Verifiable Wireless Localization via Power Modulated Coverage Areas

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Motivation

- *Localization-specific* threats
- A fixed configuration limits the ability of the infrastructure to conduct and verify localization
- Power-modulated localization is robust in security sense

Content

- Power Modulation and Geometric Localization Method
- Stochastic Localization Method
- Evaluation
- Conclusion

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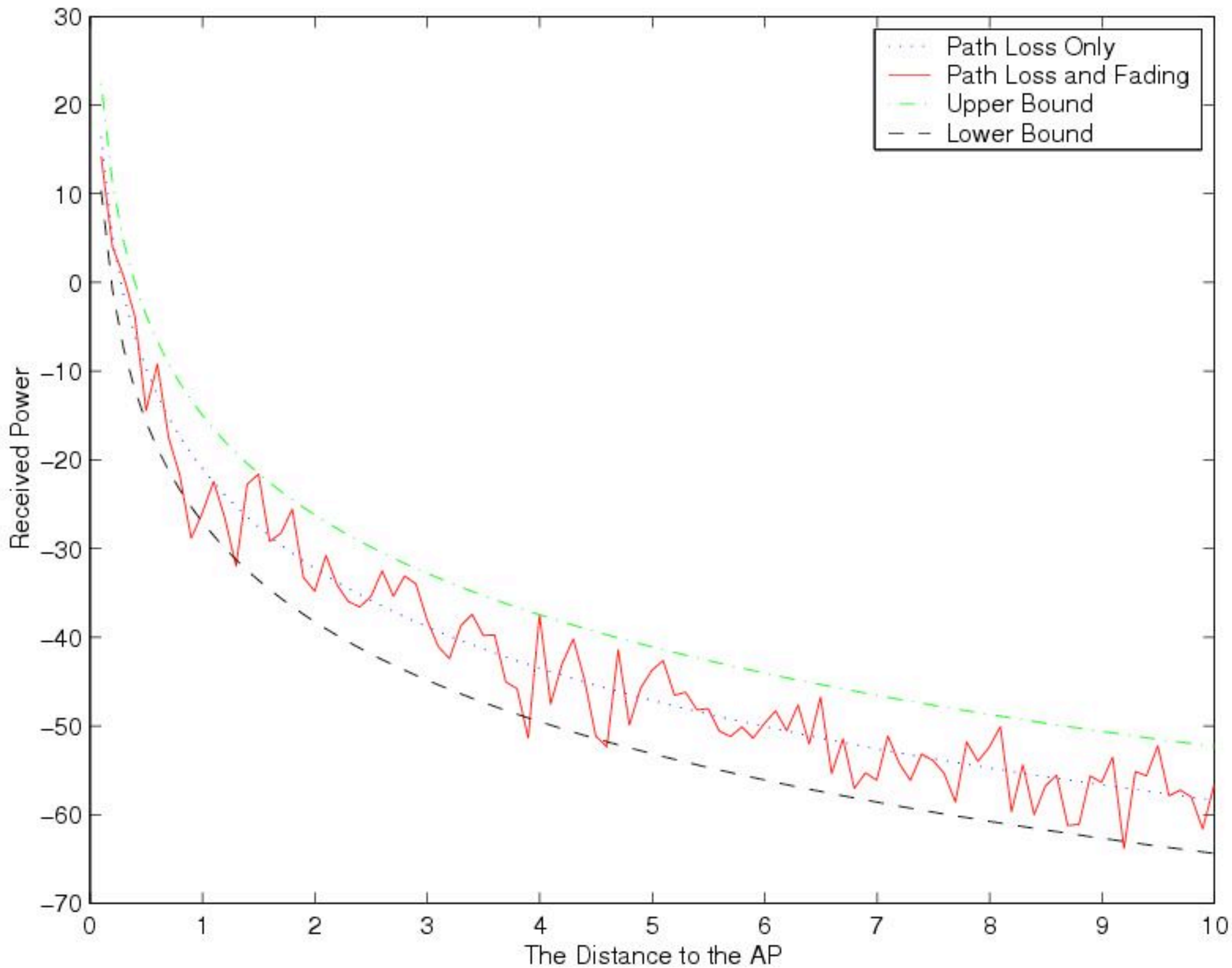
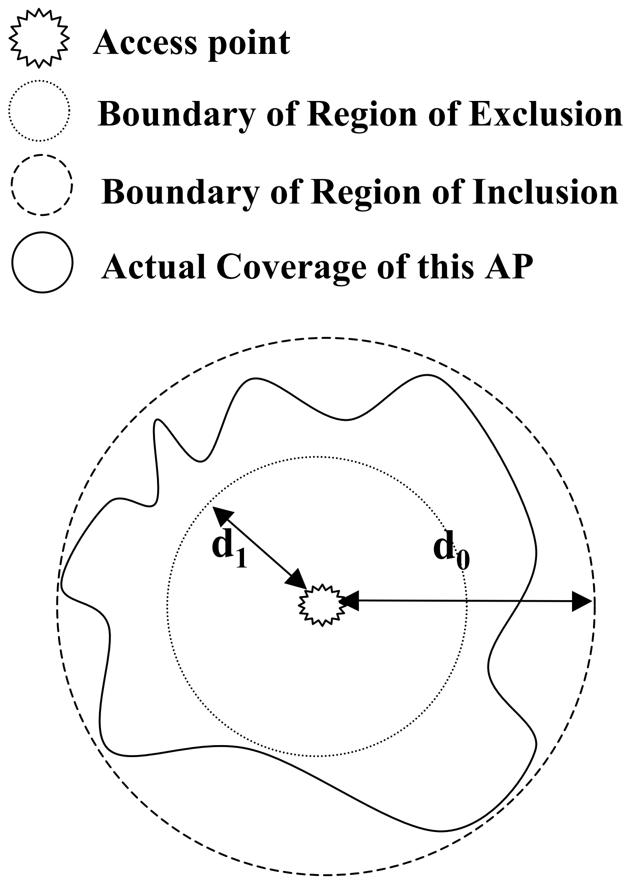
Power Modulated Localization

