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Propagation Modeling and Planning of Battery-less Tags Networks

Antonis G. Dimitriou, Stavroula Siachalou, Aggelos Bletsas and John Sahalos

28 September 2014, Toulouse

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Related Projects

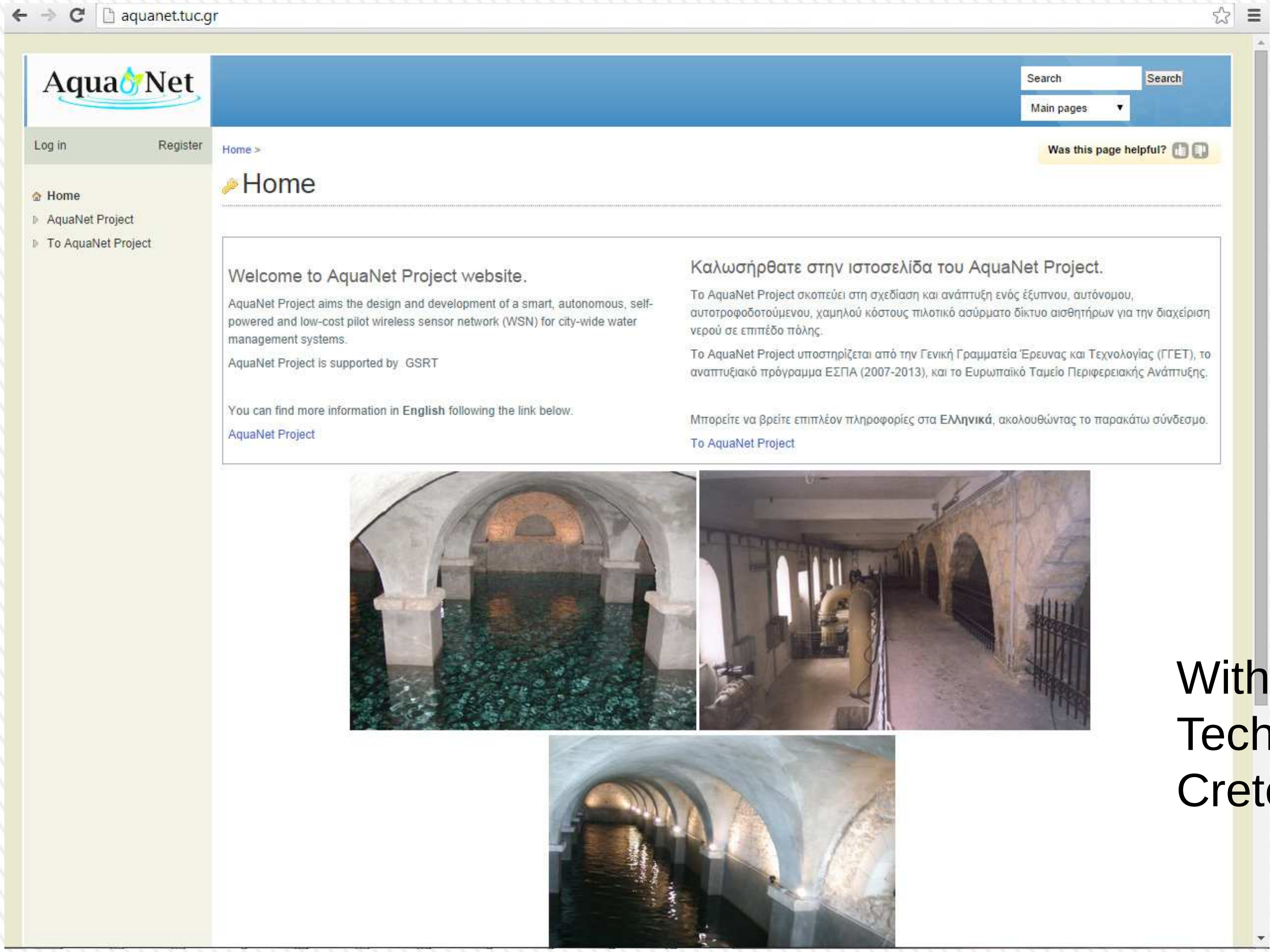
» Sensor Networks

» RFIDs

Blase – Precision Agriculture

With Prof. Bletsas from Technical University of Crete

Aquanet – Water Management



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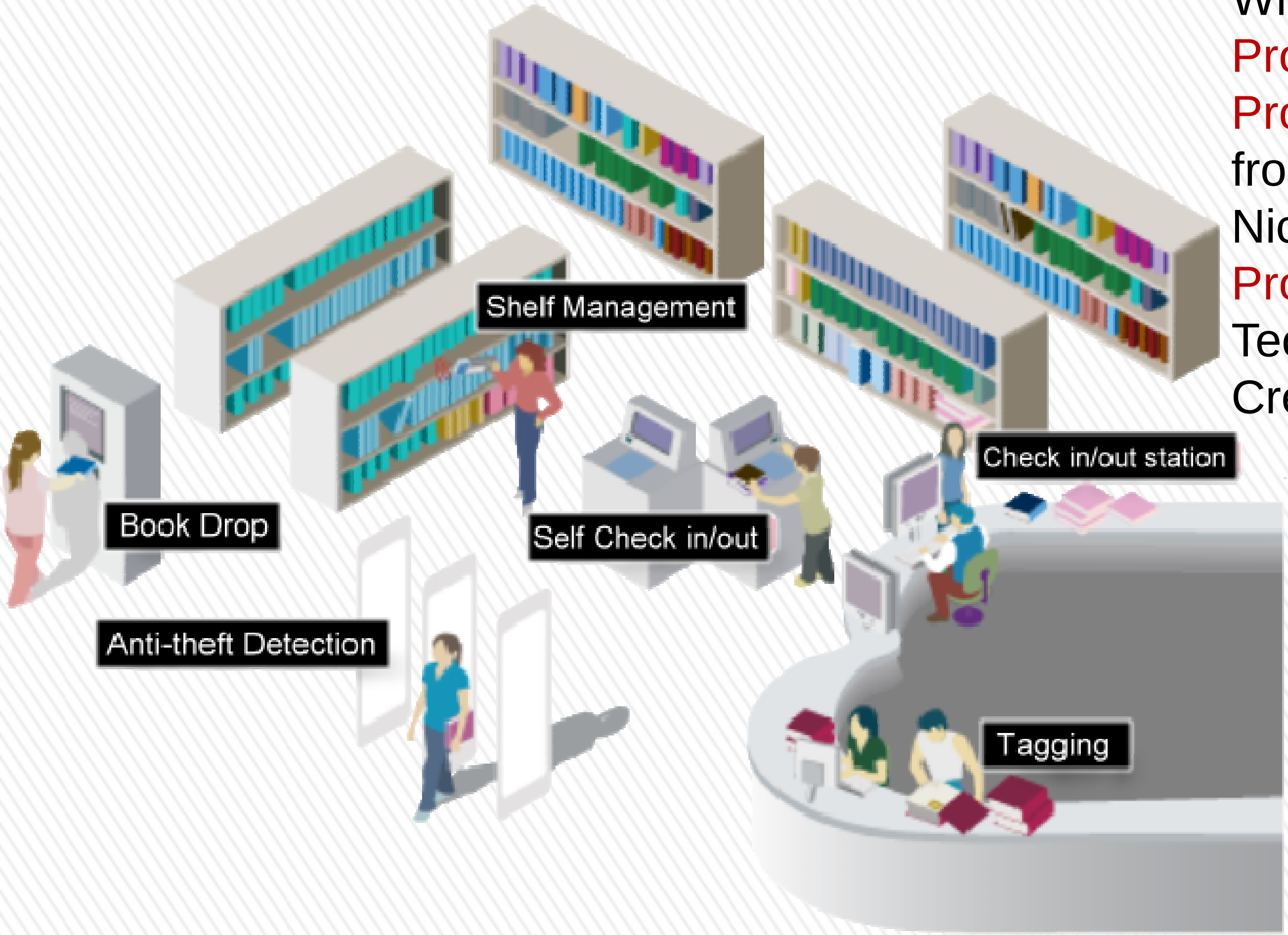
