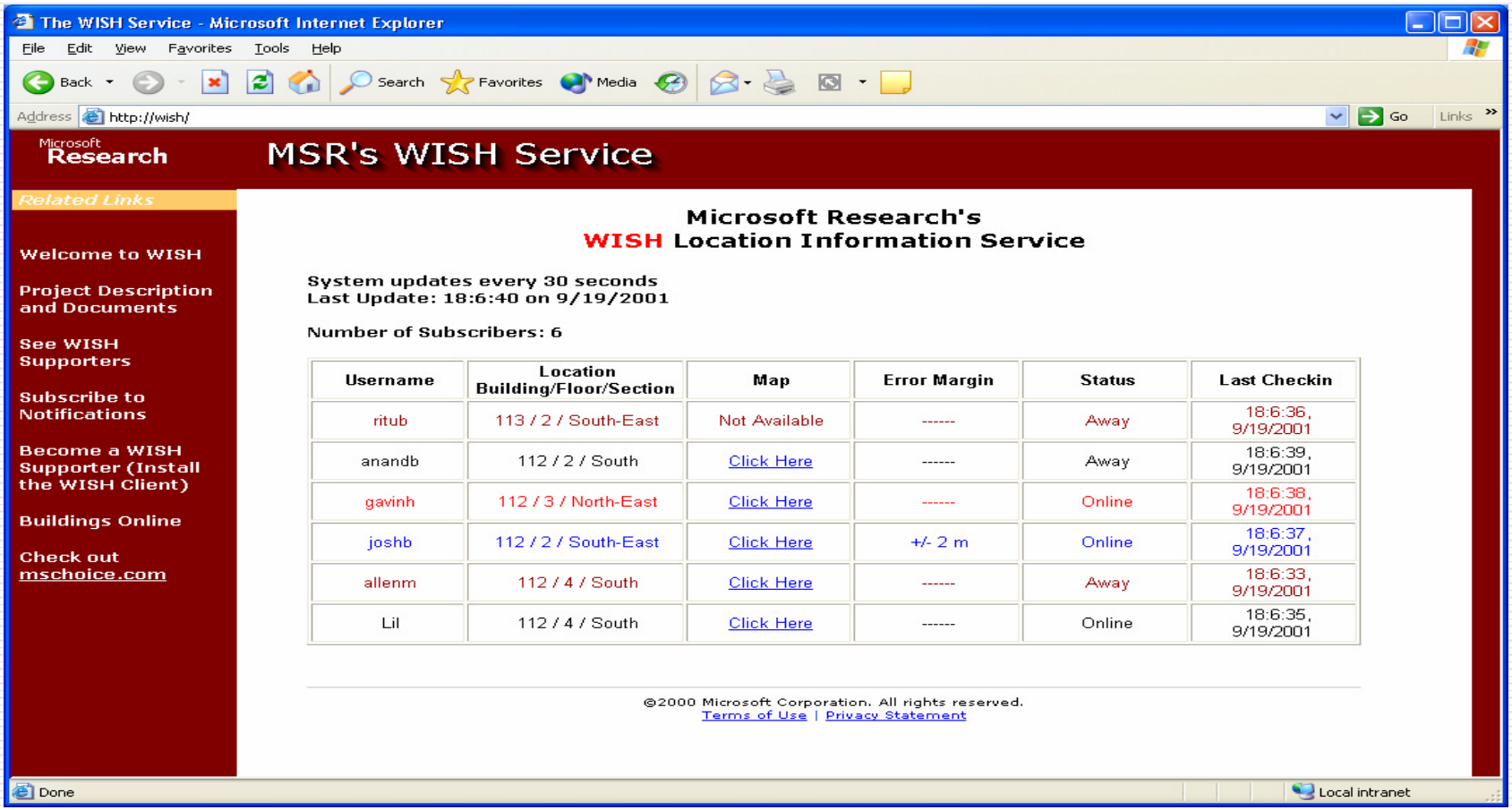

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Location Alert Service

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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

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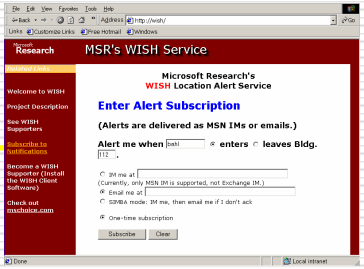
WISH Client

WISH Server

WISH Alert Service



Alert Subscription Page

Eventing Infrastructure

SIMBA Library

IM

Email

sMS

MyAlertBuddy

Email

IM

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

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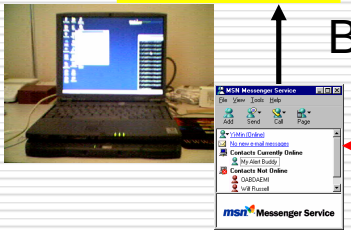
http://www.mschoice.com
http://choice

Mall Buddy Client

Wilf



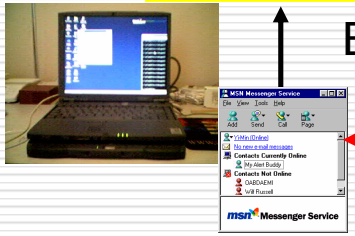
Buddy List

"Victor is in the mall."