- Transmitting devices alter their transmission powers during localization.
- The information regarding whether a device can witness different power levels assists in the localization process
- help guarantee the location of a device since devices that aren’t within a radio range are not able to spoof responses for messages they cannot witness.

Geometric Localization Method-1



Geometric Localization Method-2



If the node could hear AP, the node must be within its Region of Inclusion $\Omega^{I}(t)$

If the node cannot hear *AP*, then the node must be outside the boundary of Region of Exclusion $\Omega^{E}(t)$

Power Modulation and Geometric Localization Method-3

Estimated Location Region

$$\Upsilon(t) = \bigcap_{j \in \mathrm{I}(t)} \Omega_j^{\mathrm{I}}(t) \bigcap_{k \in \mathrm{E}(t)} \Omega_k^{\mathrm{E}}(t)$$

Refined Estimated Location Region

$$\Psi(t) = \Psi(t-1) \cap \Upsilon(t)$$

Variations of Power Modulation

- *Association Lists Assisted Localization*

  - infrastructure does power modulation

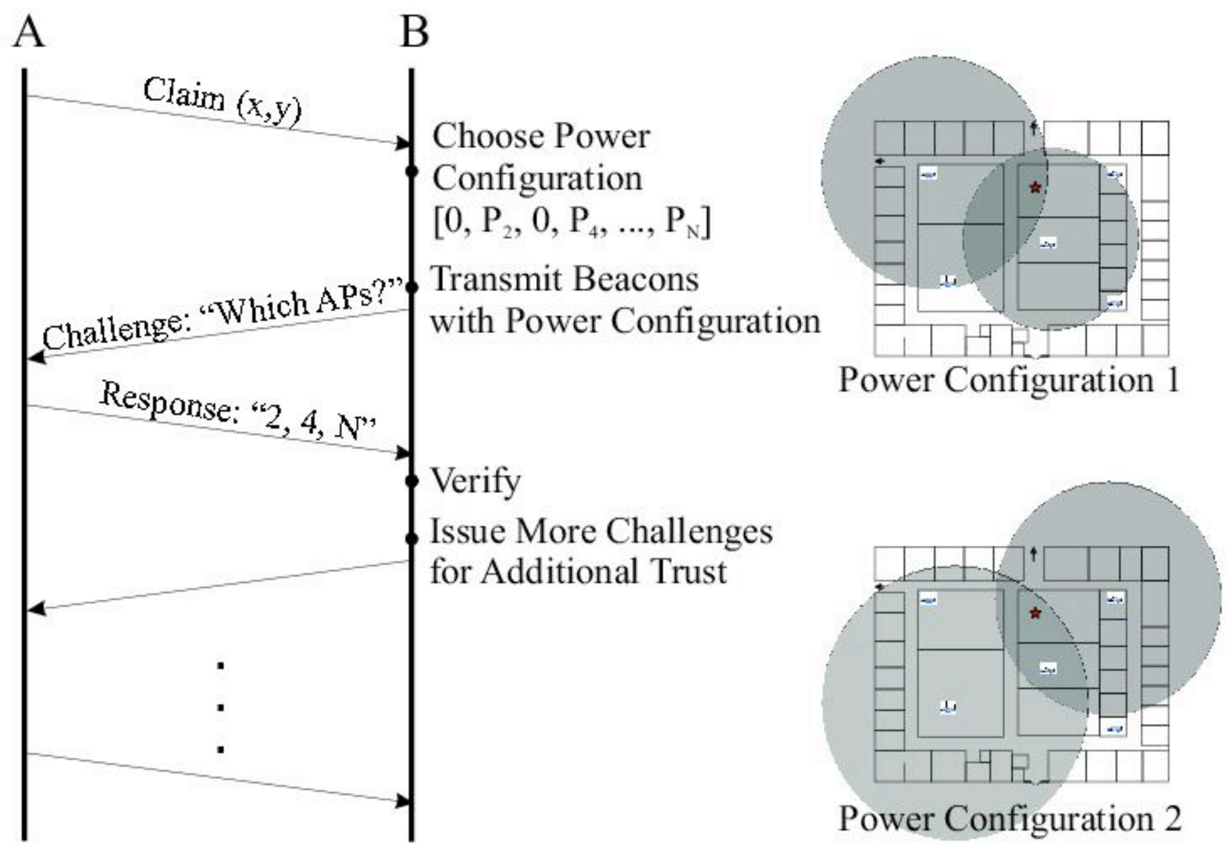
  - infrastructure localizes the emitting node

- *AP-Covering Lists Assisted Localization*

  - infrastructure does power modulation

  - node localizes itself

Power-modulated Challenge-Response



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Notations

Access Points

$$\left\{A_1, A_2, \ldots, A_K\right\}$$

Power Configuration Vector

$$\underline{P}_j = \left\{P_{A_{1j}}, P_{A_{2j}}, \ldots, P_{A_{Kj}}\right\}$$

Association Probability

$$\pi_k^{ji} = P\left(A_k \mid \underline{P}_j, L_i\right)$$

Maximum Likelihood Location Estimator-1

Suppose that we vary the power configurations according to a power configuration sequence $\underline{P}_J = \{\underline{P}_1, \underline{P}_2, \cdots, \underline{P}_j, \cdots\}$, and that we measure the corresponding observed associations $\underline{O} = \{O_1, O_2, \cdots, O_j, \cdots\}$, then $\hat{L} = \arg\max_i P(L_i \mid \underline{P}_J, \underline{O})$

$$\hat{L} = \arg\max_i P(\underline{O} \mid \underline{P}_J, L_i)$$

where

$$P(\underline{O} \mid \underline{P}_J, L_i) = \prod_j P(O_j \mid \underline{P}_j, L_i)$$

Maximum Likelihood Location Estimator-2

Example: If we observe O_1, O_2 and O_3 under power configurations $\underline{P}_1$, $\underline{P}_2$ and $\underline{P}_3$ at location L_i, then

$$P(\underline{O} \mid \underline{P}_J, L_i) = P(O_1 \mid \underline{P}_1, L_i) P(O_2 \mid \underline{P}_2, L_i) P(O_3 \mid \underline{P}_3, L_i)$$

Sequential Localization-1

By refining $P(L_i)$ with each additional observation, sequential algorithms have the advantage that their processing may be terminated when the desired estimate or desired accuracy is achieved, thereby reducing computation as well as the amount of rounds needed.

