Co-Localization from Labeled and Unlabeled Data in Wireless and Sensor Networks

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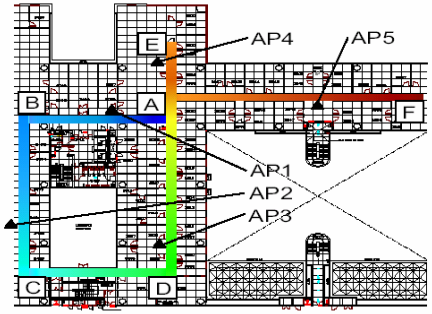
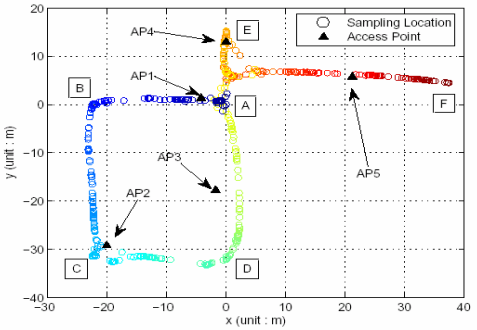
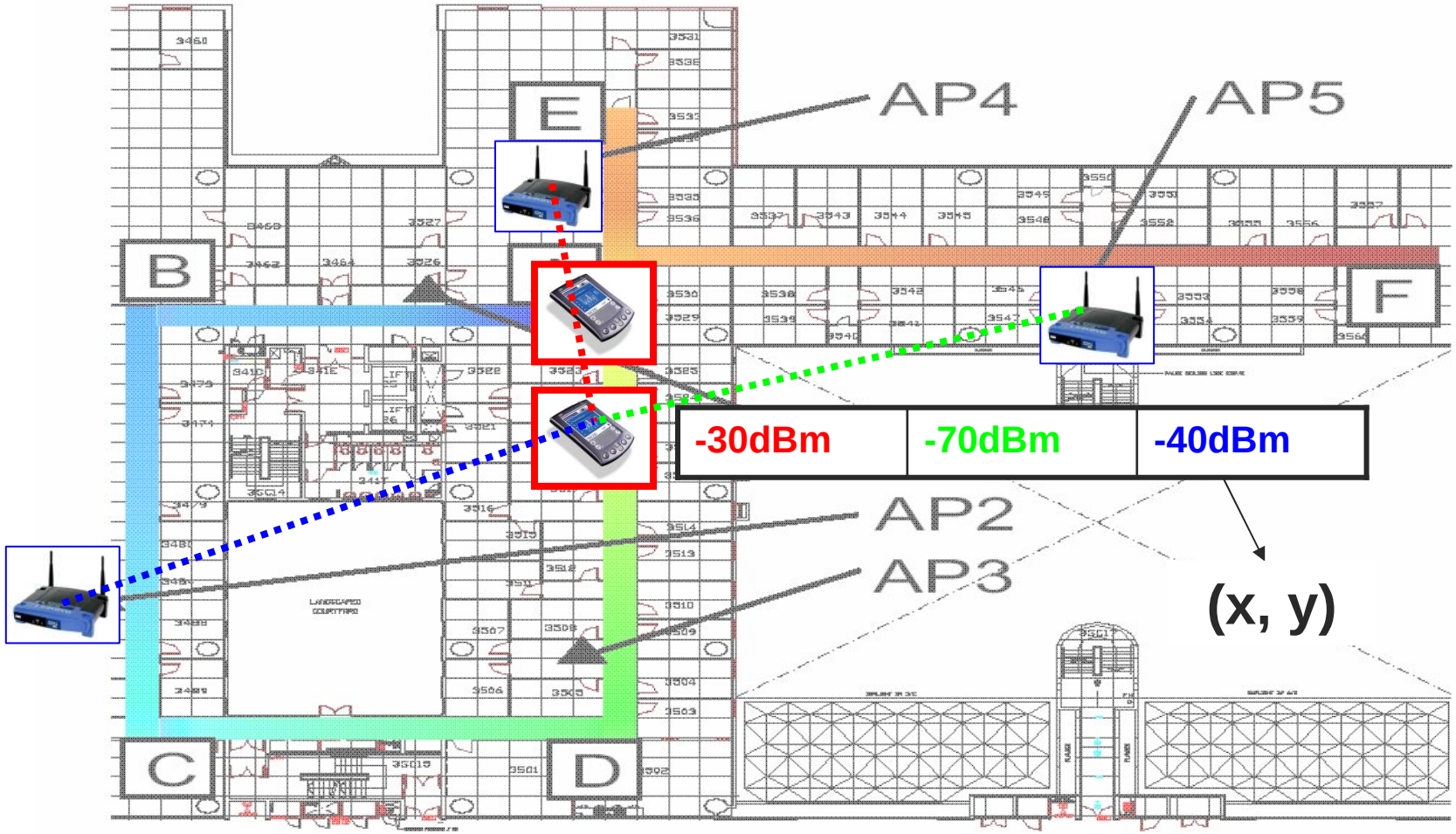




Signal-Strength-Based Localization

Where is the Mobile Device?



Signal-Strength-Based Mapping
Where are the Access Points?

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AP 1

AP 2

AP 3

AP 7

AP 8

AP 4

AP 5

AP 6

Locations Support Many Applications

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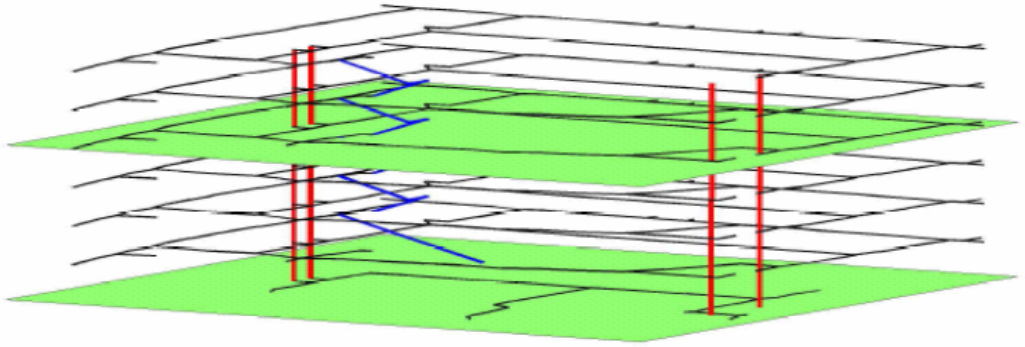
- Location Guidance & User Behavior Analysis

