Localization Techniques in Wireless Networks

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Rutgers University

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Motivation

- Technology trends creating cheap wireless communication in every computing device

- Radio offers localization opportunity in 2D and 3D
- New capability compared to traditional communication networks

A Solved Problem?

- Don’t we already know how to do this?
  – Many localization systems already exist
- Yes, they can localize, but ….
  – Missing the big picture
  – Not general

Open problem

- Analogy: Electronic communication

  1960's Leased lines (problem solved!) ->

  1970's Packet switching ->

  1980's internetworking ->

  1990's "The Internet":

    General purpose communication
- General purpose localization still open

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Research Challenge

- General purpose localization analogous to general purpose communication.
    - Work on any wireless device with little/no modification
    - Supports vast range of performance
    - Device always "knows where it is"
    - "Lost" --- no longer a concern

- Use only the existing communication infrastructure?
    - How much can we leverage?
    - If not, how general is it?
    - What are the cost/performance trade-offs?

Outline

- Motivation
- Research Challenges
- Background
- General-purpose localization system
- Open issues
- Conclusions

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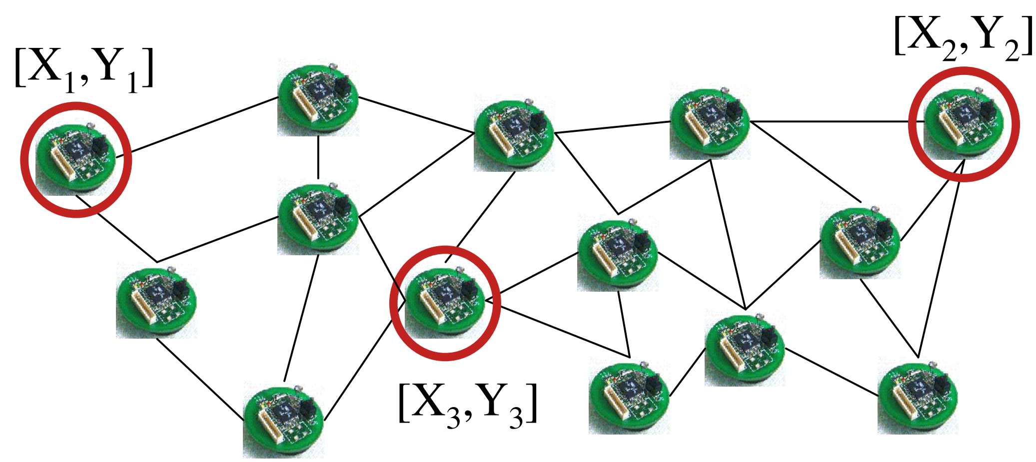
Background: Localization Strategies

- Active
  - Measure a reflected signal
- Aggregate
  - Use constraints on many-course grained measurements.
- Scene matching
  - The best match on a previously constructed radio map
  - A classifier problem: “best” spot that matches the data
- Lateration and Angulation
  - Use distances, angles to landmarks to compute positions

Aggregate Approaches

- A field of nodes + Landmarks
- Local neighbor range or connectivity

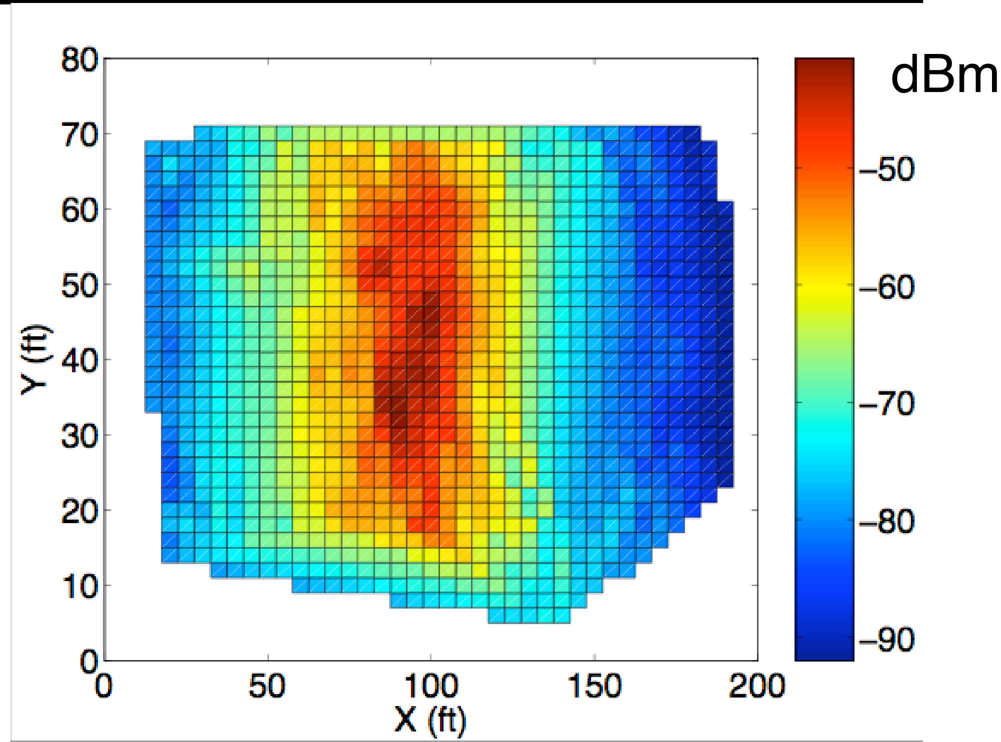


- Formulations:
  - Nonlinear Optimization problem
  - Multi-Dimensional Scaling
  - Energy minimization, e.g. springs
  - Classifiers