Sequential Localization-2

$P_0(L_i) = 1/M$ where M is the amount of discrete locations we wish to localize over.

$$P_j(L_i) = \frac{P(O_j \mid \underline{P}_j, L_i) P_{j-1}(L_i)}{\sum_{i \in \Omega^j} P(O_j \mid \underline{P}_j, L_i) P_{j-1}(L_i)}$$

where

$$\Omega^j = \{L_i : P(O_l \mid \underline{P}_l, L_i) > \tau, 1 \leq l \leq j-1\}$$

and τ is a threshold that may be adjusted to control the size of the regions.

Sequential Localization-3

Suppose the decision is made after we receive N observations:

$$\hat{L} = \arg\max_{i} P_N\left(L_i\right)$$

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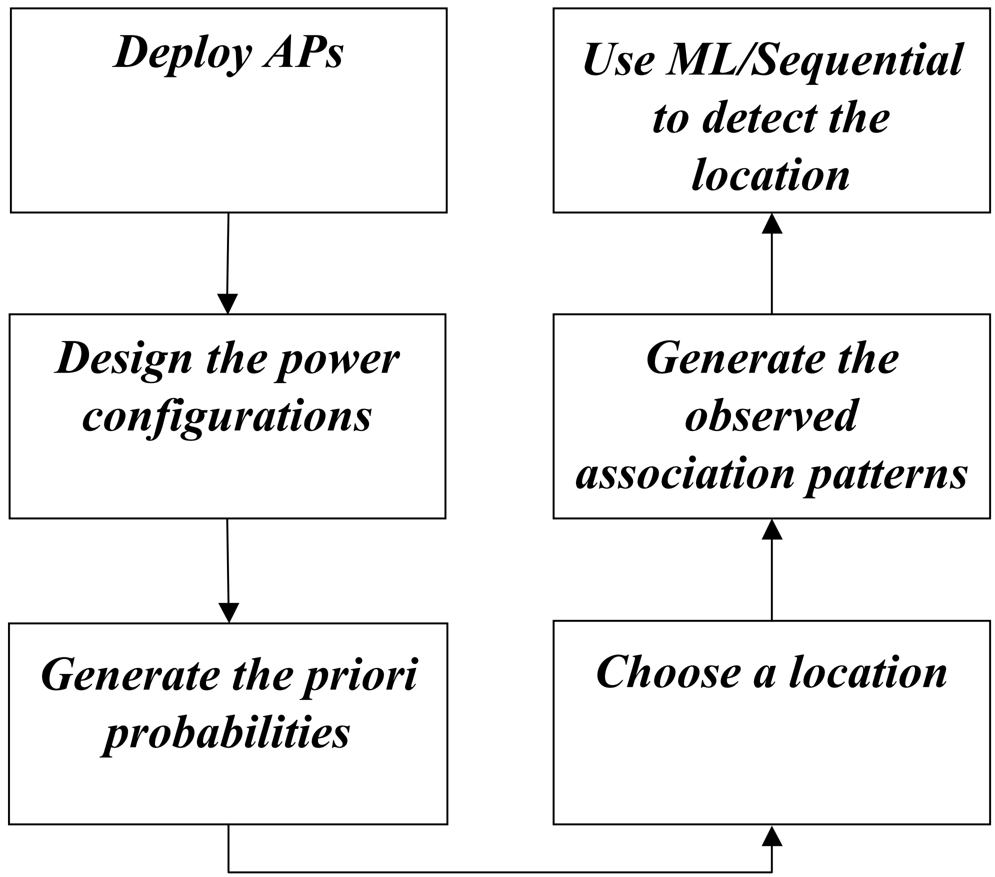
Evaluation Goal

