INDOOR LOCALIZATION

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CMSC 818G

February 27, 2014

BIBLIOGRAPHY

- RADAR: An In-Building RF-based User Location and Tracking System (Paramvir Bahl and Venkata N. Padmanabhan)
- WLAN Location Determination via Clustering and Probability Distributions (Moustafa A. Youssef, Ashok Agrawala and A. Udaya Shankar)
- Locus: An Indoor Localization, Tracking and Navigation System for Multi-story Buildings Using Heuristics Derived from Wi-Fi Signal Strength (Preeti Bhargava, Shivsubramani Krishnamoorthy, Aditya Karkada Nakshathri, Matthew Mah, Ashok Agrawala)

INTRODUCTION

- GPS
  - ★ microwave signal attenuation
- Indoor positioning system (IPS): location (not orientation nor direction)
  - ★ optical systems
  - ★ radio systems
  - ★ acoustic systems

IPS

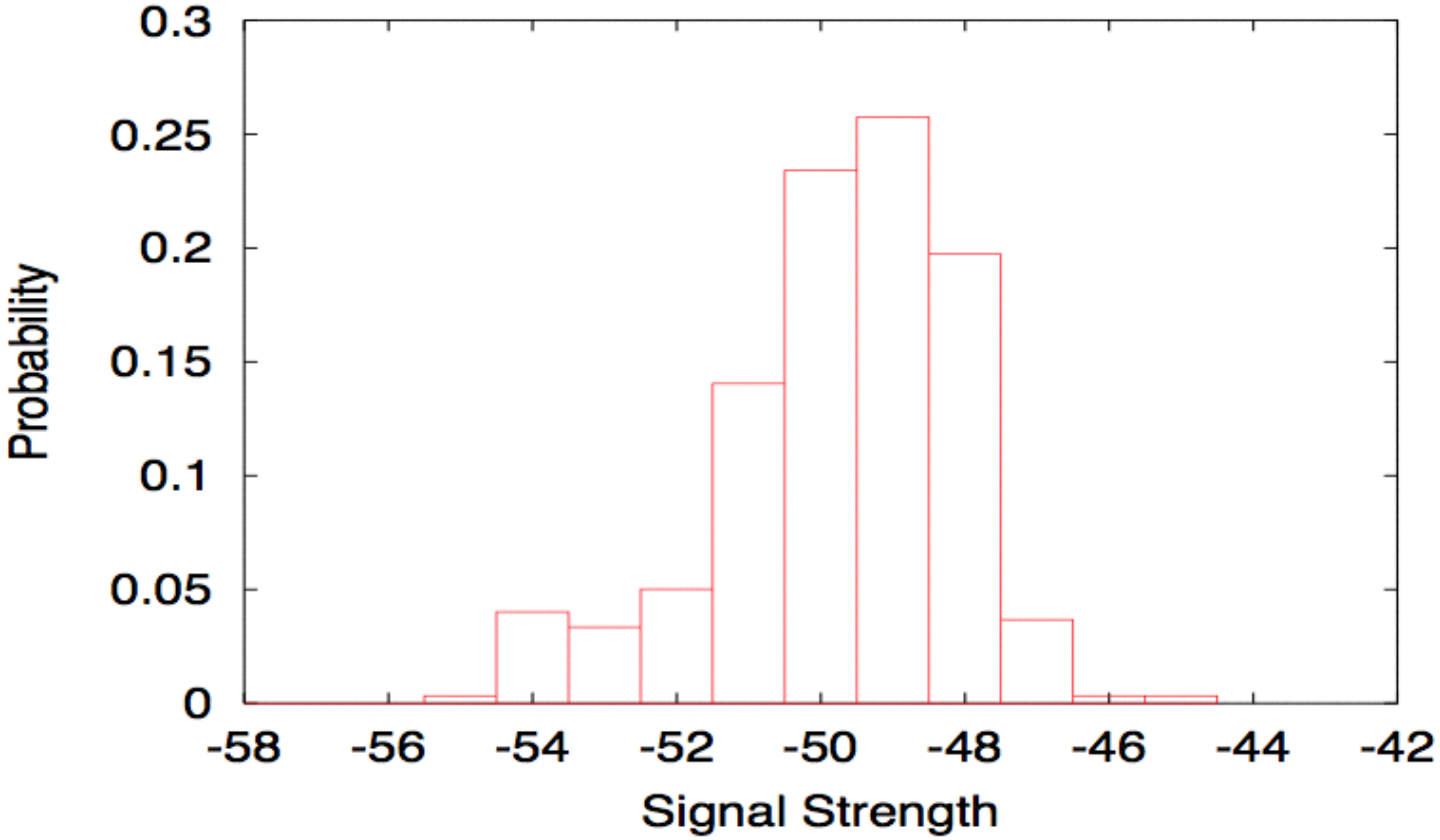
- InfraRed (IR) wireless networks
  - ★ limited range
  - ★ no data networking system, significant installation and maintenance cost
  - ★ affected by sunlight (windows)
  - ★ unsuitable for large-scale
  - ★ useful in gaming

IPS

- RF based wireless network
  - ⋆ range
  - ⋆ scalability
  - ⋆ deployment
  - ⋆ maintenance
  - ⋆ widely used, such us 802.11

IPS

- RF based wireless network
    - ★ noisy characteristics of the wireless channel. Affected by:
        - ✳ bluetooth devices
        - ✳ mirowave ovens
        - ✳ temperature and humidity
    - ★ multi-path fading



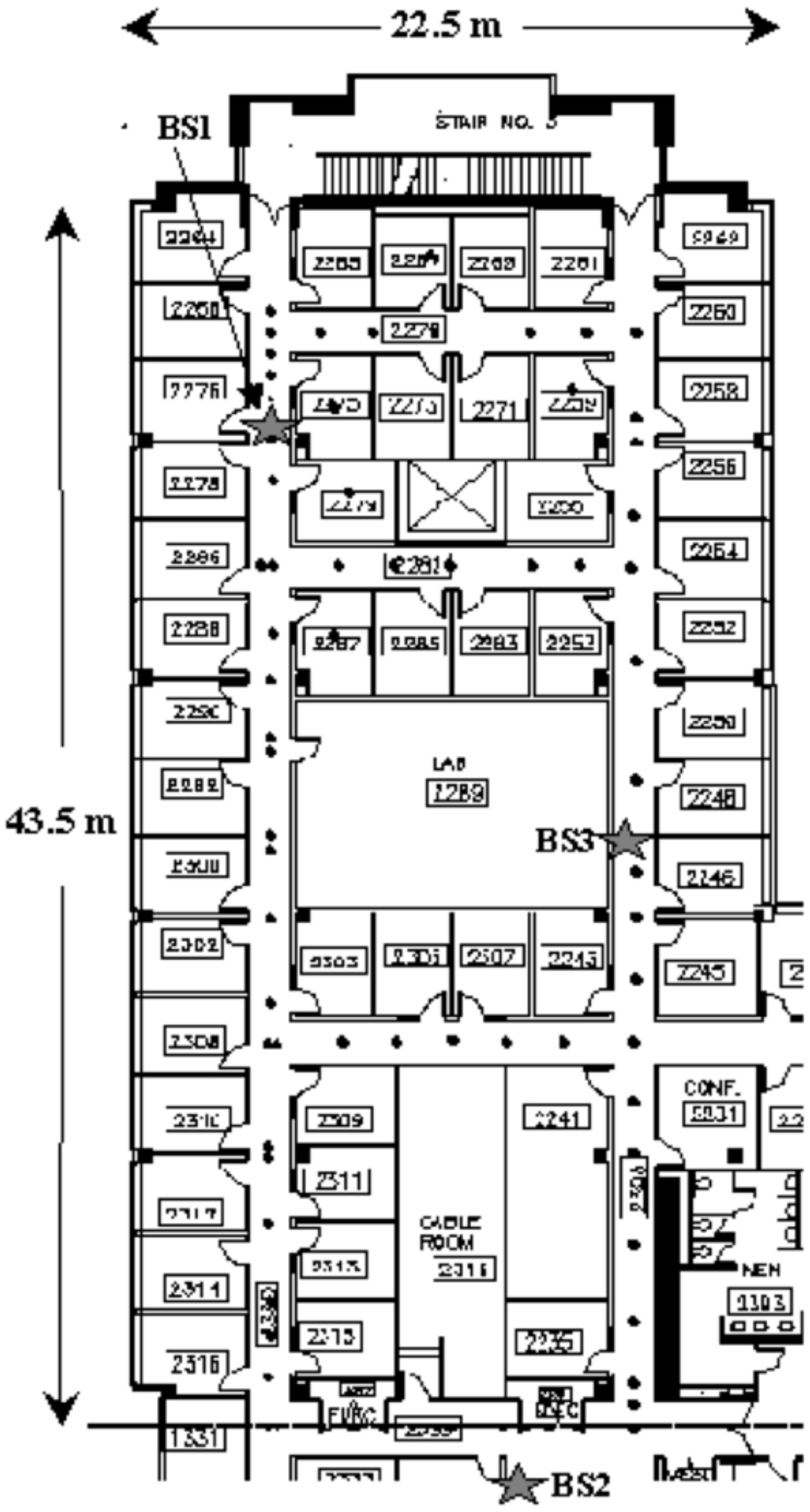
(Image from Joint Clustering paper)