Source of Photo

J. Letchner, D. Fox and A. LaMarca. Large - Scale Localization from Wireless Signal Strength. AAAI2005

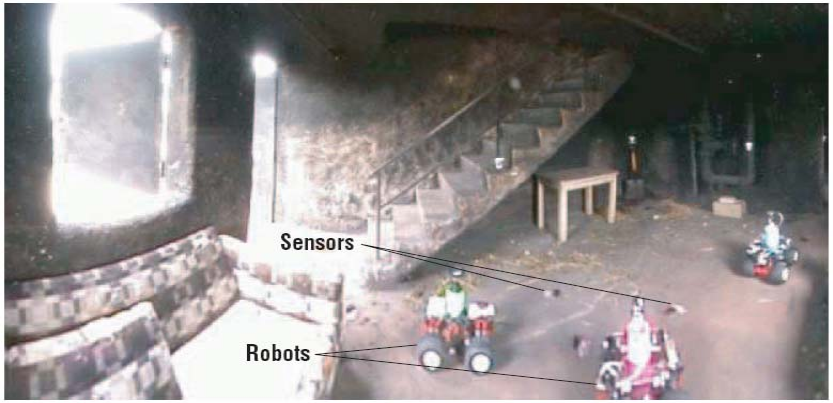
Photo www.bucu.ac.uk

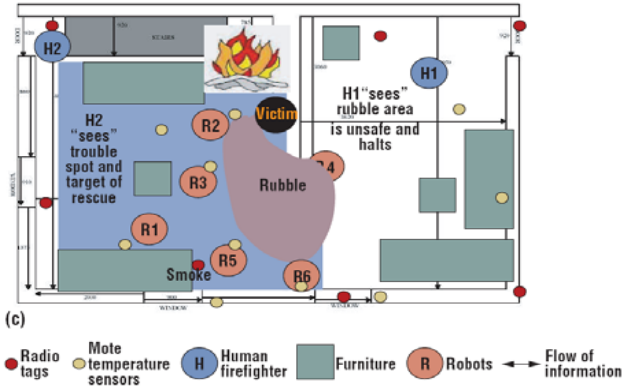


- Robots & Sensor Networks Collaboration

Source of Photo

V. Kumar, D. Rus and S. Singh, Robot and Sensor Networks for First Responders. IEEE Pervasive Computing, 2004





Building a Tracking System Needs

Calibration – Labeling Data

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- Calibration Effort
  - Special Devices
    - GPS, Laser, Ultrasonic
    - Expensive (cost, size, energy)
  - Manually Setup
    - Carry a device and mark down location
    - Time Consuming
- Our Focus
  - Use cheap and ubiquitous Radio-Signal-Strength (RSS)
  - Reduced calibration & Reasonable Accuracy

What Kind of Data We Have?

- The Location of Access Points
  - Known for those deployed by us
  - Unknown for those deployed by other persons
- The Location of Mobile Devices
  - Known when walking by landmarks (corners, doors)
  - Unknown elsewhere

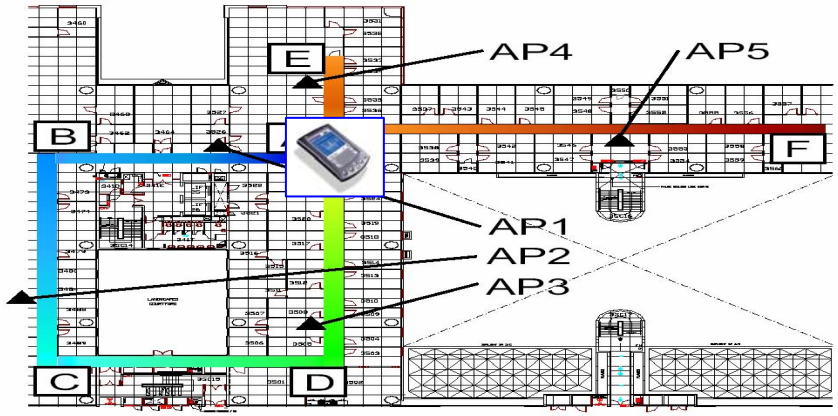

Table 1: Signal Strength (unit:dBm)

	AP_1	AP_2	AP_3	AP_4	AP_5
t_A	-40		-60	-40	-70
t_B	-50	-60		-80	
t_C		-40	-70		
t_D	-80		**-40**	-70	
t_E	-40		-70	-40	-80
t_F	-80			-80	-50

(All values are rounded for illustration)

A Solution for Localization and Mapping?

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- Co-Localization (3b)
  - Localize both access points and mobile devices
  - Exploit both labeled and unlabeled data
  - Labels from both access points and mobile devices
- Reduce Calibration Effort
  - **A small amount of Labeled data (expensive)**
    - (-60dBm,-50dBm,-70dBm) => (x,y)
  - **A large amount of Unlabeled data (cheap)**
    - (-60dBm,-50dBm,-70dBm)

Roadmap

HKUST

- Radio-Signal-Strength-based Tracking
  - RSS-based Tracking
  - Radio Characteristics
  - Co-Localization
- Co-Localization Algorithm
  - Observation of Radio Signal Strength
  - Basic Ideas
  - The Algorithm
- Experiments
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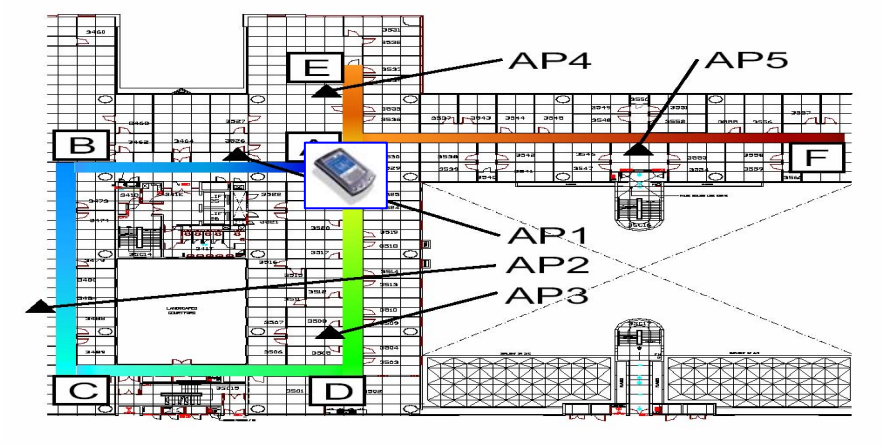
Observation of Signal Strength