Scene Matching

- Build a radio map
  [X,Y,RSS_1,RSS_2,RSS_3]
  Training data

- Classifiers:
  Bayes' rule
  Max. Likelihood
  Machine learning (SVM)
- Slow, error prone
- Have to change when environment changes



Landmark 2

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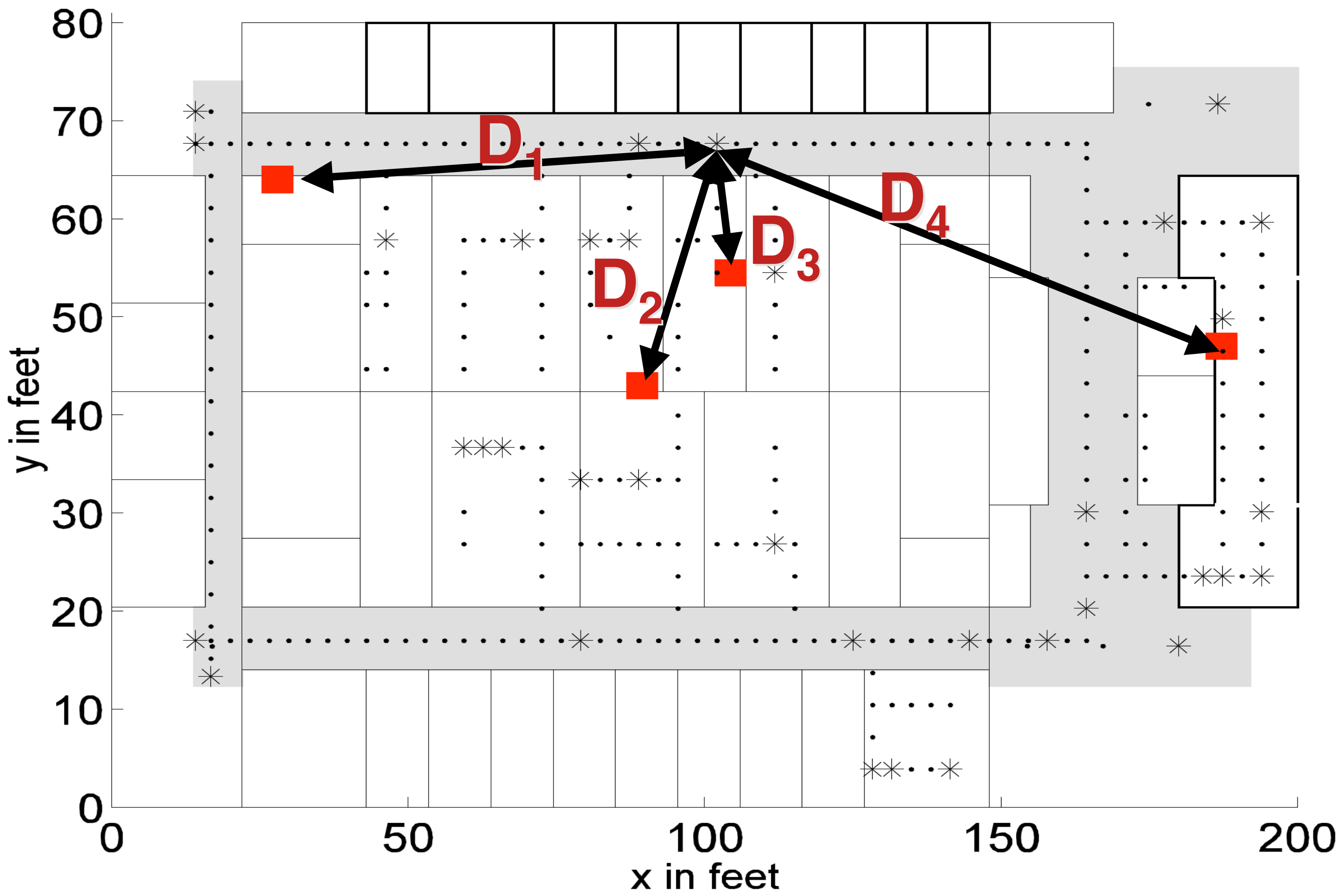
Lateration and Angulation