RADAR: An In-Building RF-based User Location and Tracking System

(Paramvir Bahl and Venkata N. Padmanabhan)

RADAR - TESTBED

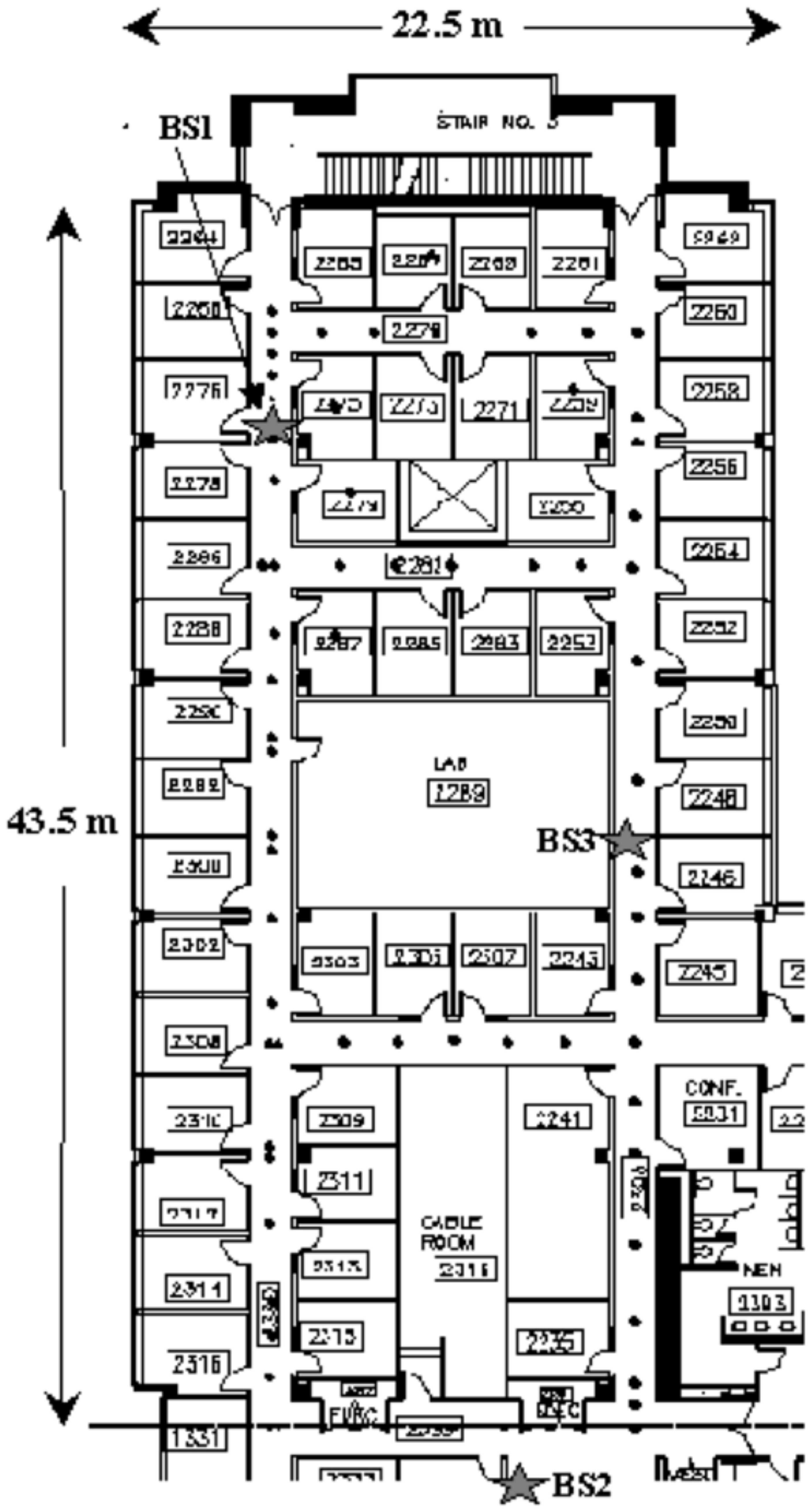
- 2^{nd} floor of 3 storey building
- $10,500\ ft^2$
- more than 50 rooms
- 3 base stations (overlapping coverage)
- WaveLAN™ RF LAN technology, range:
  - ⋆ 25m closed environment
  - ⋆ 50m semi-open
  - ⋆ 200 m open