- A user with a mobile device walks through A B,C,D,E,F



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t_E	-40		-70	-40	-80
t_F	-80			-80	-50

(All values are rounded for illustration)

- Characteristics
  - Two rows are similar ⇔ Two mobile devices are close (t_A & t_E)
  - Two columns are similar ⇔ Two access points are close (AP_1 & AP_4)
  - Strong cell ⇔ mobile device and access point are close (t_D at AP_3)

Idea I - Latent Semantic Indexing

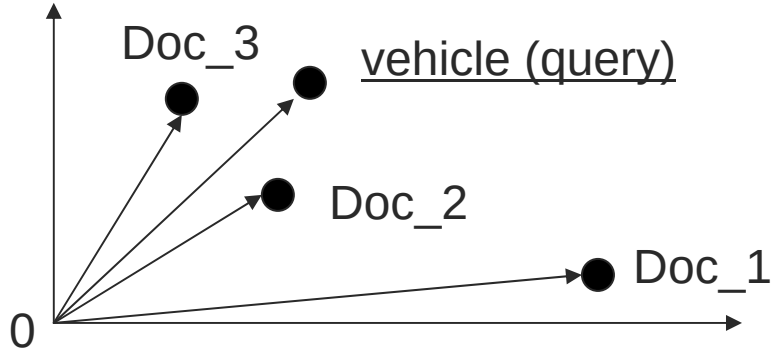
- Capture the Similarity
  - between n access points and m mobile devices

n Term

m Doc

Doc\Term	moon	car	truck
Doc_1	1	0	0
Doc_2	0	2	1
Doc_3	0	1	2

SVD



n Access Point

m Mobile Device

	AP_1	AP_2	AP_3	AP_4	AP_5
t_A	-40		-60	-40	-70
t_B	-50	-60		-80	
t_C		-40	-70		
t_D	-80		**-40**	-70	
t_E	-40		-70	-40	-80
t_F	-80			-80	-50

SVD

?

Solution I – Latent Semantic Indexing

- Transform signal matrix to weight matrix

$$S = [s_{ij}]_{m \times n} \longrightarrow A = [a_{ij}]_{m \times n}$$

- Normalize the weight matrix

$$A_{\mathcal{N}} = D_1^{-1/2} A D_2^{-1/2}.$$

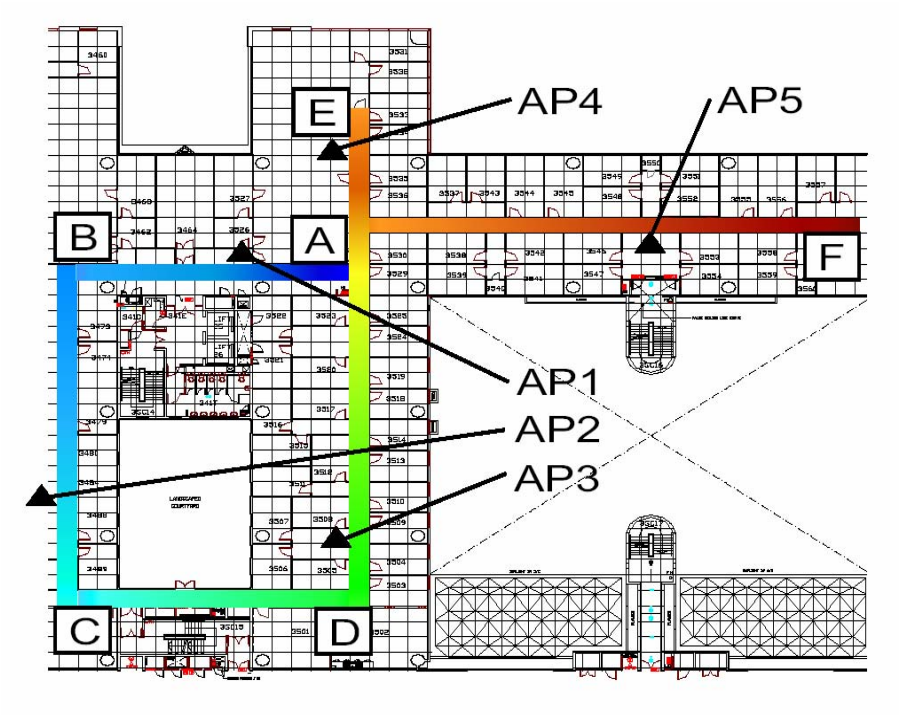
$$D_1 = diag(d_1^1, d_2^1, \ldots, d_m^1) \text{ where } d_i^1 = \sum_{j=1}^{n} a_{ij}$$
$$D_2 = diag(d_1^2, d_2^2, \ldots, d_n^2) \text{ where } d_j^2 = \sum_{i=1}^{m} a_{ij}.$$