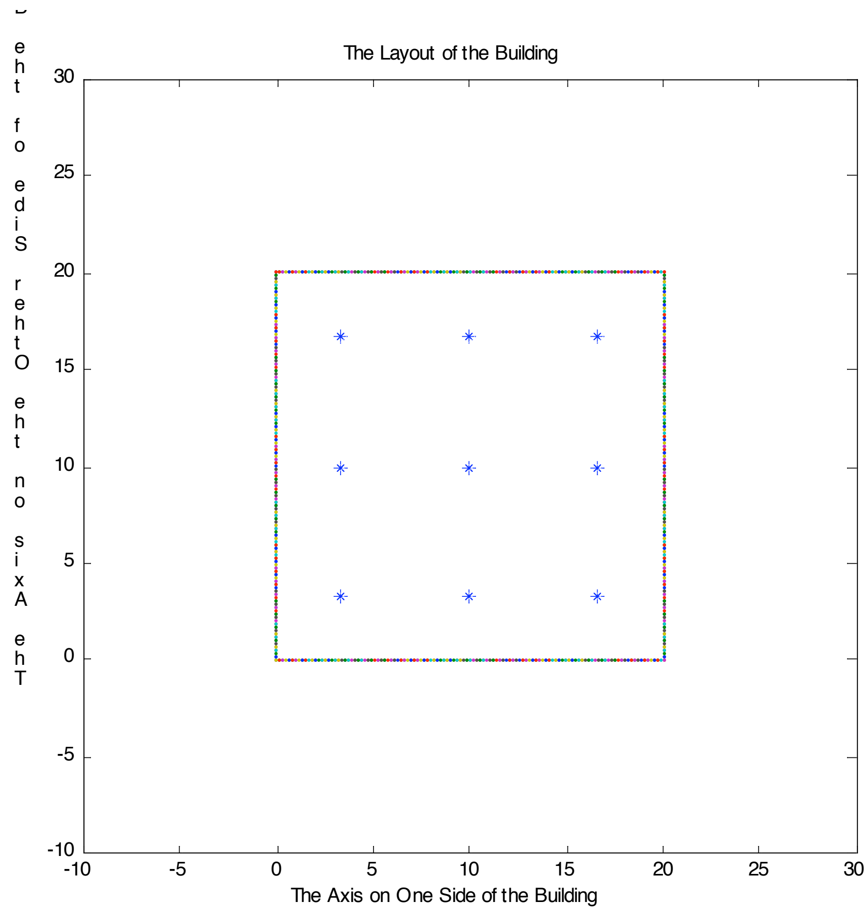
- Use power modulated localization to determine whether a wireless transmitter is inside of an enclosed region
- ML detection
- Sequential detection