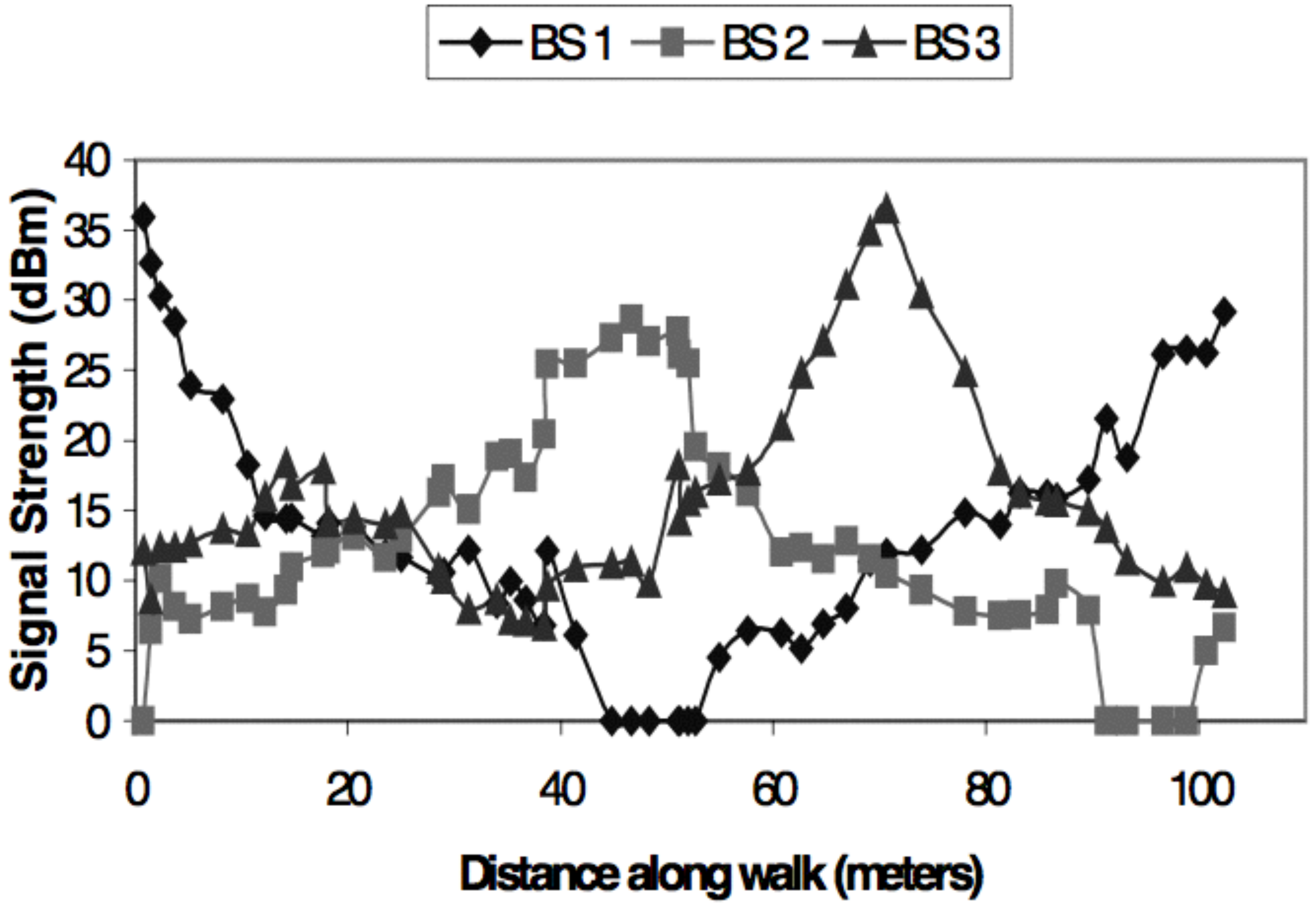


EXPERIMENT (offline)

- Clocks synchronized (mobile host and BS)
- WaveLAN makes available the signal strength (SS) in dBm
- User's orientation impact (up to 5 dBm)
- Mobile host broadcasts UDP packets at a rate of 4 per second. Each BS records (t, bs, ss)
- 4 directions, 70 physical locations and 20 measurements in each.
- Mobile host records (t, x, y, d)
- Data processing: (x,y,d,ss_i)

ANALYSIS





- Triangulation: given a set of SS measurements at each BS, determine the location that best matches the observed SS data.

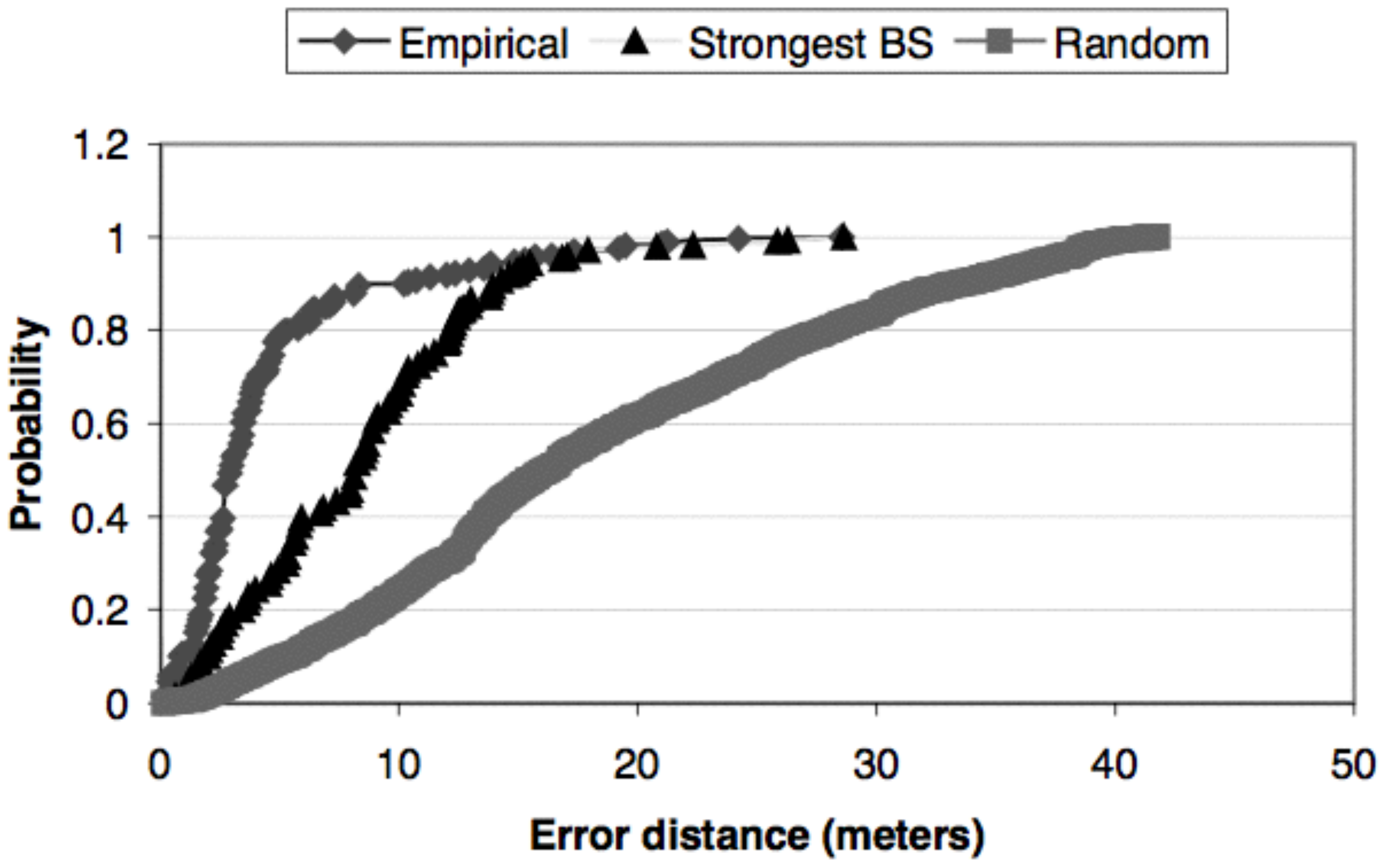
PROBLEMS

- How to summarize the SS samples already measured
- Basis for determining best match:
  - ★ Empirical method: using the offline empirical data
  - ★ Signal Propagation Modeling
- Metric for determining best match:
  - ★ Nearest Neighbor in Signal Space (NNSS) with Euclidean distance