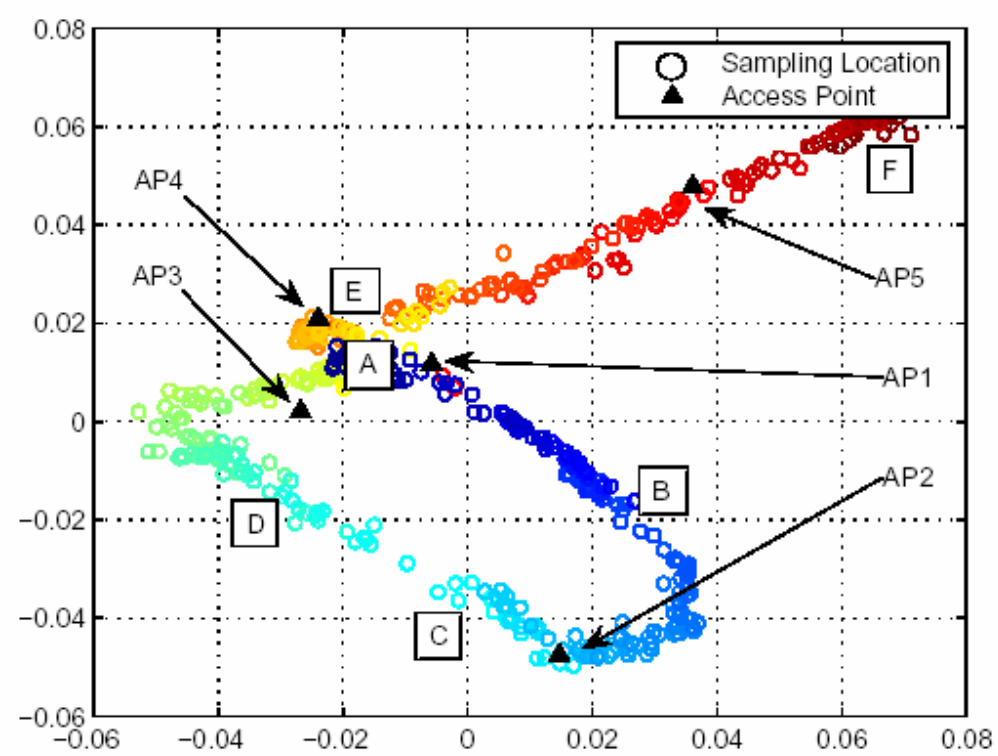
- Recover the relative coordinates by SVD

$$A_{\mathcal{N}} \approx U_{m \times r} \Sigma_{r \times r} V'_{n \times r}.$$

- Notation
  - m mobile devices, n access point, r=2 dimension

Illustration of Latent Semantic Indexing

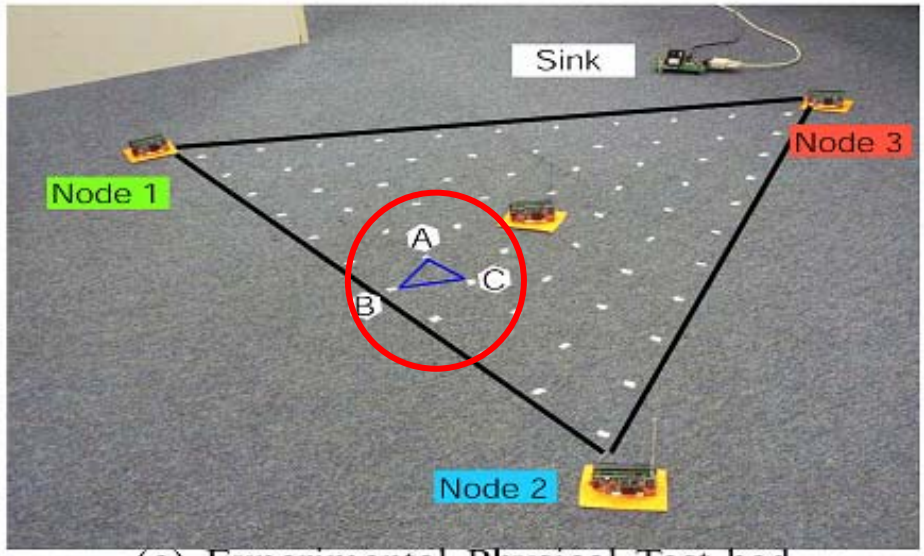




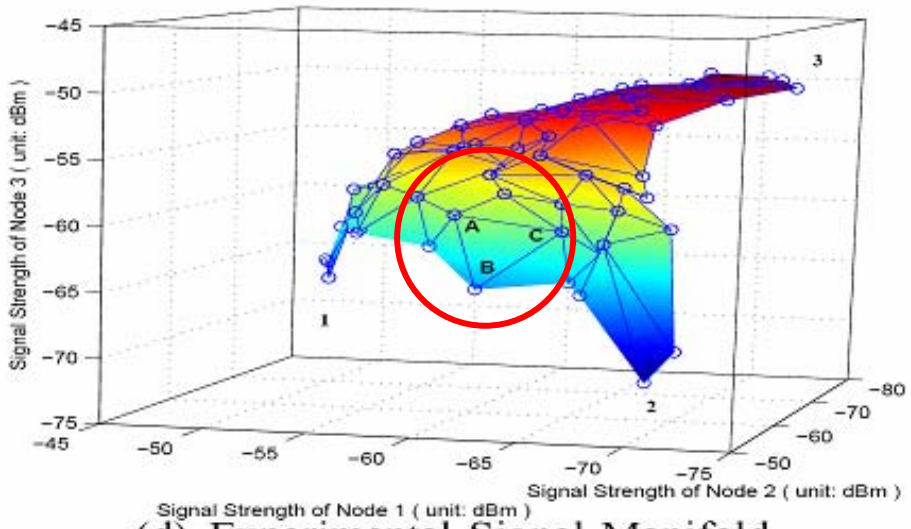
- Retrieve Relative Coordinates
- Well Alignment between Mobile Device and Access Points