Evaluation Setup-1

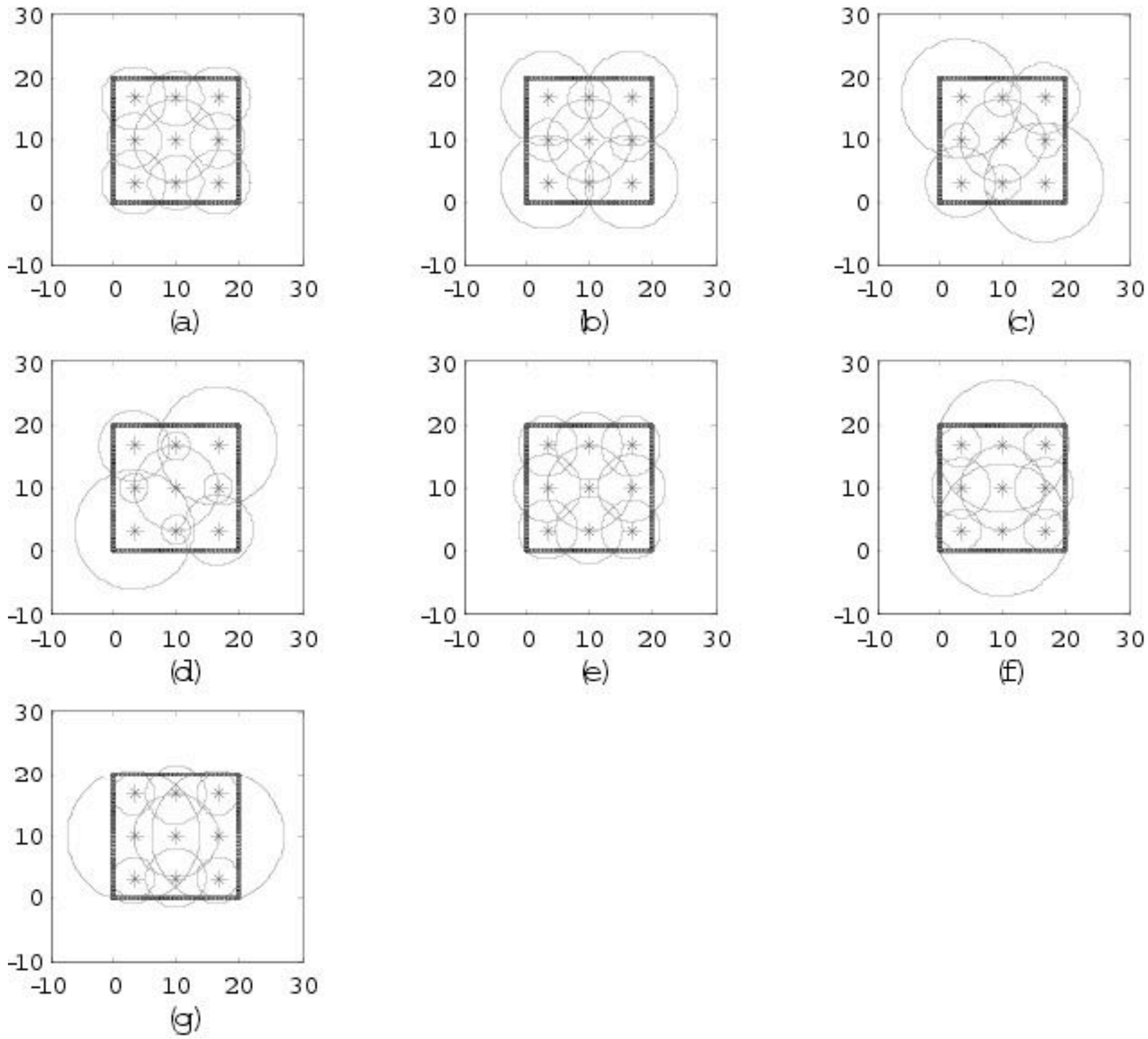


Evaluation Setup-Deploy APs

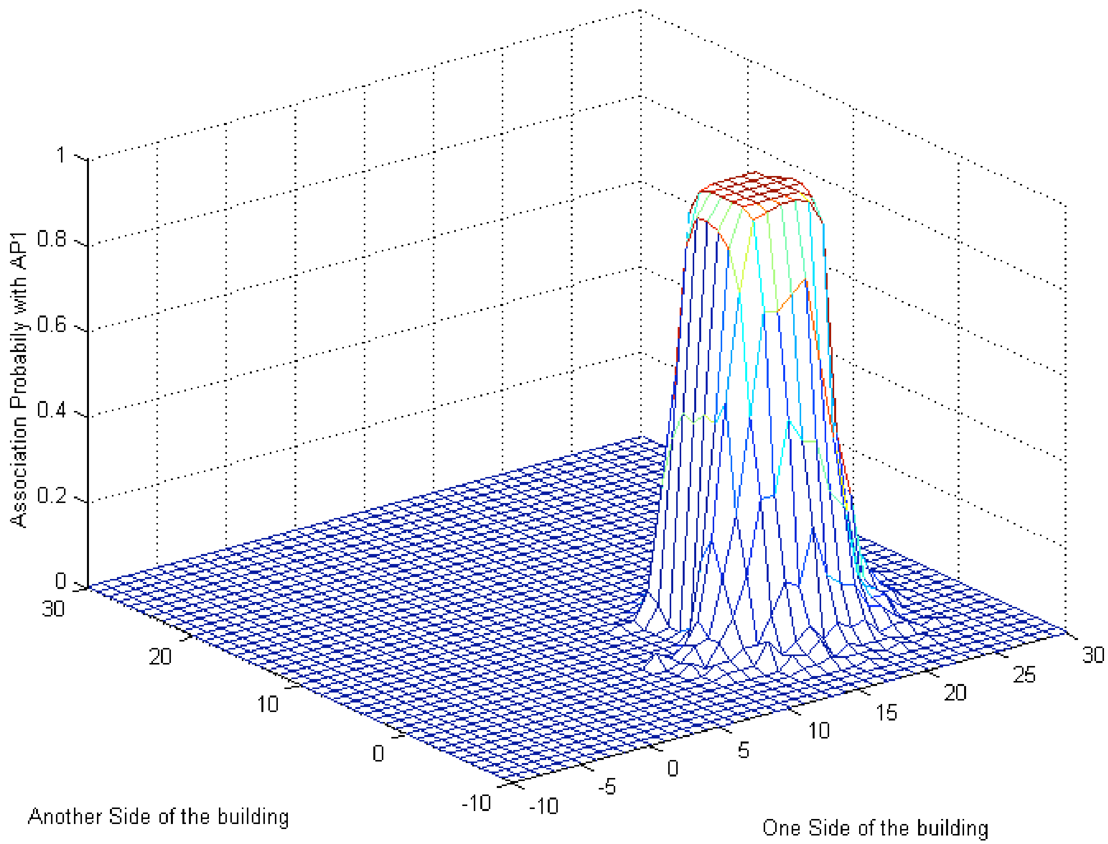
- Locations that $(x, y) \in [0,20] \times [0,20]$ are inside
- APs (represented by '*') are regularly deployed