EMPIRICAL METHOD

- Randomly pick one location and orientation from offline data

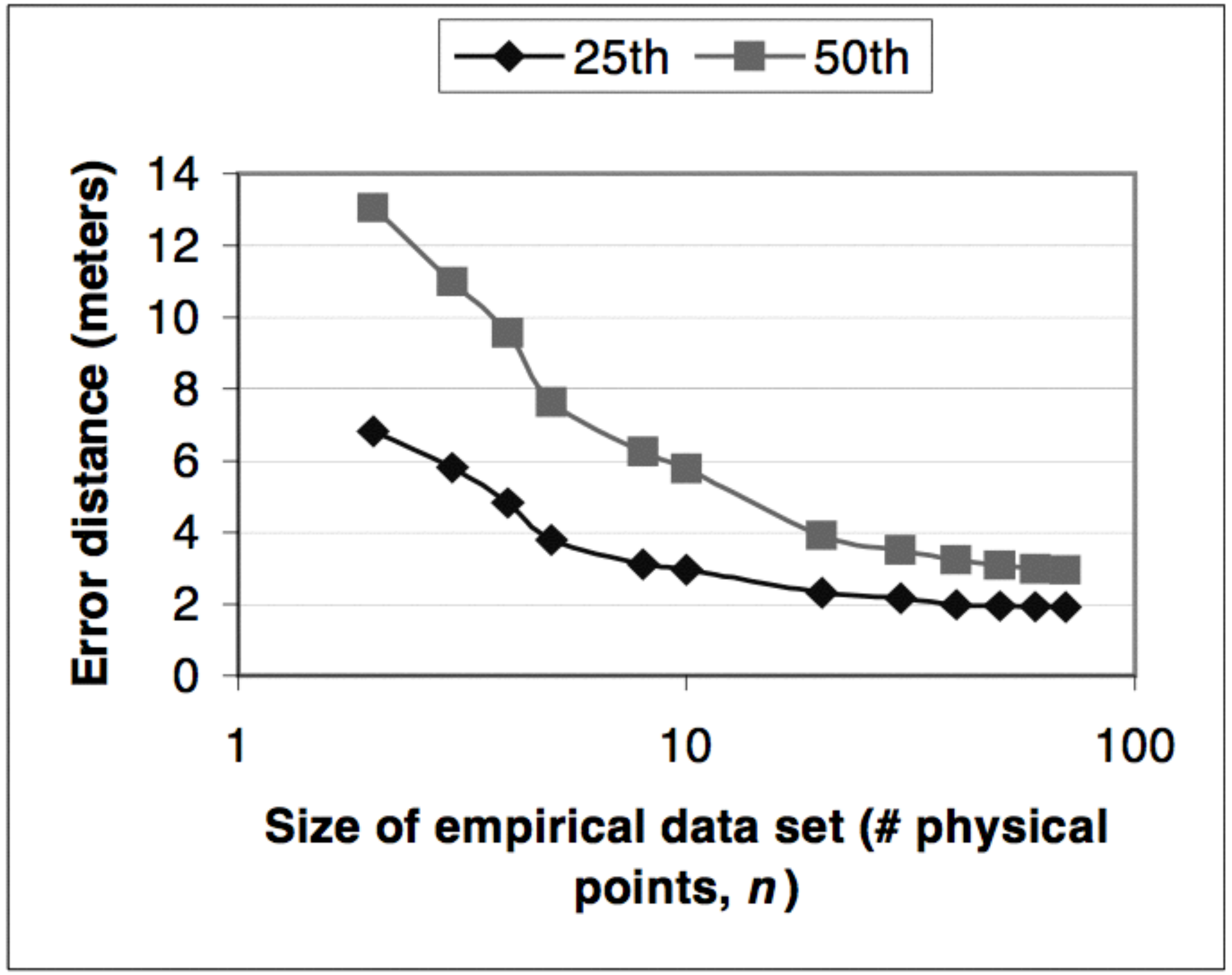
- NNSS search for the SS tuple in the space defined by 69 points and 4 directions.



RADAR

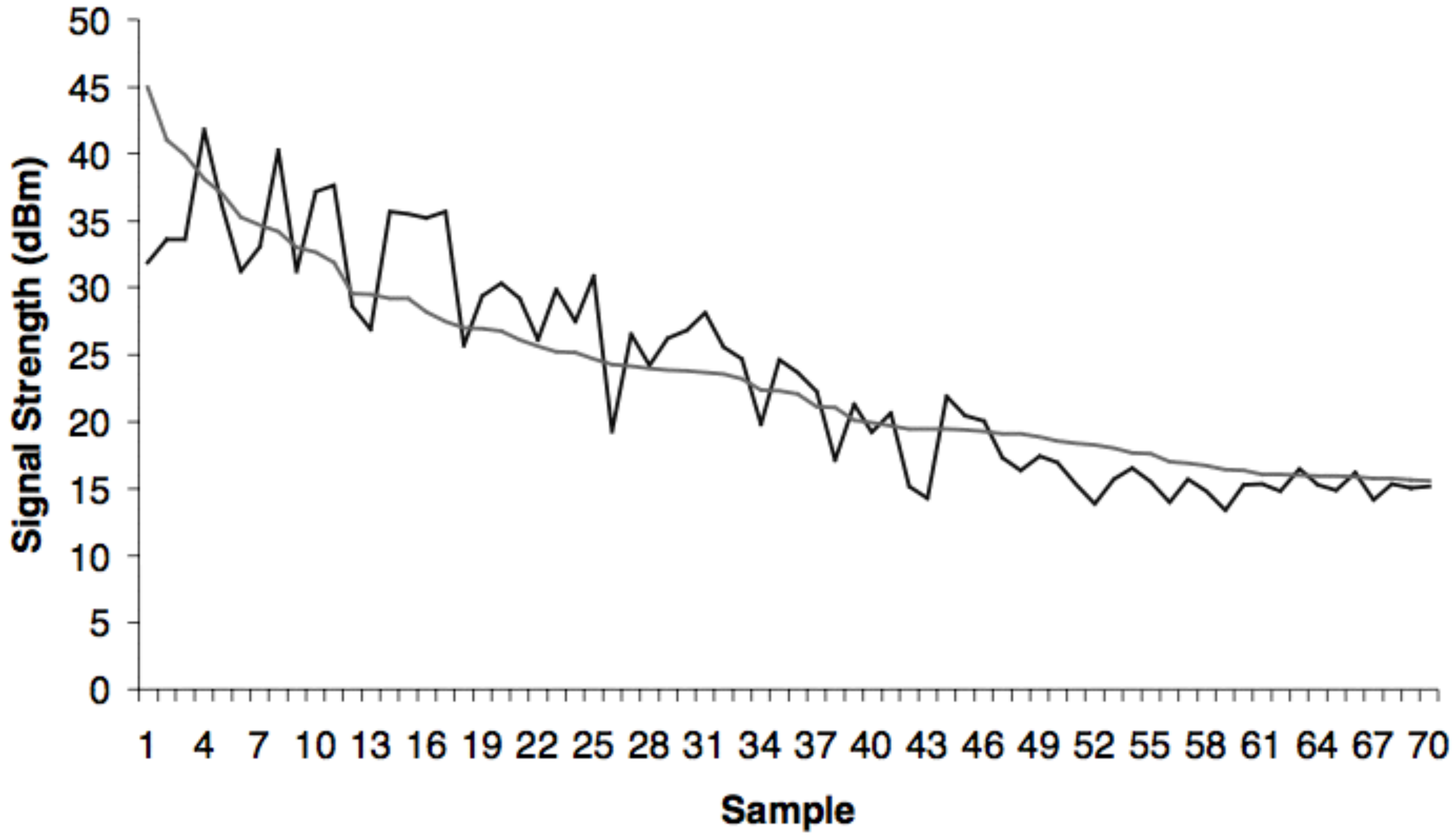
FURTER ANALYSIS

- Multiple Nearest Neighbors (kNNSS)
  - ★ for small k, introduces some benefit, but not significant
  - ★ useful due to signal variations
- Impact of number of data points



RADIO PROPAGATION MODEL

- Avoid the effort of offline data acquisition
- Mathematical model of indoor signal propagation
  - **Rayleigh Fading Model**: assumes that all signals reaching the receiver have equal strength
  - **Rician Distribution Model:** strong path (LoS) + low level scattered paths
  - **Floor Attenuation Factor Model:** uses attenuation factor for building walls. More scalable