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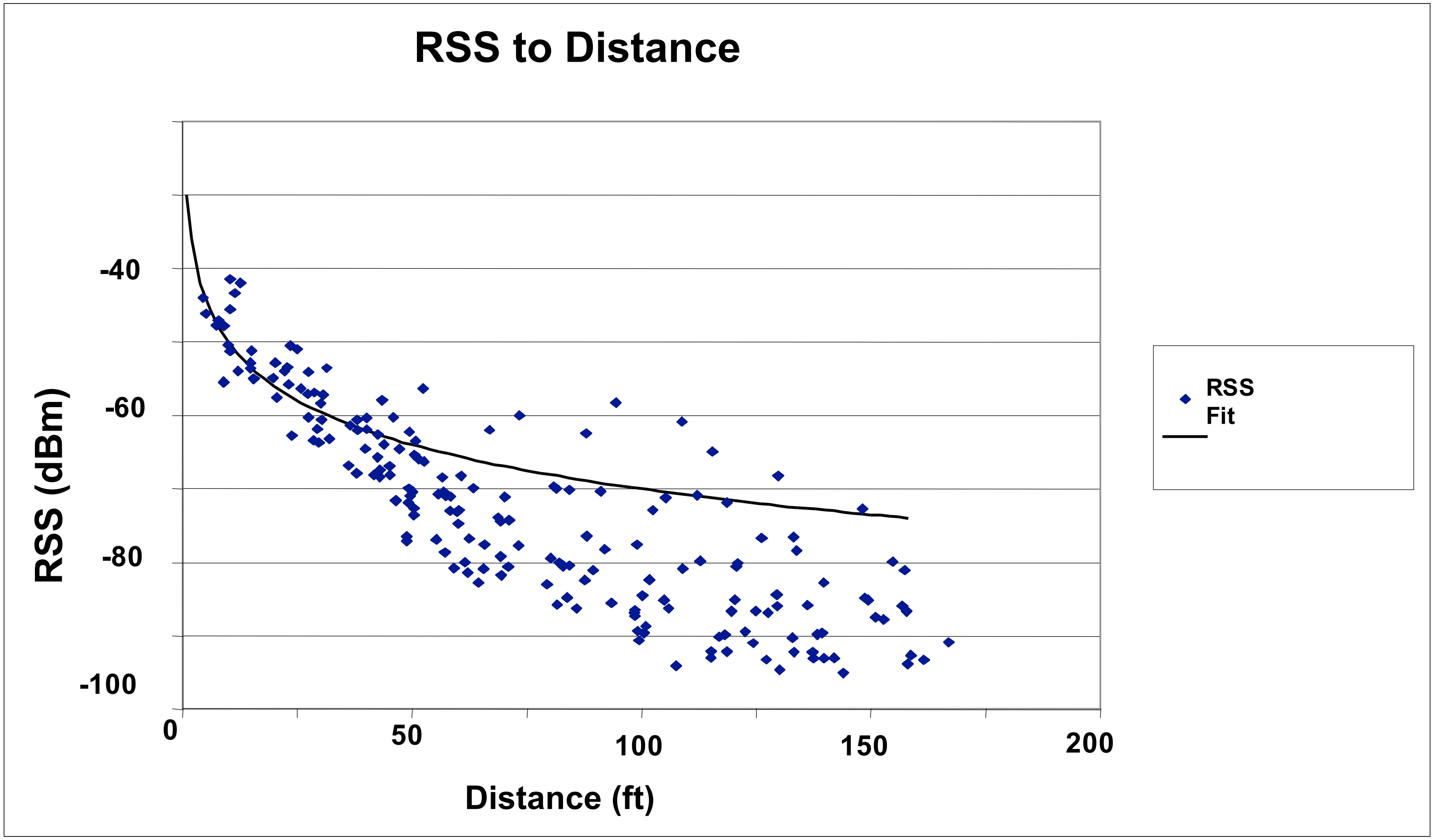
Observing Distances and Angles

- Received Signal Strength (RSS) to Distance
  - Path loss models
- RSS to Angle of Arrival (AoA)
  - Directional antenna models
- Time-of-Flight to distance(ToF)
  - Speed of light

RSS to Distance



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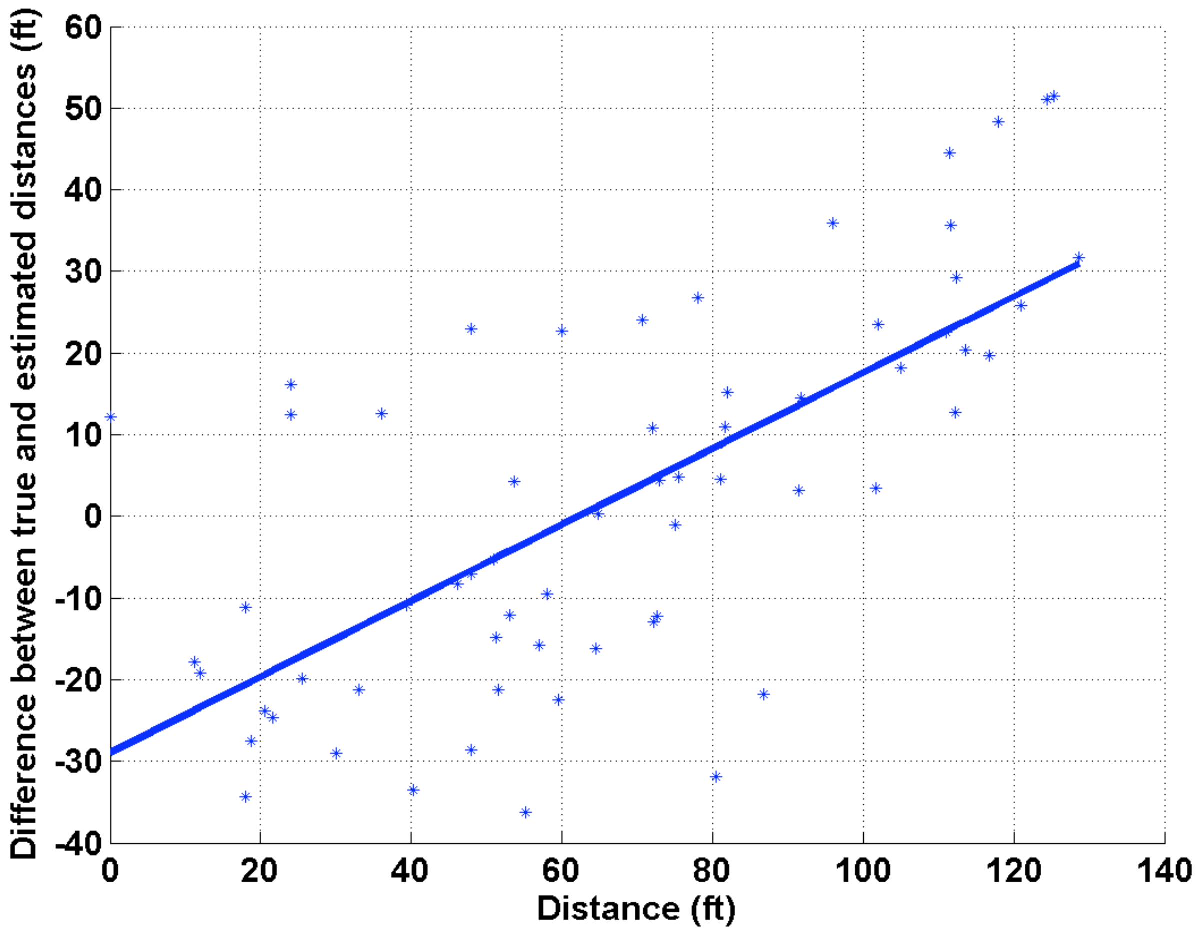
Time-of-Arrival to Distance