Evaluation Setup-Design Power Configurations

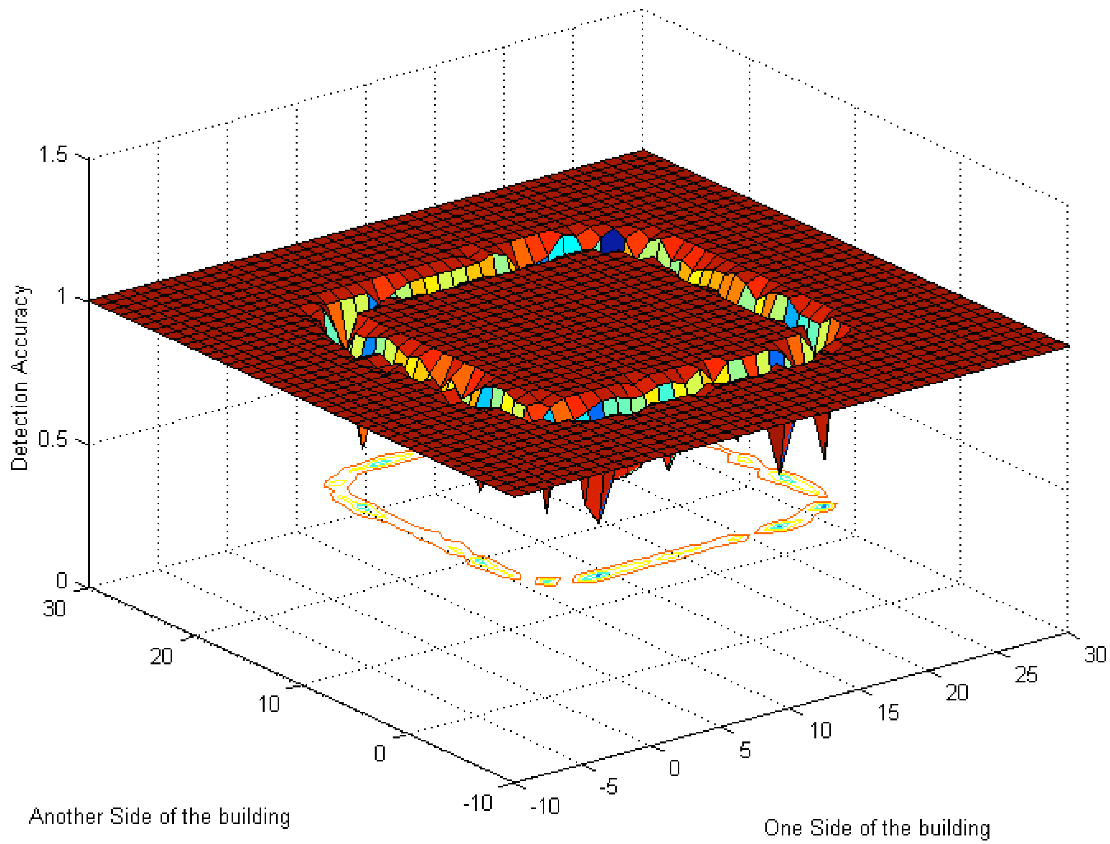


Evaluation Setup-Generate Priori Probabilities



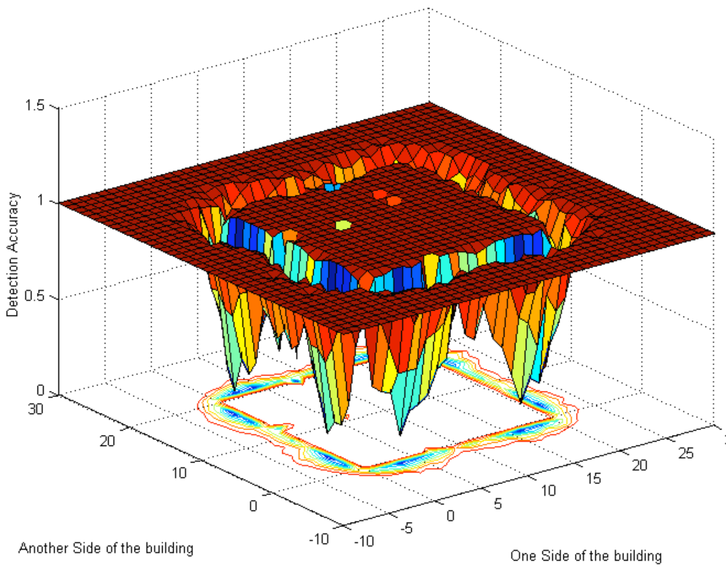
Association probabilities for *AP*1 corresponding to power configuration 1

Result of ML Detection

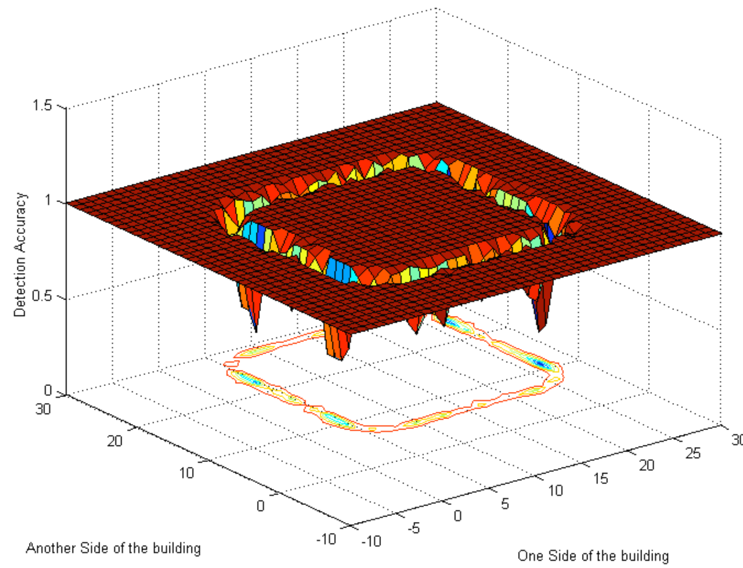


detection accuracy of ML method

Result of Sequential Detection



detection accuracy with two power configurations



detection accuracy with six power configurations

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Conclusion

- The infrastructure can change its configuration in order to assist in the localization and location verification process
- A geometric formulation of the power-modulation localization process
- Power-modulation can be used in a challenge-response position verification procedure
- Maximum likelihood and sequential localization algorithm that employ a stochastic propagation model

Thank you!