Mall Buddy Server

Mall Buddy Client

Victor



Buddy List

"Wilf is in the mall."

Eventing Infrastructure

OnSale Mall Buddy Service

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Personalized sales announcements

"Alert me when electronics are on sale."

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

OnSale Mall Buddy Service Architecture

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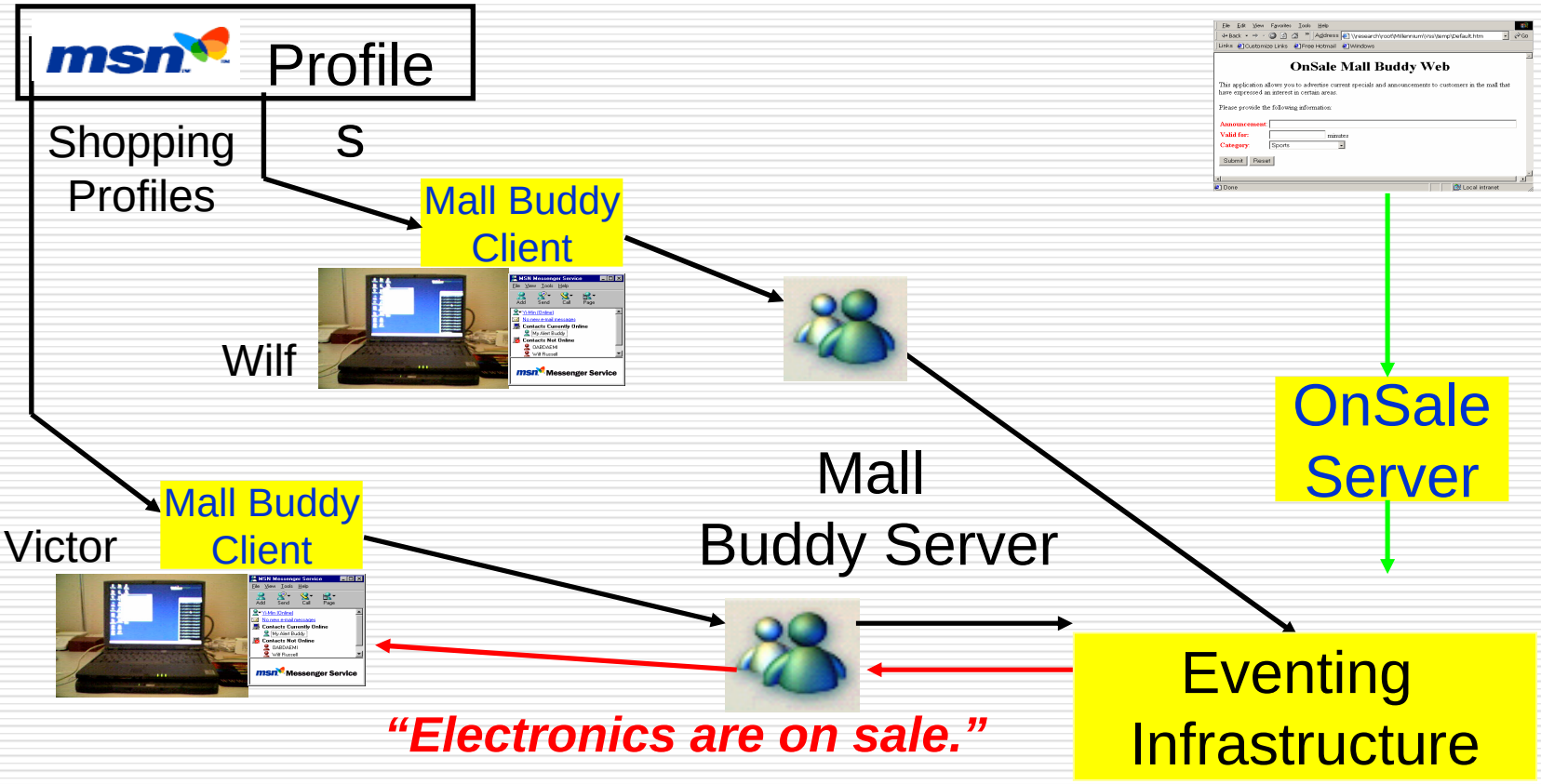

Summary

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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

Thanks!

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