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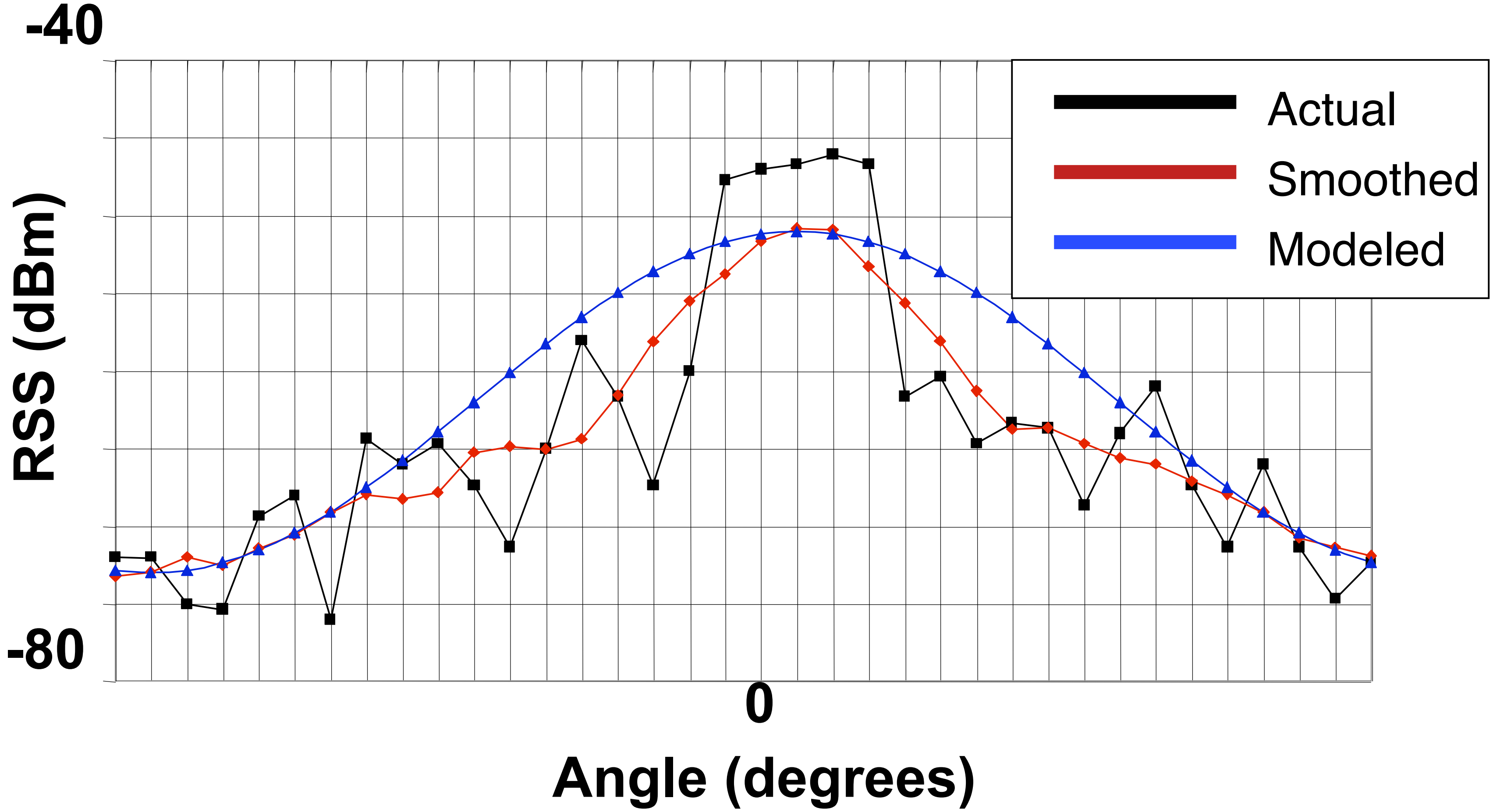
RSS to Angle



Results Overview

- Last 6 years --- many,many varied efforts
  - Most are simulation, or trace-driven simulation
- Aggregate
    - 1/2 1-hop radio range typical.
    - Requires very dense networks (degree 6-8)
- Scene matching
    - 802.11, 802.15.4: Room/2-3m accuracy [Elnahrawy 04]
    - Need lots of training data
- Lateration and Angulation
    - 802.11, 802.15.4: Room/3-4m accuracy
    - Real deployments worse than theoretical models predict (1m)