RADAR

WLAN Location Determination via Clustering and Probability Distributions

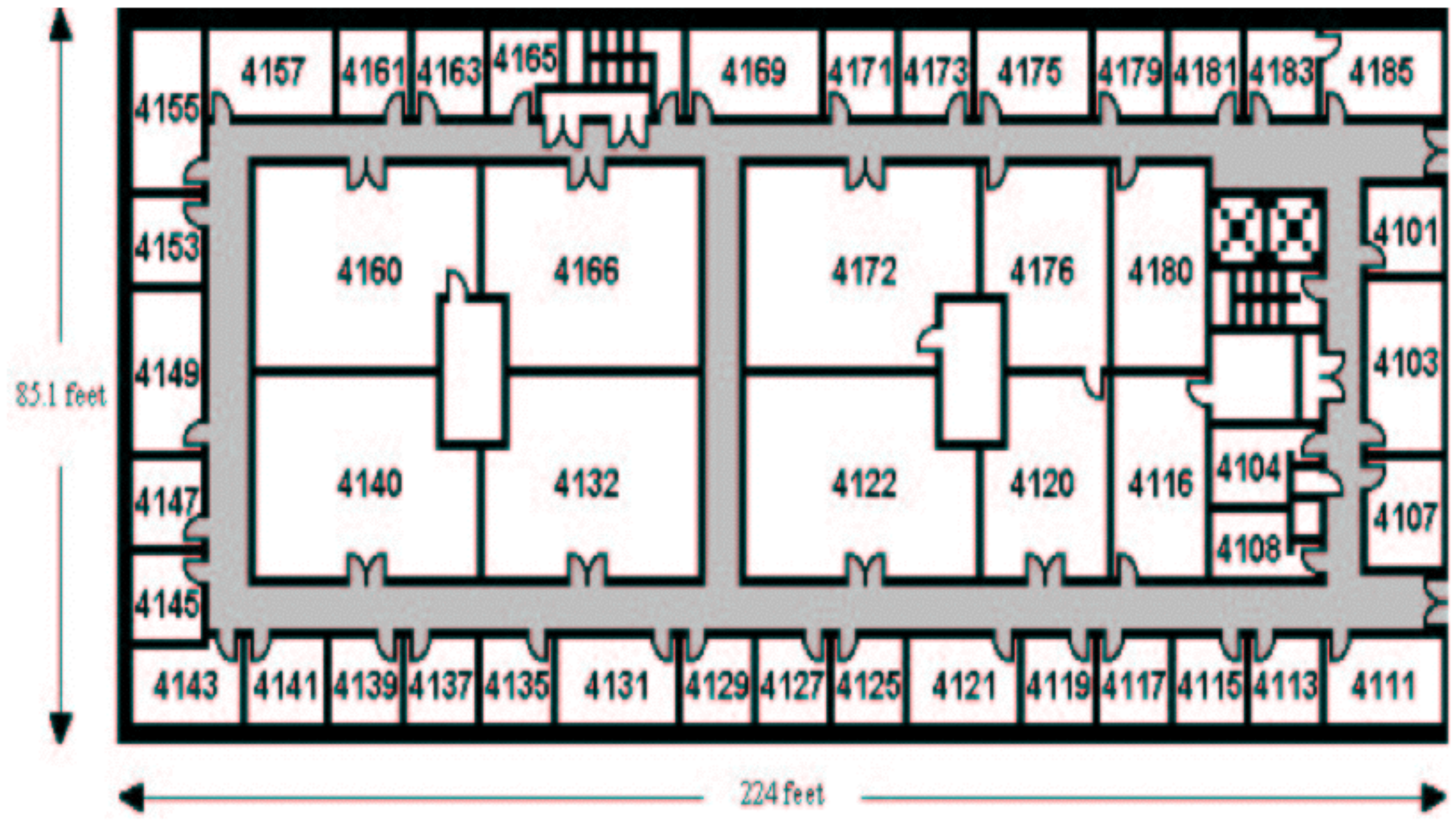
(Moustafa A. Youssef, Ashok Agrawala and A. Udaya Shankar)

JOINT CLUSTERING

- Developed over 802.11 wireless LAN
- Lucent Orinoco silver NIC (up to 11 MBit/s data rate)
- Location determination run on the mobile unit.
  - ★ Preserve user privacy
  - ★ Energy contraints: reduce computational requirements

TESTBED

- 4^{th} floor of A.V. Williams
- 19,050 ft^2
- more than 40 rooms
- each location covered by 4 AP
- 110 locations along corridors



EXPERIMENT (offline)

- Joint Clustering to reduce computational overhead.

- Model for the joint probability distribution of the AP at each location

  - ★ How to determine the value *k* of the dimension of the joint distribution?

  - ★ Which *k* AP to use?

  - ★ How to estimate the joint probability distribution?

ESTIMATION OF JOINT DISTRIBUTION

- $P(AP_1 = s_1, \dots, AP_k = s_k) = \mathrm{Count}(s_1, \dots, s_k) / (\mathrm{Size\ of\ Training\ Data})$
  - ★ Large training set required, works just for small *k*
- Assumming that APs are independent:

$$P(AP_1 = s_1, \dots, AP_k = s_k) = P(AP_1 = s_1) \dots P(AP_k = s_k)$$

where $P(AP_i = s_i)$ can be estimated with normalized histogram of AP_i

CLUSTERING

- Reduce computation overhead
- Partitioning the AP space
  - ★ locations l_1 and l_2 are in the same cluster iff the APs covering the locations are identical; or
  - ★ given q, cluster all locations that share q APs
    - ✴ How to determine q and which APs are chosen for clustering
    - ✴ Which q APs to choose for clustering?

EXPERIMENT (online)

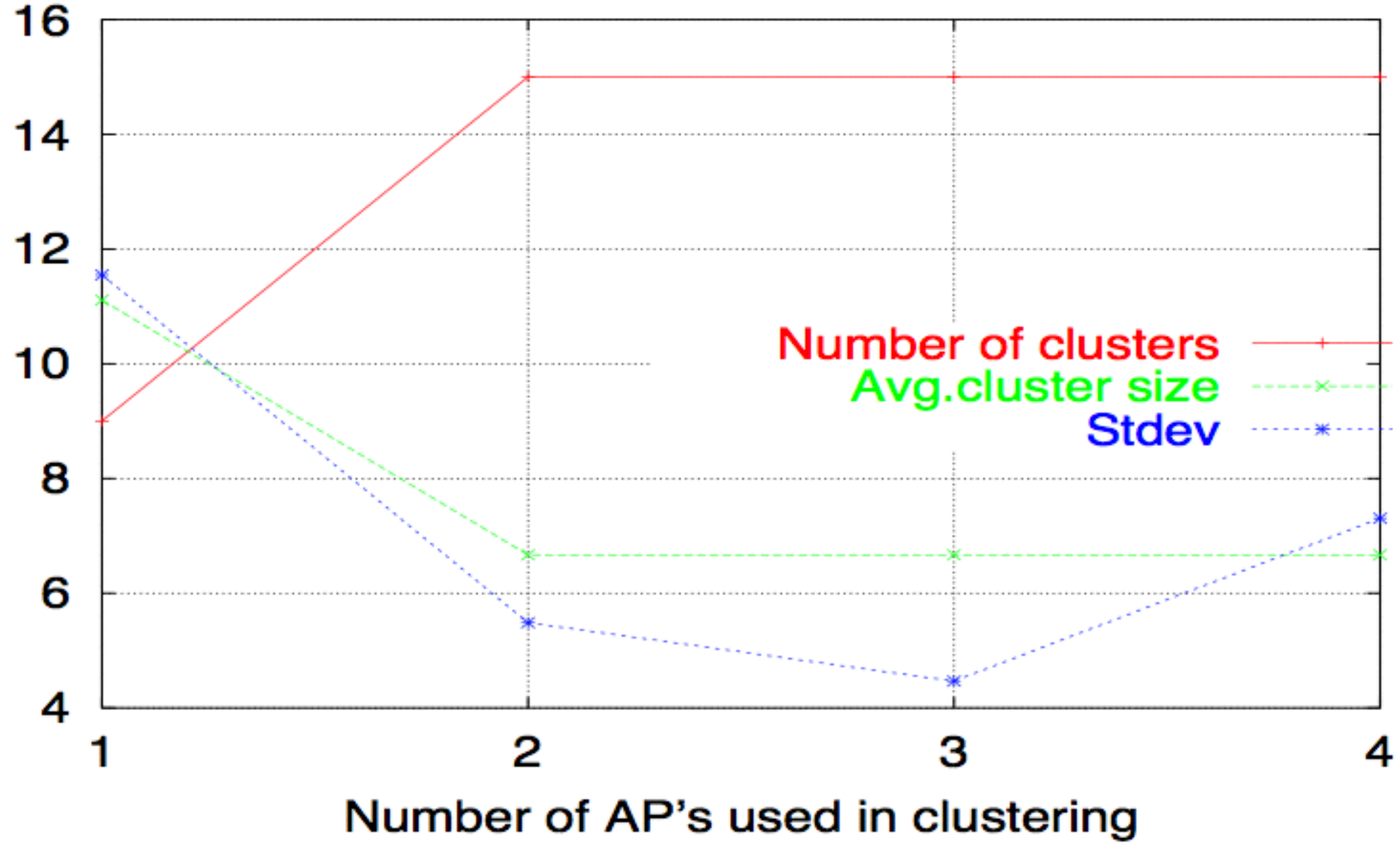
- The idea: we use the q strongest access points to determine one cluster to search within for the most probable location.