Idea II – Manifold Learning

- Capture the Similarity
  - within mobile devices / access points



(c) Experimental Physical Test-bed



(d) Experimental Signal Manifold

Combine the Two Ideas Together

- Optimal locations of mobile devices and access points

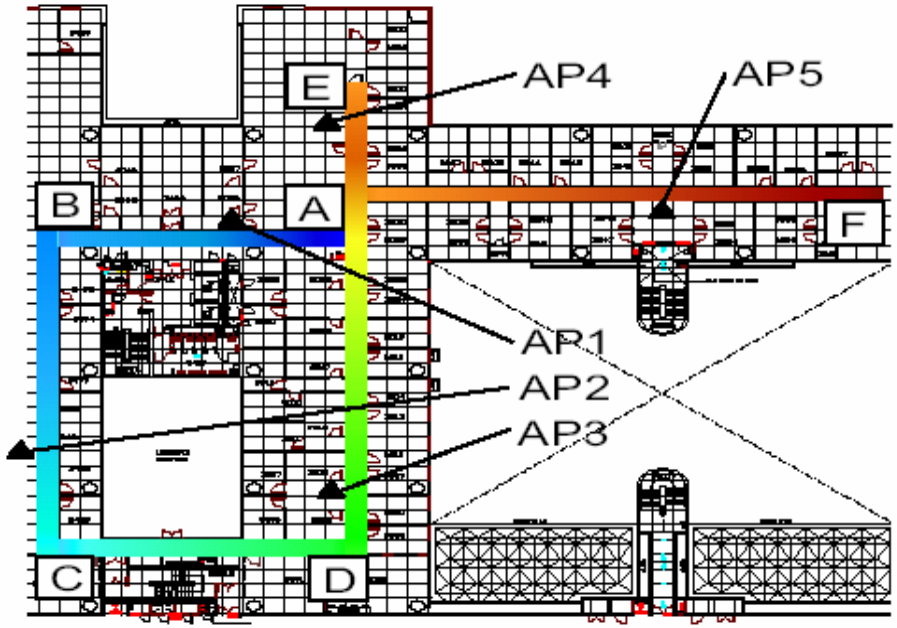
$$R^* = \arg\min_{R \in \mathbb{R}^{(m+n)\times 2}} (R-Y)'J(R-Y) + \gamma R'LR$$

$$R = [P' \; Q']' \quad Y = [Y_P' \; Y_Q']' \quad J = \begin{bmatrix} J_P & 0 \\ 0 & J_Q \end{bmatrix}$$

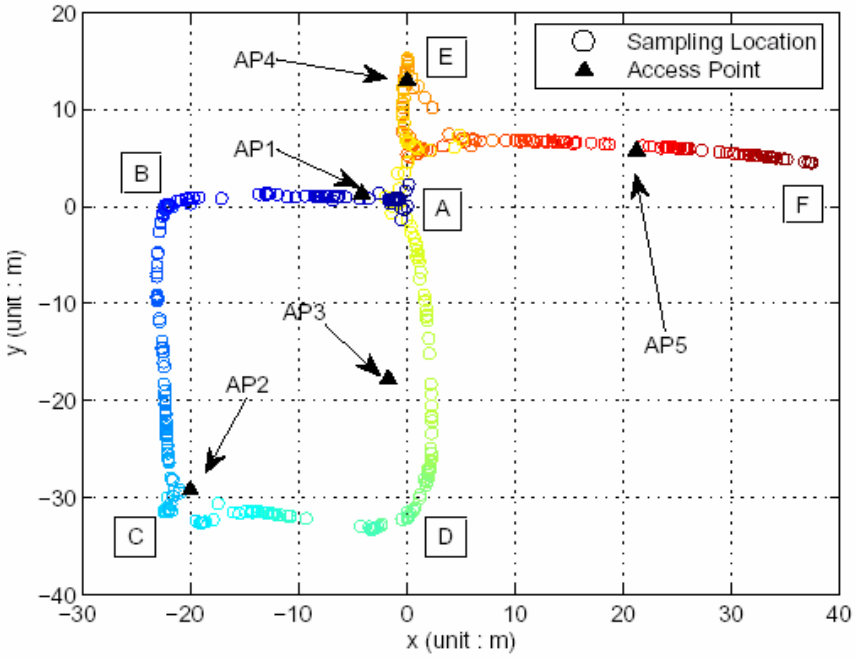
W =

W_P Manifold Matrix Correlation within mobile devices	**$A_{N'}$ Latent Semantic Index** Correlation between mobile devices and access points
A_N Latent Semantic Index Correlation between access points and mobile devices	**L_Q Manifold Matrix** Correlation within access points

Co-Localization Example



802.11 WLAN Test-bed



Co-Localization Result

Roadmap

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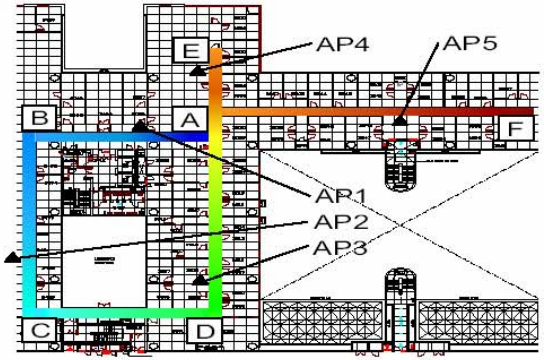
Experimental Setups

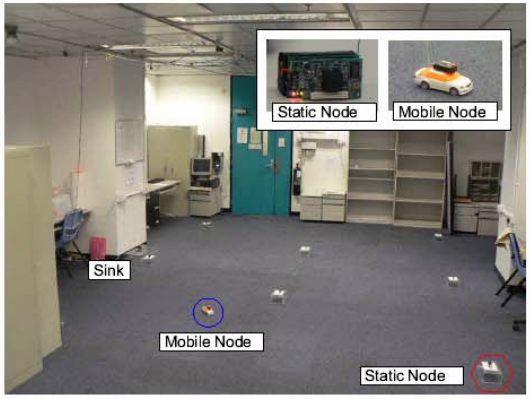
- 802.11 Wireless LAN (WLAN)
- Wireless Sensor Network (WSN)
- Radio-frequency identification (RFID)

Table 2: The experimental setups of WLAN, WSN and RFID

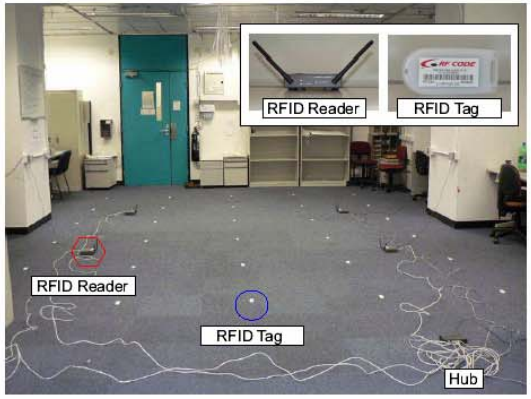
Infrastructure	AP	MD	Test-bed	Scale	Dataset Size	Motion Pattern
WLAN	5 Access Points	1 Notebook	Hallway	$60m \times 50m$	2000	Mobile (robot)
WSN	8 Static Nodes	1 Mobile Node	Room	$5m \times 4m$	4000	Mobile (human)
RFID	4 RFID Readers	30 RFID Tags	Room	$5m \times 4m$	2000	Static