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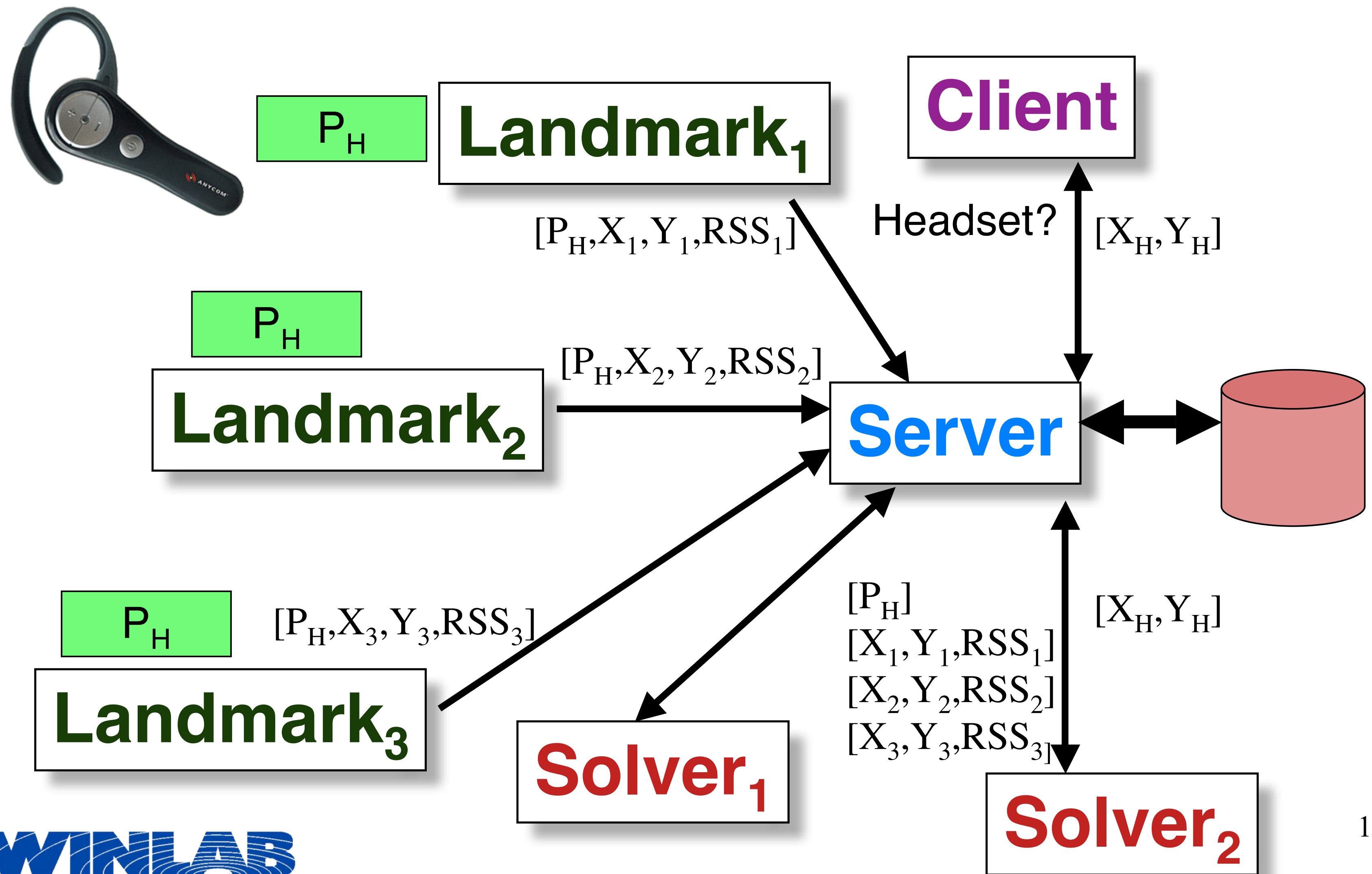
General Purpose Localization

- Goal: Infrastructure for general-purpose localization
- Long running, on-line system
  - Weeks, months
- Experimentation
- Data collection

Packet-level, Centralized Approach

- Deploy **Landmarks**
  - Monitor **packet traffic** at known positions
  - Observe packet radio properties
    - Received Signal Strength (RSS)
    - Angle of Arrival (AoA)
    - Time of Arrival (ToA)
    - Phase Differential (PD)
- **Server** collects per-packet/bit properties
  - Saves packet information over time
- **Solvers** compute positions at time T
  - Can use multiple algorithms
- **Clients** contact server for positioning information

Software Components



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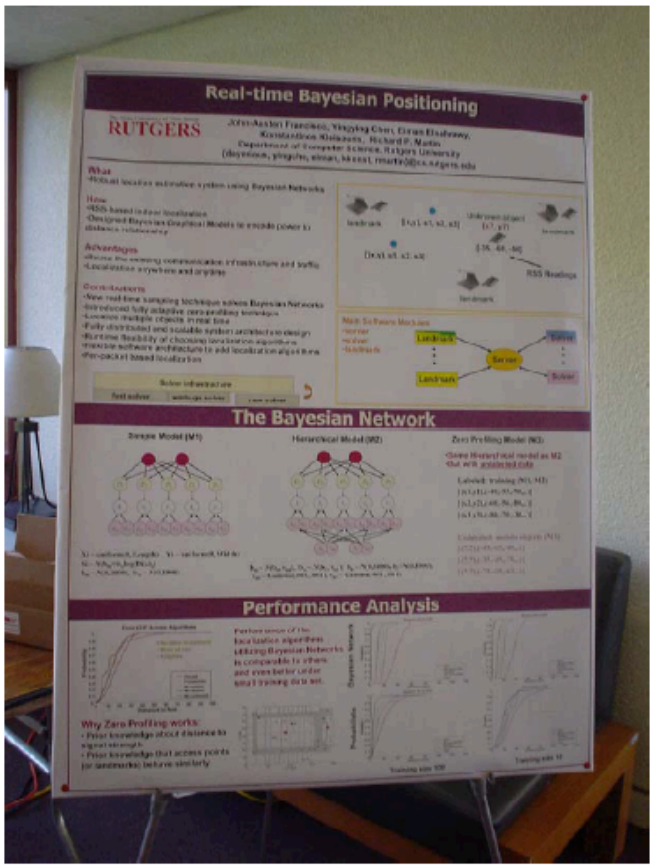
Award for Demo at TinyOS Technology Exchange III

Technology Innovation



- Real-time Bayesian Positioning
- Rutgers University

Landmarks

- 802.11:
  - RSS
  - AoA
  - ToA
- 802.15.4
  - RSS
- Future work:
  - Combo 802.11, 802.15.4
  - Reprogram radio boards, more accurate ToA
  - MIMO AoA?