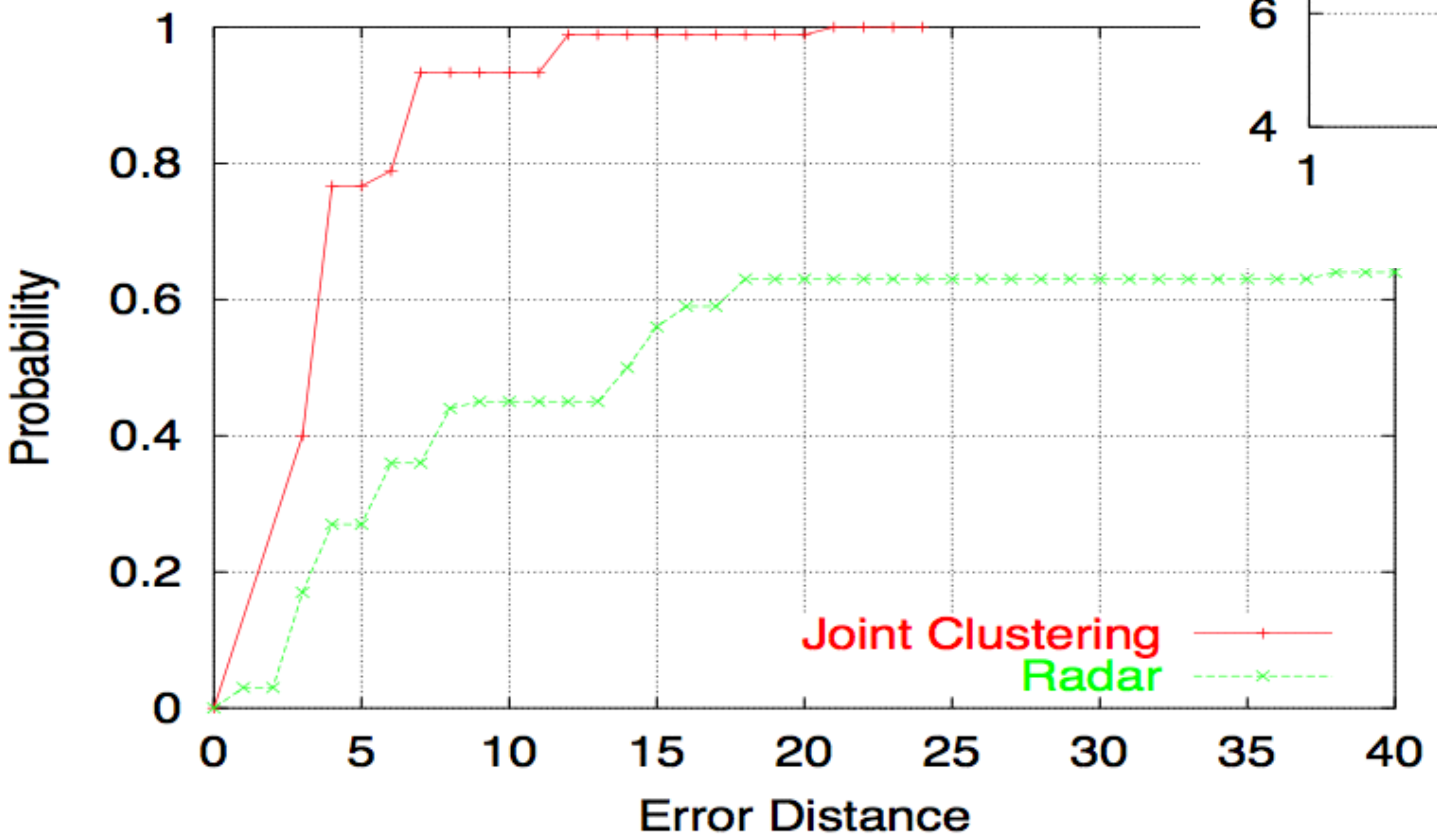
- Observation vector: $\overline{S}=(s_1,\ldots,s_k)$

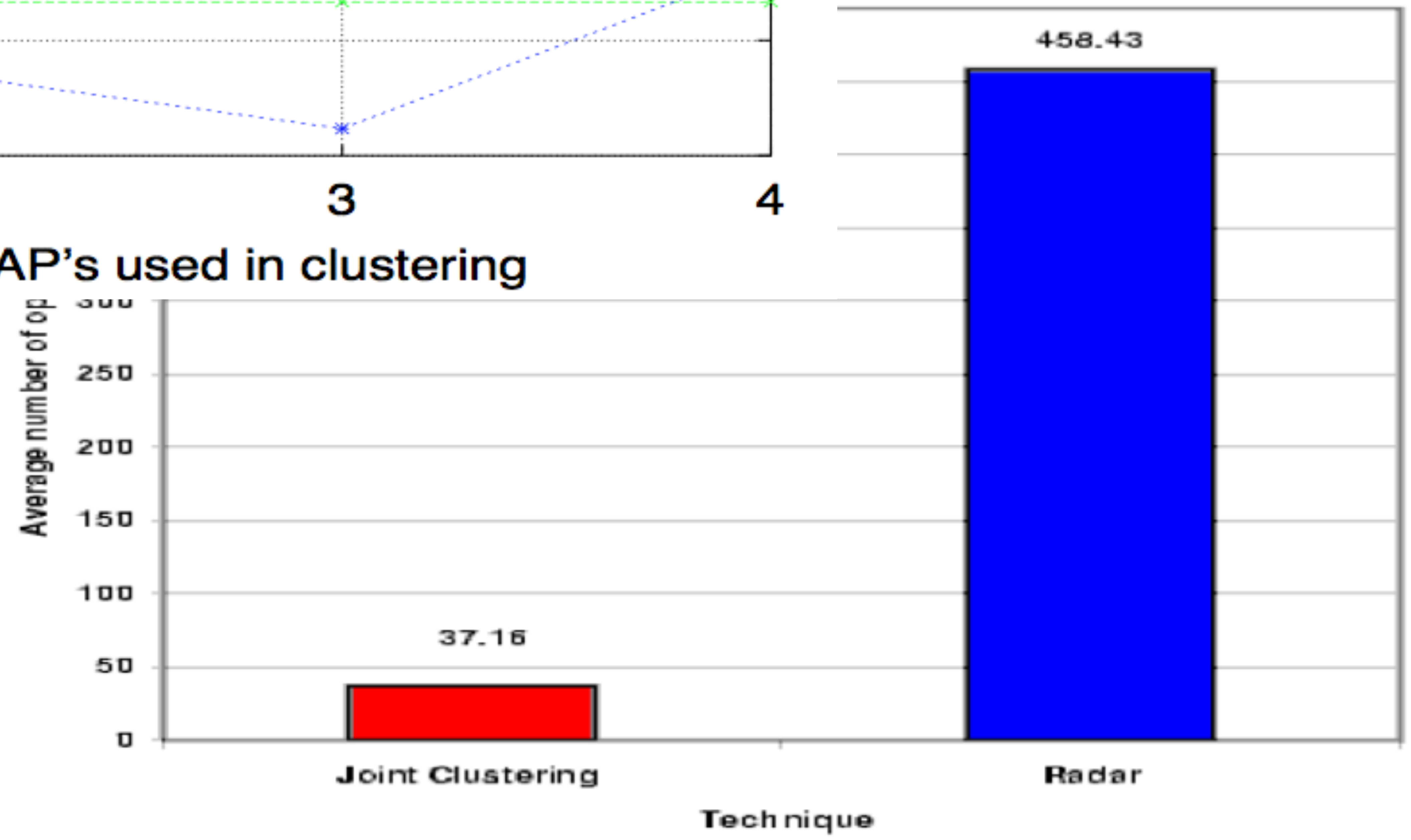
  - Find l: $\text{argmax}_l[P(l|\overline{S})]=\text{argmax}_l[P(\overline{S}|l).P(l)]=\text{argmax}_l[P(\overline{S}|l)]=\text{argmax}_l\left[\prod_{i=1}^{k}P(s_i|l)\right]$