(a) WLAN Test-bed

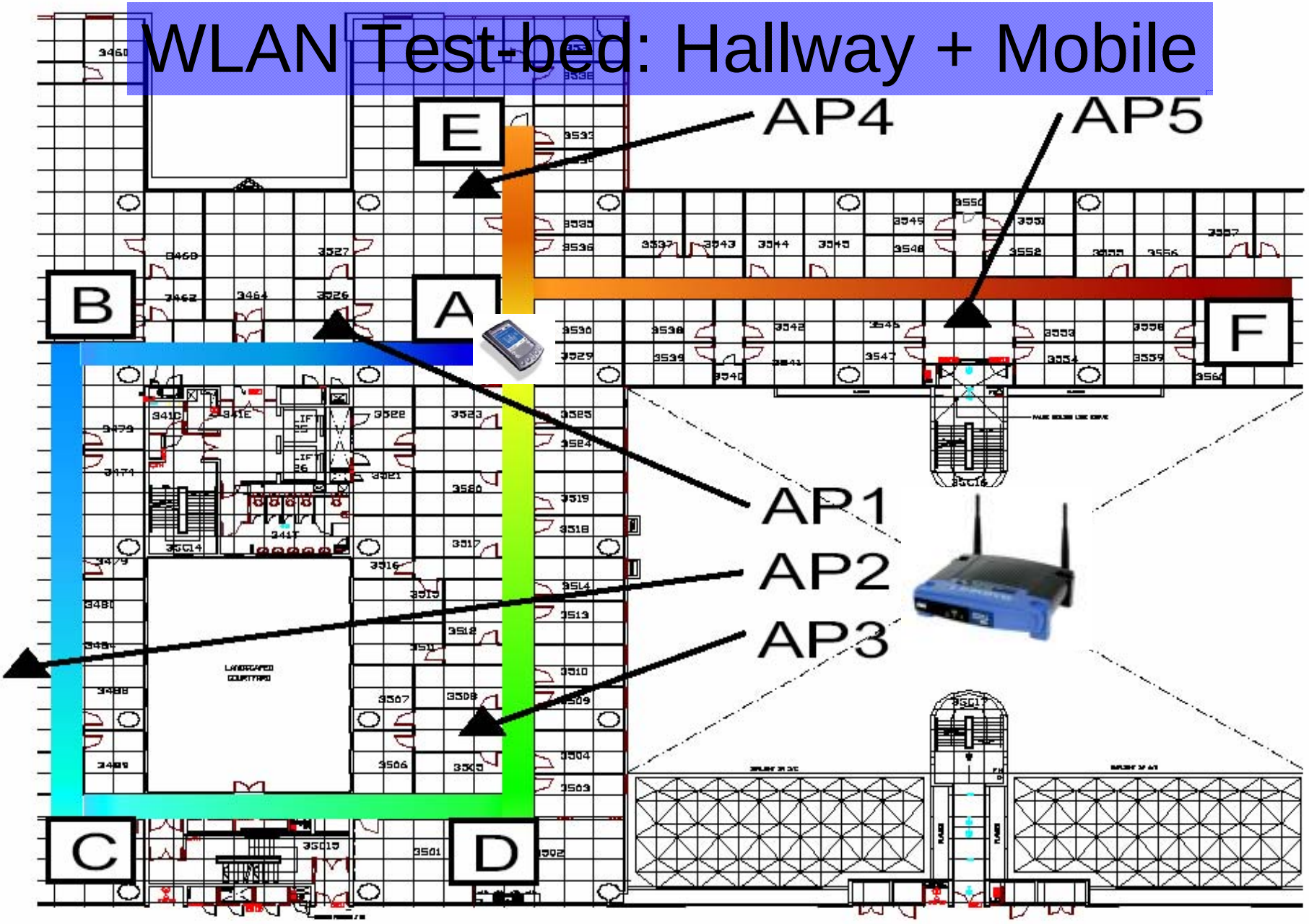


(b) WSN Test-bed

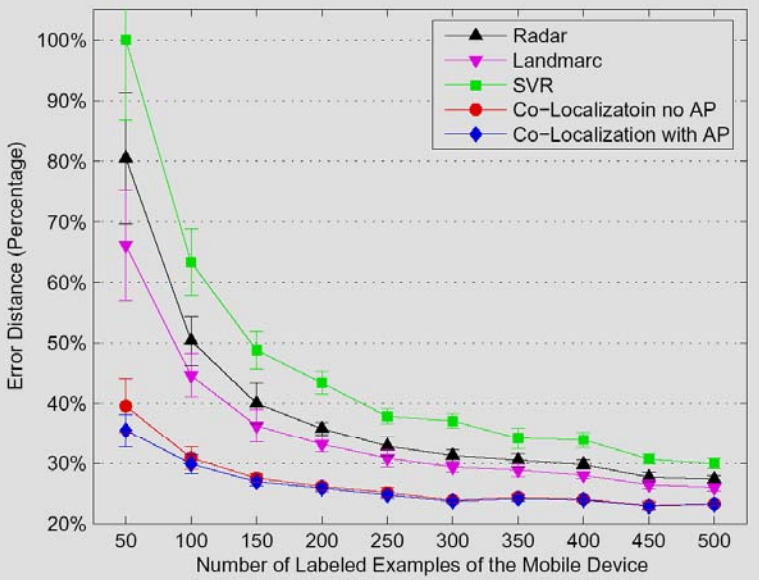


(c) RFID Test-bed

WLAN Test-bed: Hallway + Mobile

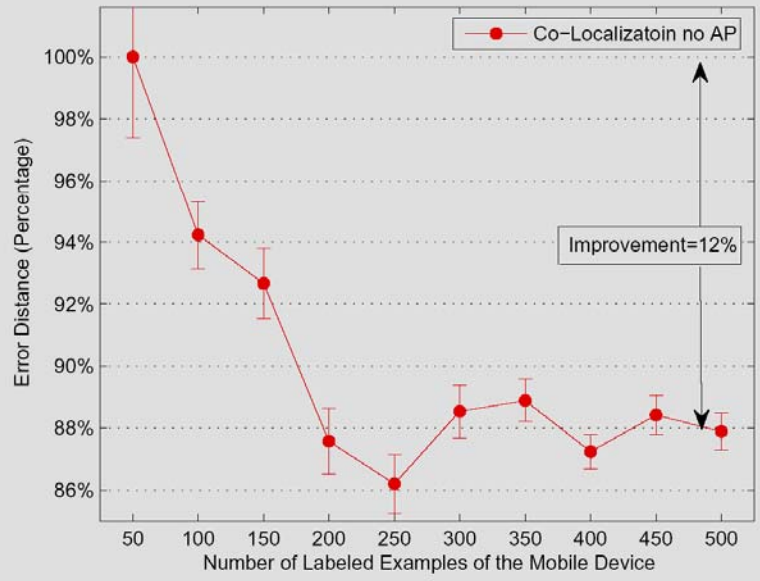


Error Distance is rescaled to percentage referring to the max error in each figure