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Angle-of-Arrival Landmark

Rotating Directional Antenna

Reduces number of landmarks and training set needed to obtain good results

Does not improve absolute positioning accuracy (3m)

[Elnahrawy 06]

Localization Server

- Server maintains all info for the coordinate space
  - Spanning coordinate systems future work
- Protocols to landmarks, solver and clients are simple strings-over-sockets
- Multi-threaded Java implementation
  - State saved as flat files

Localization Solvers

- Winbugs solver [Madigan 04]
- Fast Bayesian Network solver [Kleisouris 06]
- Scene Matching Solver future work
  - Simple Point Matching
  - Area-Based Probability

Example Solver: Bayesian Graphical Models

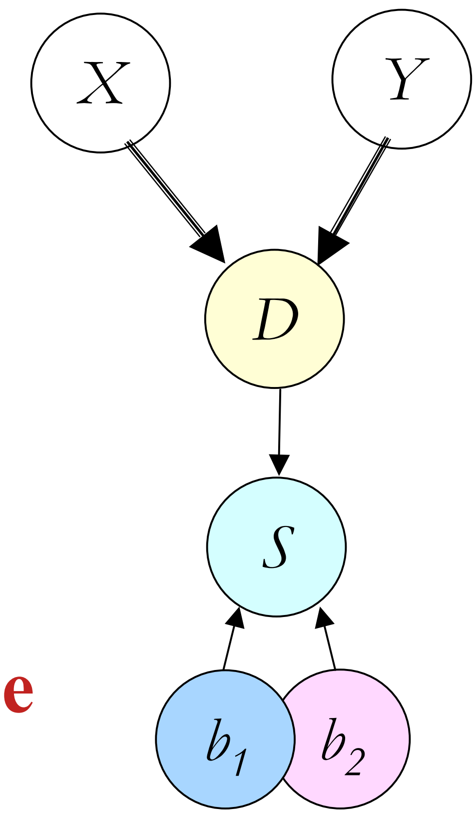
Vertices = random variables
Edges = relationships

Example:

Log-based signal strength propagation

$$S = b_1 + b_2 \log(D)$$

$$D = \sqrt{(x - x_b)^2 + (y - y_b)^2}$$



Can encode arbitrary prior knowledge

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Incorporating Angle-of-Arrival