  - $P(s_i|l)$ can be estimated from the signal strength distribution in the map

ANALYSIS







JOINT CLUSTERING

Locus: An Indoor Localization, Tracking and Navigation System for Multi-story Buildings Using Heuristics Derived from Wi-Fi Signal Strength

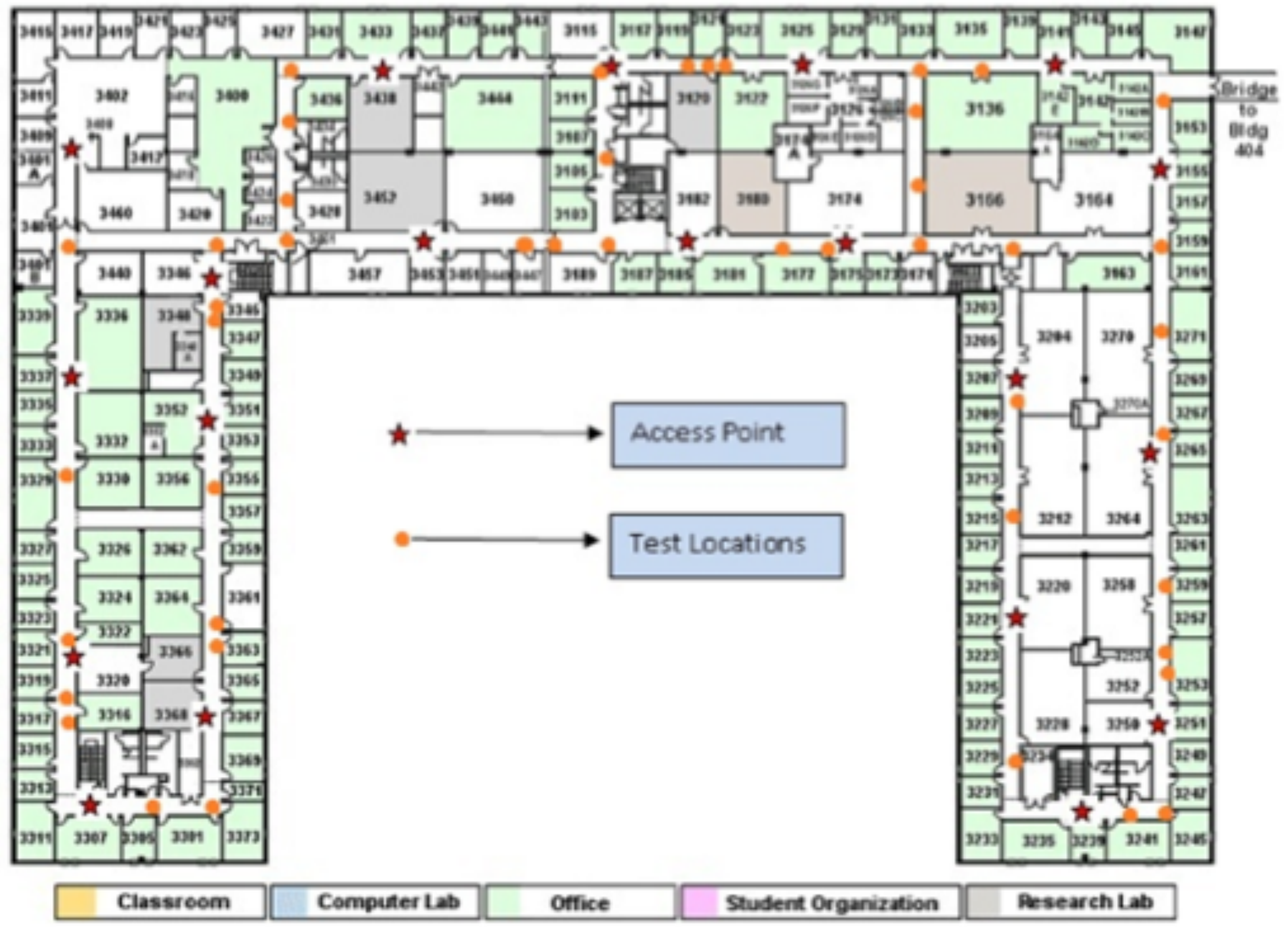
(Preeti Bhargava, Shivsubramani Krishnamoorthy, Aditya Karkada Nakshathri, Matthew Mah, Ashok Agrawala)

LOCUS - TESTBED

- A.V. Williams
- 175,152 ft^2
- 15, 19, 20 and 10 APs: Cisco AIR-LAP1142N-AK9 with multiple virtual APs
- 300 samples

(a) Floor Map of the first floor

(b) Floor Map of the second floor



(c) Floor Map of the third floor

(d) Floor Map of the fourth floor

CLIENT PROCESSING

- Android mobile application (on tablet)
  - ★ scans for Wi-Fi access points using standard Android scan functionality
  - ★ data sent to the client in XML format
  - ★ Server then lookup the database for AP's coordinates and floor

FLOOR DETERMINATION

- Properties:
  - ★ maxNumFloors: floor with maximum count of signals
  - ★ maxSSFloor: floor with maximum signal strength
  - ★ maxAvgFloor: floor with maximum average signal strength
  - ★ maxVarFloor: floor with maximum signal strength variance

FLOOR DETERMINATION - HEURISTICS

- If four properties are equal, then the floor which matches all the four properties is the label floor
- If three properties are equal, then the floor which matches the three equal properties is the label floor
- If two properties are equal and the other two are not equal, then the floor which matches the two equal properties is the label floor
- If pairs of properties are equal, then the pair with the higher F-Score is the label floor.