(c) WLAN MD (notebook)

Error Distance is rescaled to percentage referring to the max error in each figure



(f) WLAN AP (access points)

Tests on WLAN / WSN / RFID

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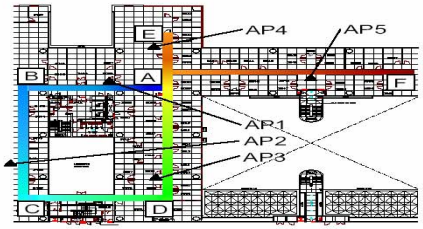
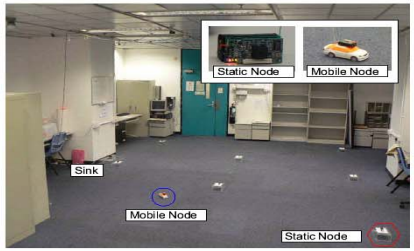
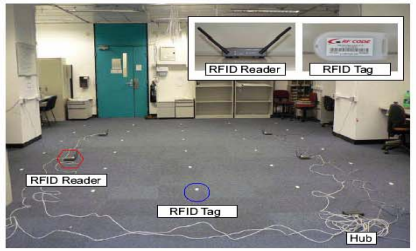
Different Test-beds



(a) WLAN Test-bed

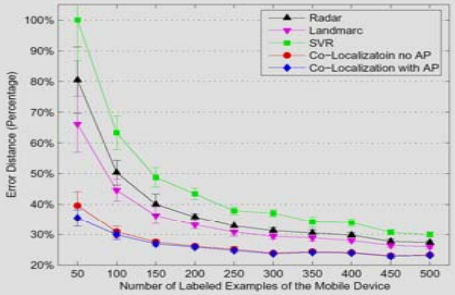


(b) WSN Test-bed

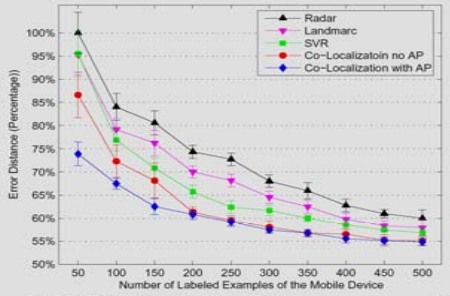


(c) RFID Test-bed

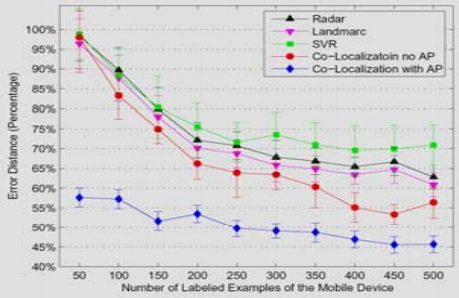
Locate Mobile Devices



(c) WLAN MD (notebook)

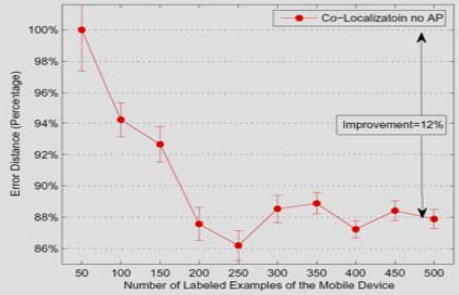


(b) WSN MD (mobile sensor node)

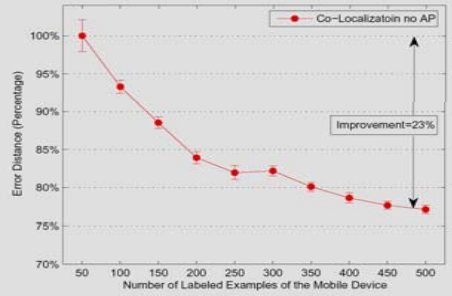


(a) RFID MD (tags)

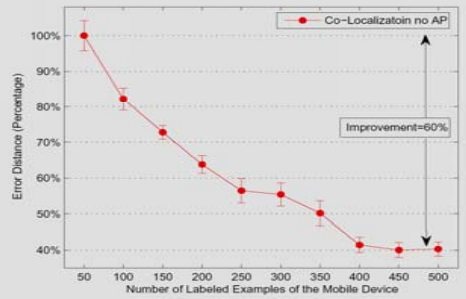
Locate Access Points



(f) WLAN AP (access points)



(e) WSN AP (static sensor nodes)



(d) RFID AP (readers)

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- Future Works
  - Combine a User Motion Model

Localization and Tracking on Wireless and Sensor Networks

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- **Accurate and Low-cost Location Estimation Using Kernels (IJCAI-2005)**
- **A Manifold Regularization Approach to Calibration Reduction for Sensor-Network Based Tracking (AAAI-2006)**
- **Co-Localization from Labeled and Unlabeled Data Using Graph Laplacian (IJCAI-2007)**