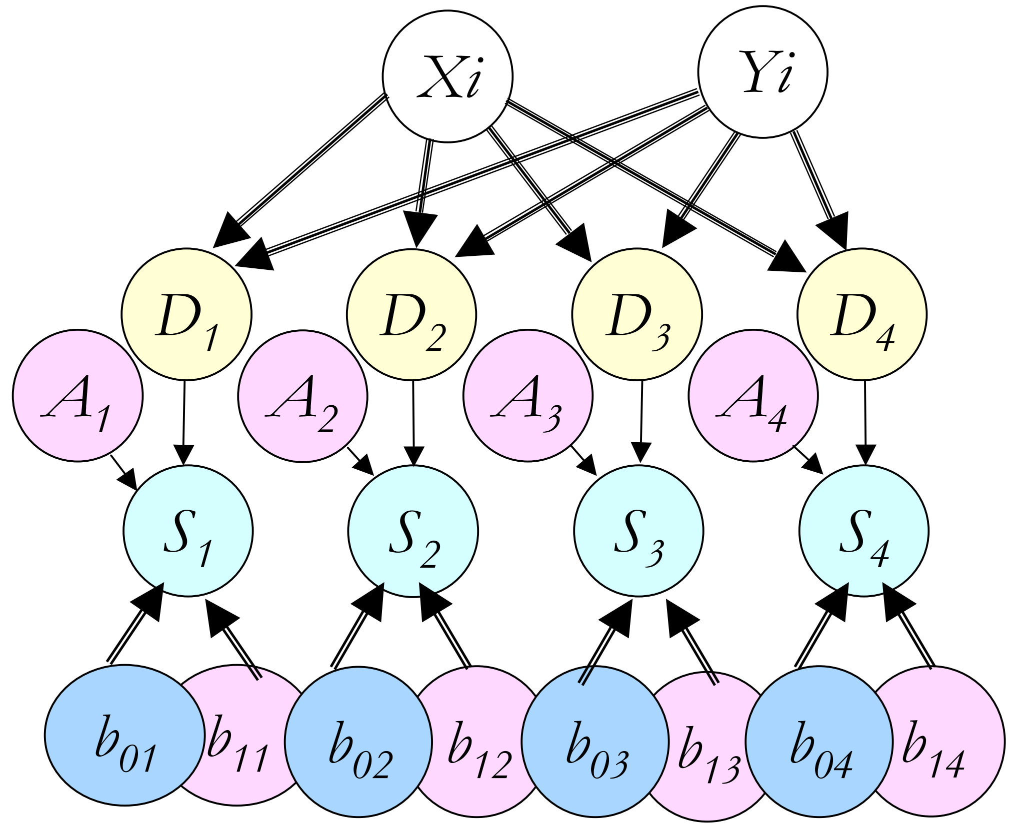
Position

Distance

Angle

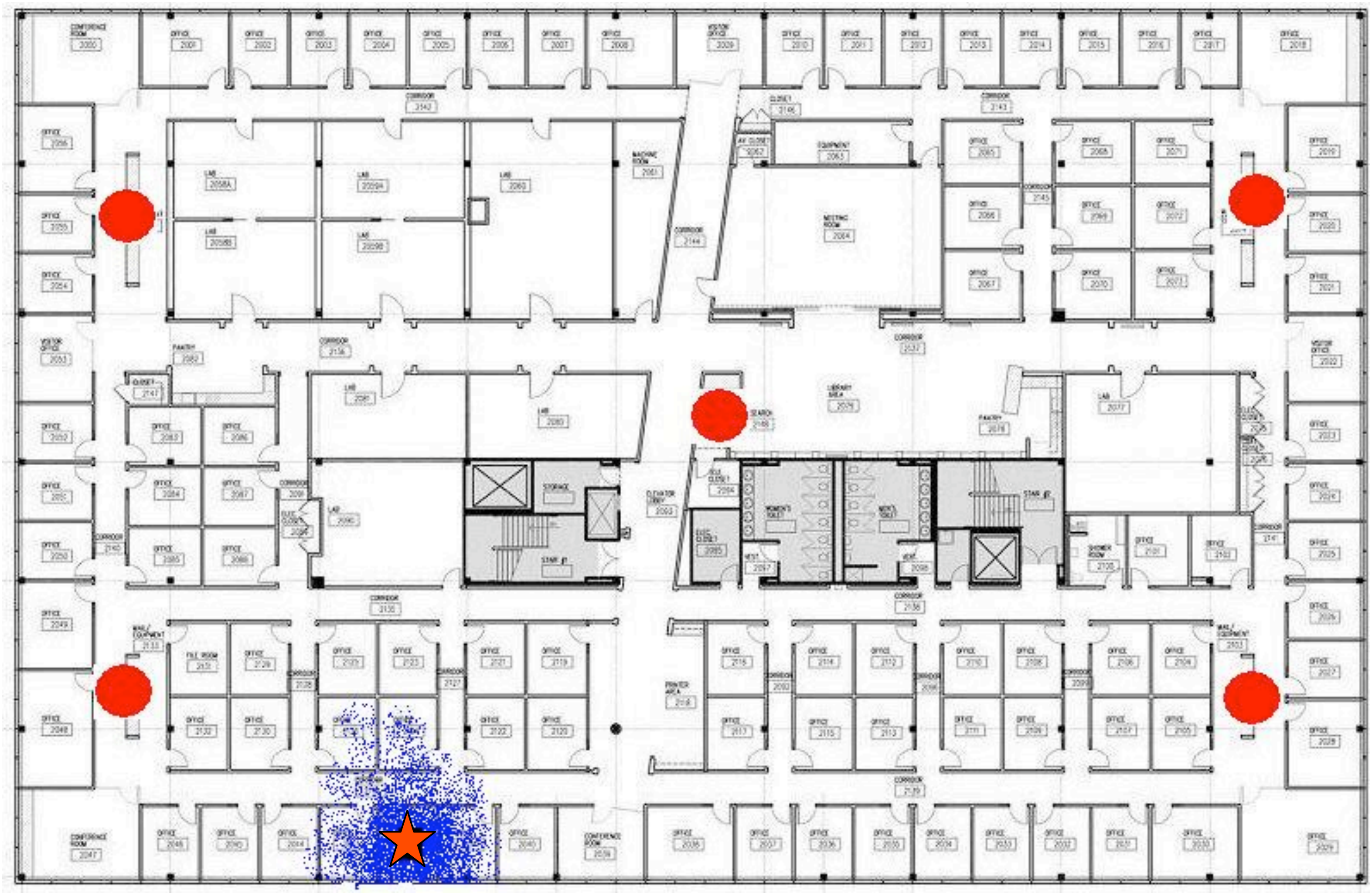
RSS

Propagation Constants



Minus: no closed form solution for values of nodes

Computing the Probability Density using Sampling



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Clients

- Text-only client
- GUI client is future work
  - CGI-scripts to contact server, update map
  - GRASS client
  - Google

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Open Issues

- Social Issues
  - Privacy, security
- Resources for communication vs. localization
- Scalability