LOCATION DETERMINATION

- Simplified radio propagation model

  1. Normalization of signal strength

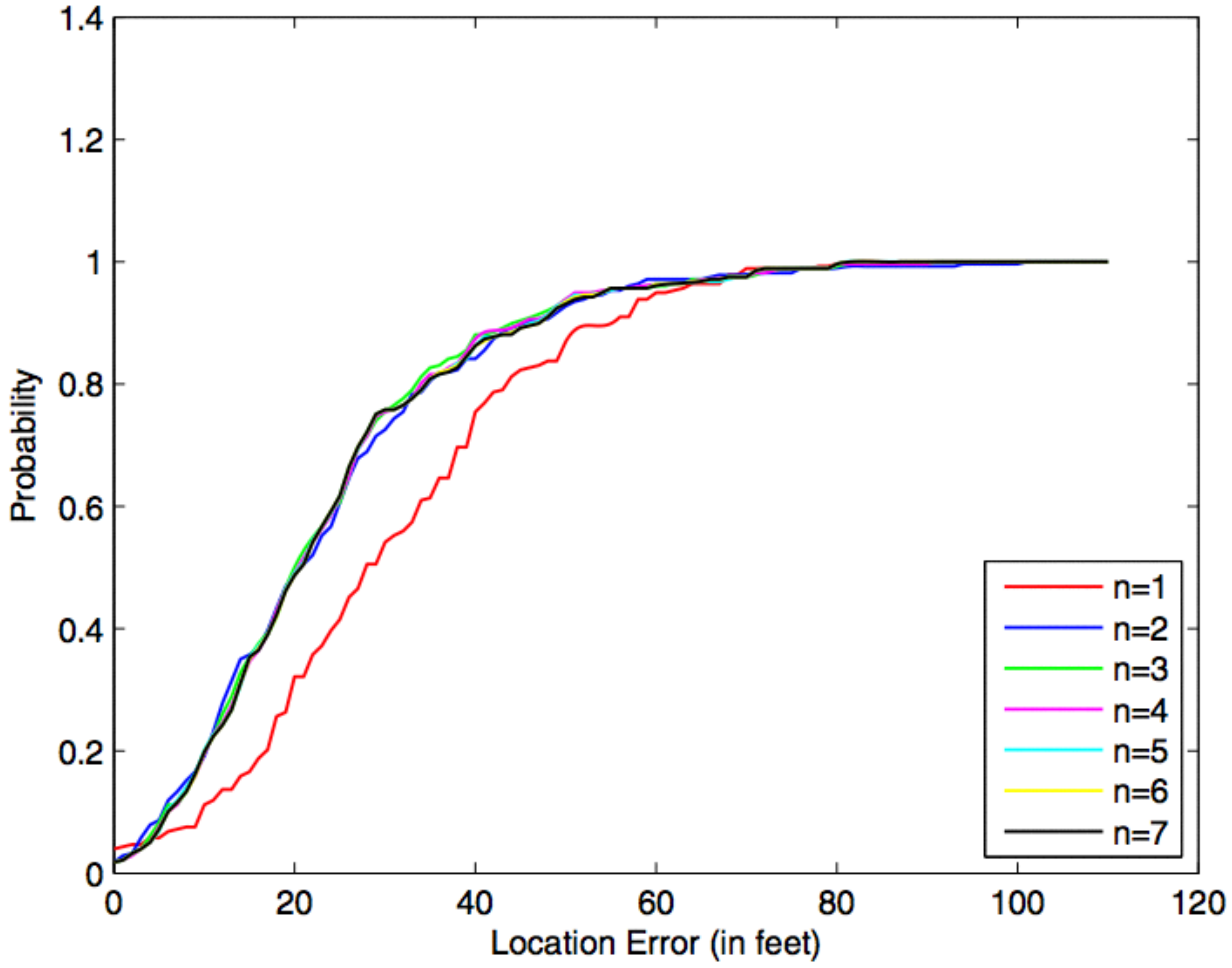
  2. Weighted average of location of the *n* strongest APs

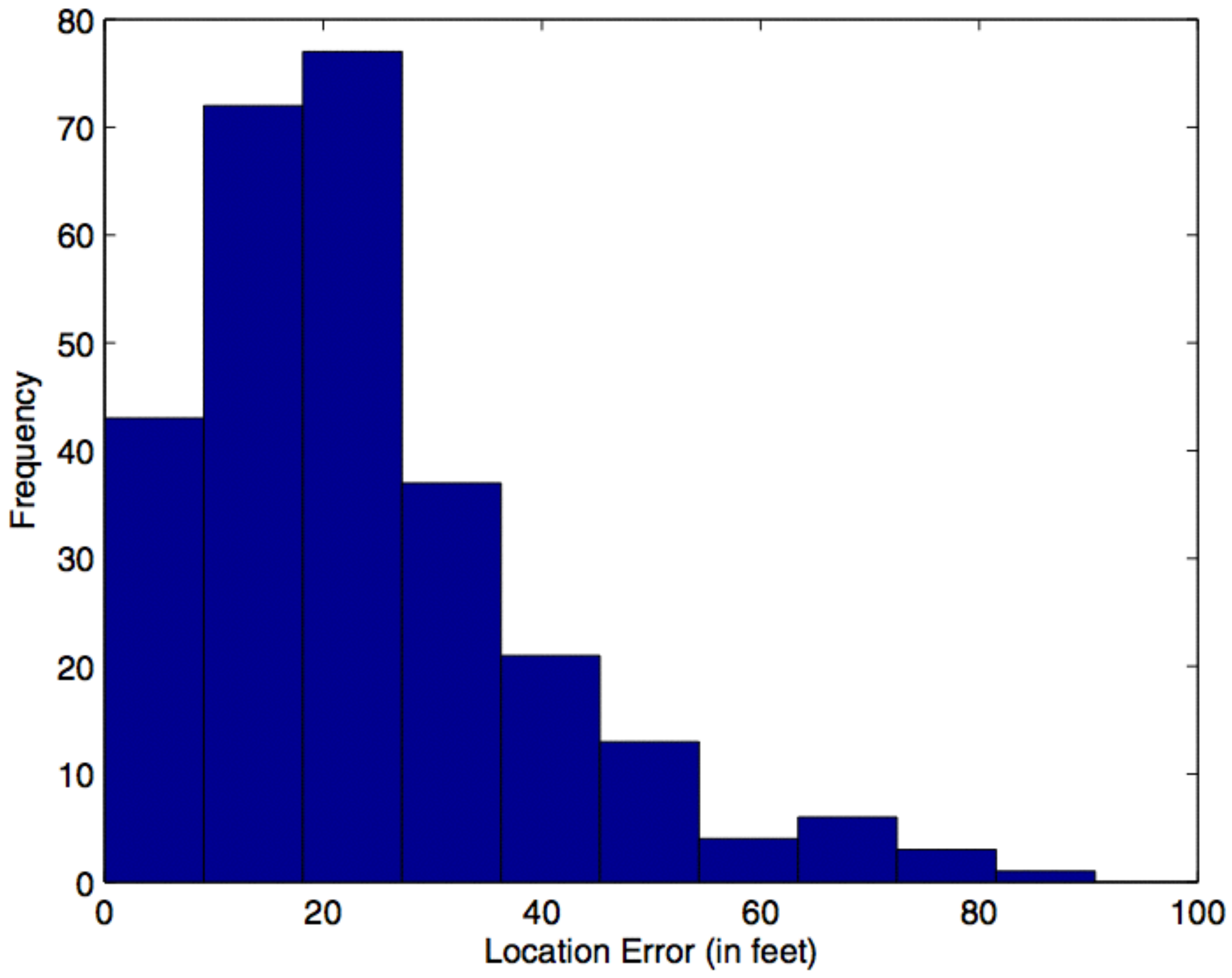
$$\text{Power } P_i = 10^{\frac{\text{signal strength of AP}}{10}} \qquad \text{Weight } w_i = \frac{P_i}{\sum_{i=1}^{n} P_i}$$

ANALYSIS

- Floor accuracy of 99.97%
- Client side app very lightweight
- Scalable
- Robust to changes - no radio maps
- Low cost for deployment and maintenance

ANALYSIS


1.4
1.2
1
0.8
0.6
0.4
0.2
0
Probability
0
20
40
60
80
100
120
Location Error (in feet)
n=1
n=2
n=3
n=4
n=5
n=6
n=7


80
70
60
50
40
30
20
10
0
Frequency
0
20
40
60
80
100
Location Error (in feet)

COMPARISON OF METHODS

	RADAR	Joint Clustering	Locus
WLAN	WaveLAN	802.11	802.11
Location determination	In server	On mobile unit	On mobile unit
Calibration	Offline	Offline	Calibration-free
Floor determination	No	No	Yes
Floor accuracy	—	—	99.97%
Location error		Best determination	