The End

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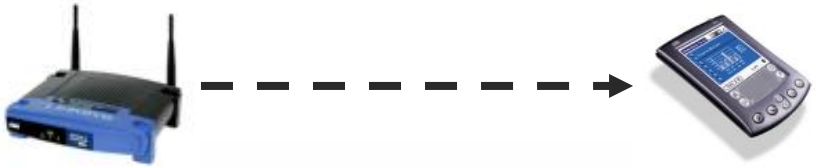
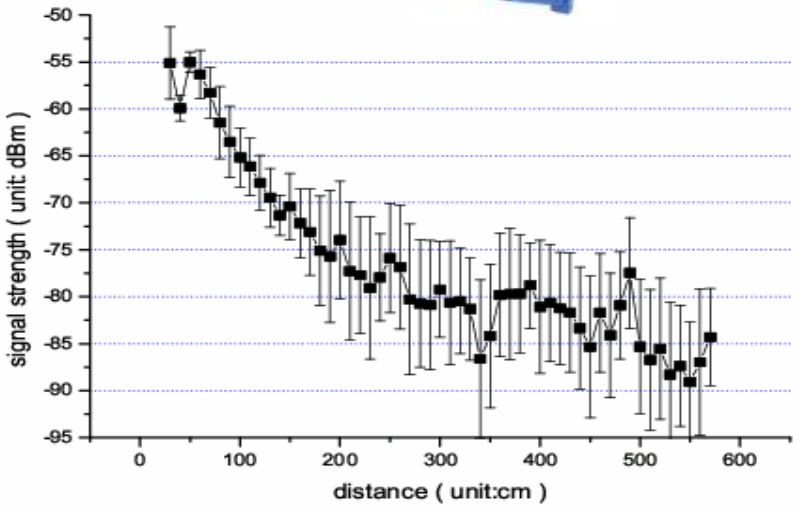
Thank You

Question ?

"Cheap and Ubiquitous RSS" ?

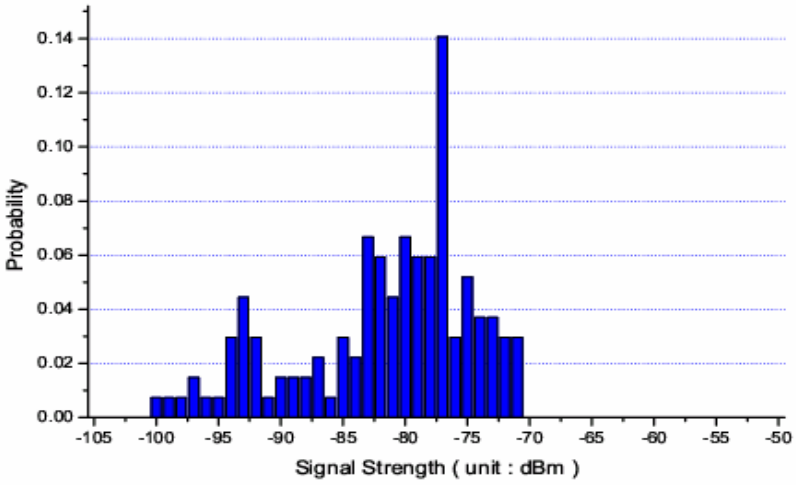
- Simple Triangulation – Inaccurate & Less Calibration
- Machine Learning – Accurate & More Calibration





Signal attenuation along with distance

nonlinear



Signal Distribution at a fixed location

noisy

RFID Test-bed: Free space + Static

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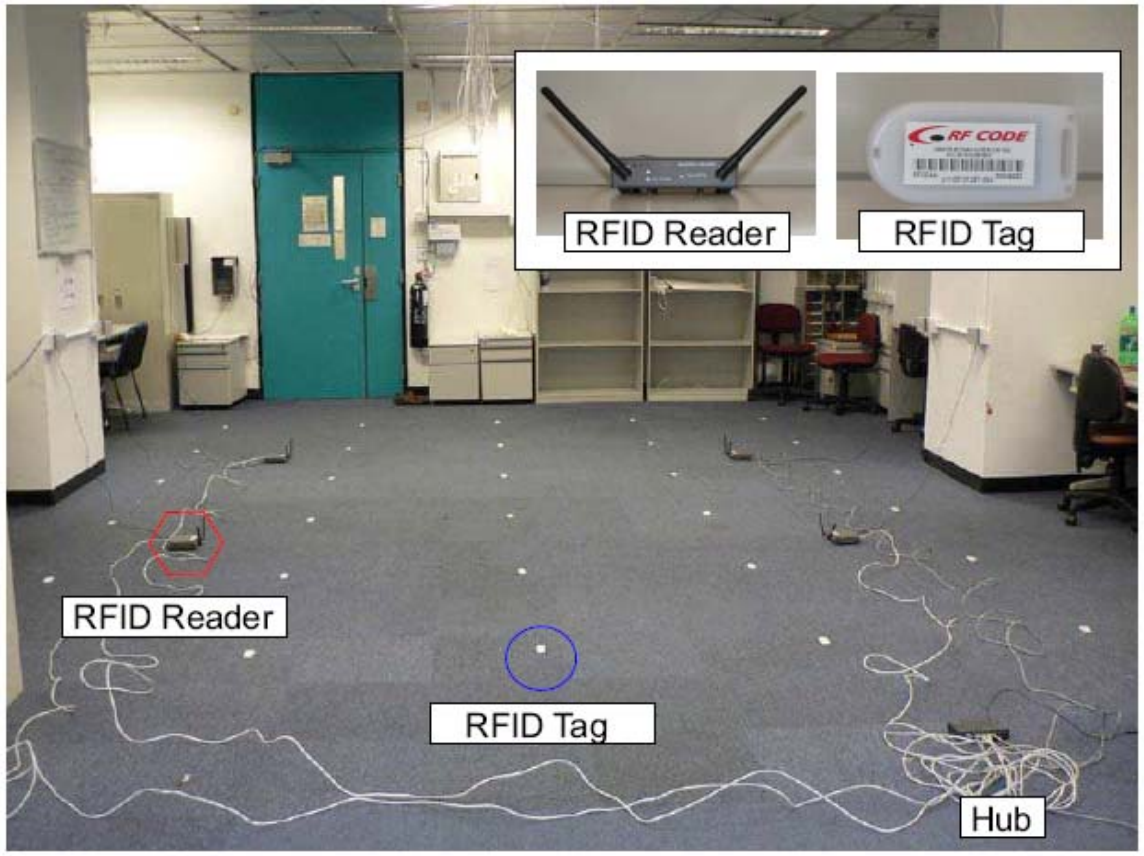

WSN Test-bed: Free space + Mobile