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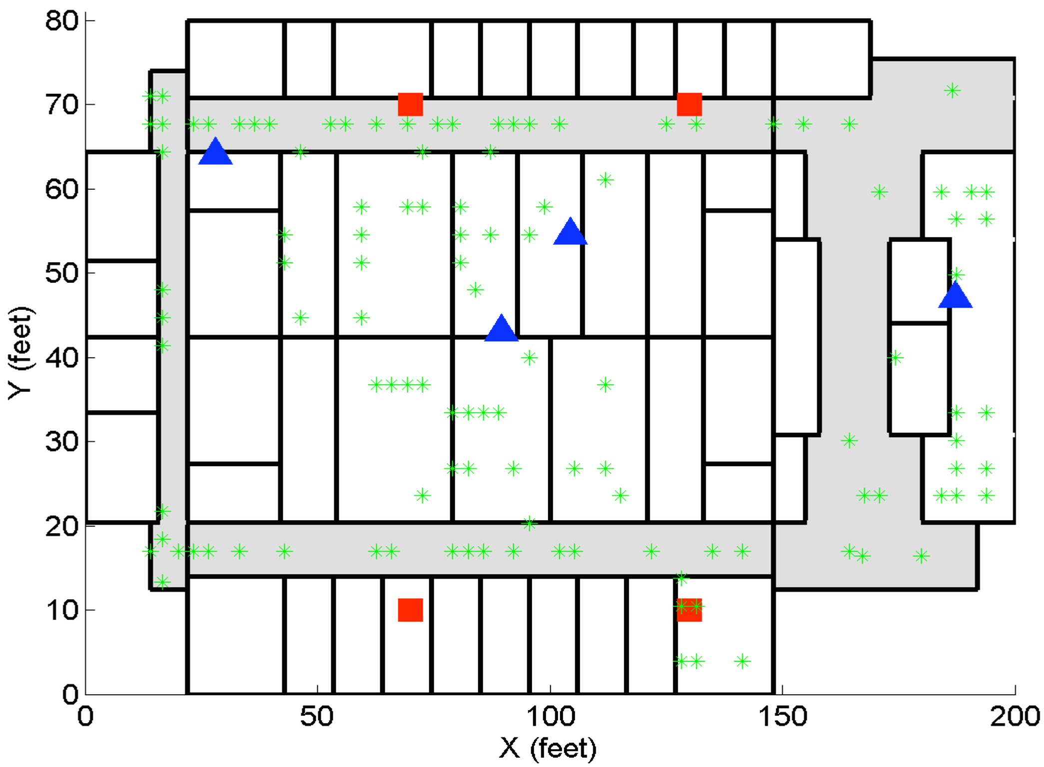
Social Issues

- Privacy
  - Who owns the position information?
    - Person who owns the object, or the infrastructure?
  - What are the "social contracts" between the parties?
    - Economic incentives?
  - Centralized solutions make enforcing contracts and policies more tractable.
- Security
  - Attenuation/amplification attacks [Chen 2006]
    - Tin foil, pringles can
  - No/spoofed source headers?
  - Attack detection

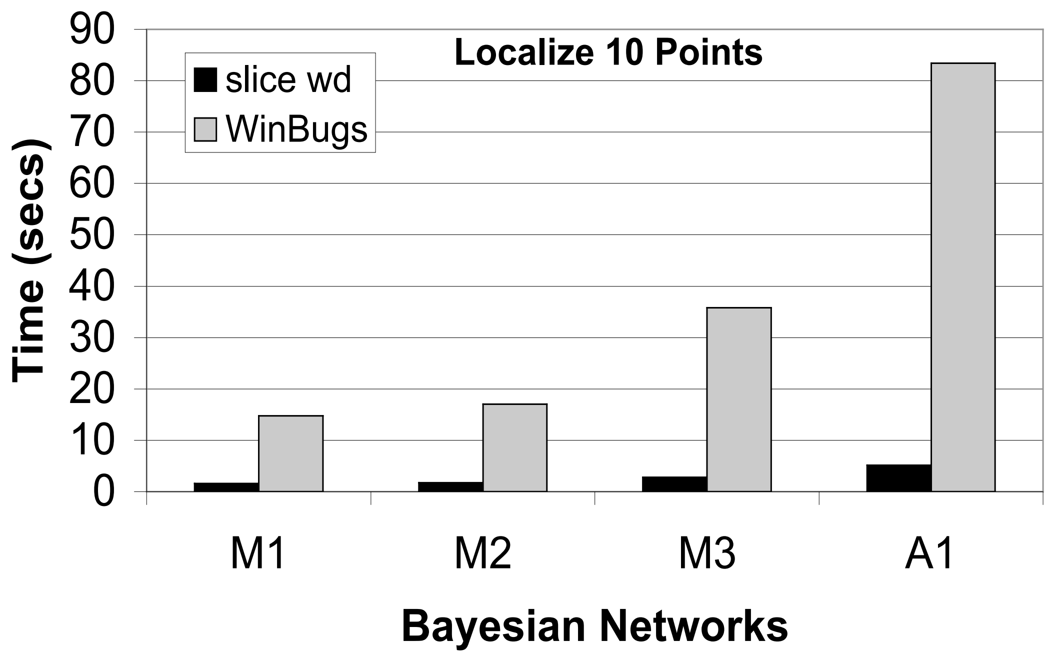
Communication vs. Localization

- Resource use for Localization vs. Comm.?
  - Ideal landmark positions not the same as for comm. coverage [Chen 2006]



Scalability

- Can scale to 10's of unknowns in a few seconds
- Can we do 1000s?



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Future Work

- Rebuild and deploy system
  - Gain experience running over weeks, months
- Continue to improve landmarks
  - High frequency, bit-level timestamps
- Scalability
  - Parallelize sampling algorithms
- Security
  - Attack detection
  - Algorithmic agreement
- Social issues?

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Conclusions

- Time to defocus from algorithmic work
- Localization of all radios will happen
  - Expect variety of deployed systems
  - Demonstration of cost/performance tradeoffs
- Technical form, social issues not understood

References

- Today's talks:
  - Kosta: Rapid sampling of Bayesian Networks
  - Yingying: Landmark placement

- E. Elnahrawy ,X. Li ,R. P. Martin, The Limits of Localization Using Signal Strength: A Comparative Study In Proceedings of the IEEE Conference on Sensor and Ad Hoc Communication Networks, SECON 2004
- D. Madigan , E. Elnahrawy ,R. P. Martin ,W. H. Ju ,P. Krishnan ,A. S. Krishnakumar, Bayesian Indoor Positioning Systems , INFOCOM 2005, March 2004
- Y. Chen, W. Trappe, R. P. Martin, The Robustness of Localization Algorithms to Signal Strength Attacks: A Comparative Study, DCOSS 2006