Intelligent Library Management System Using RFIDs



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Prof Polycarpou
from the University of Nicosia and
Prof. Bletsas from
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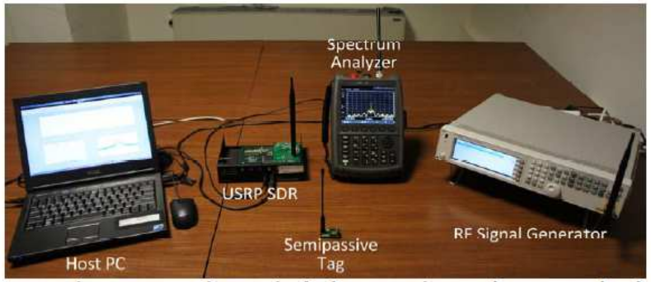
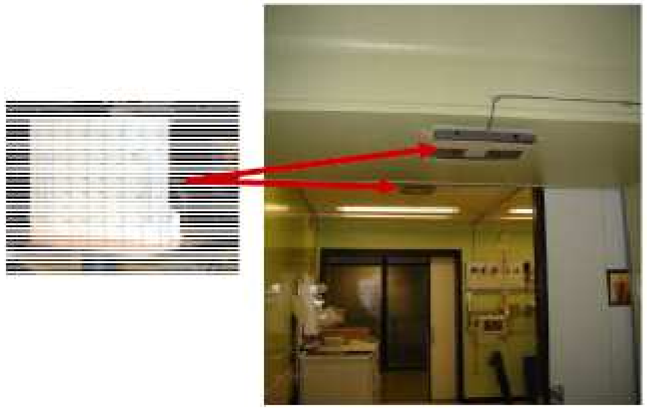
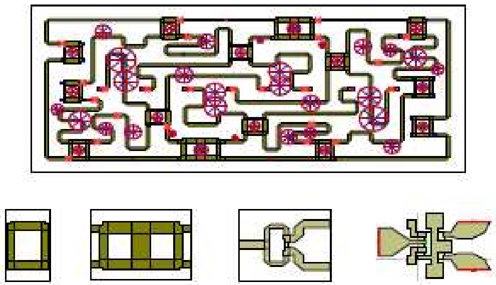
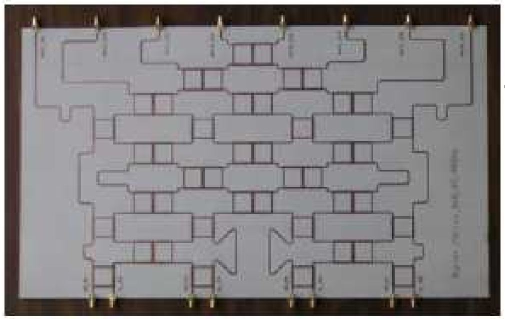
Development of RF/RFID systems for COntrol and REgistration of goods and personnel









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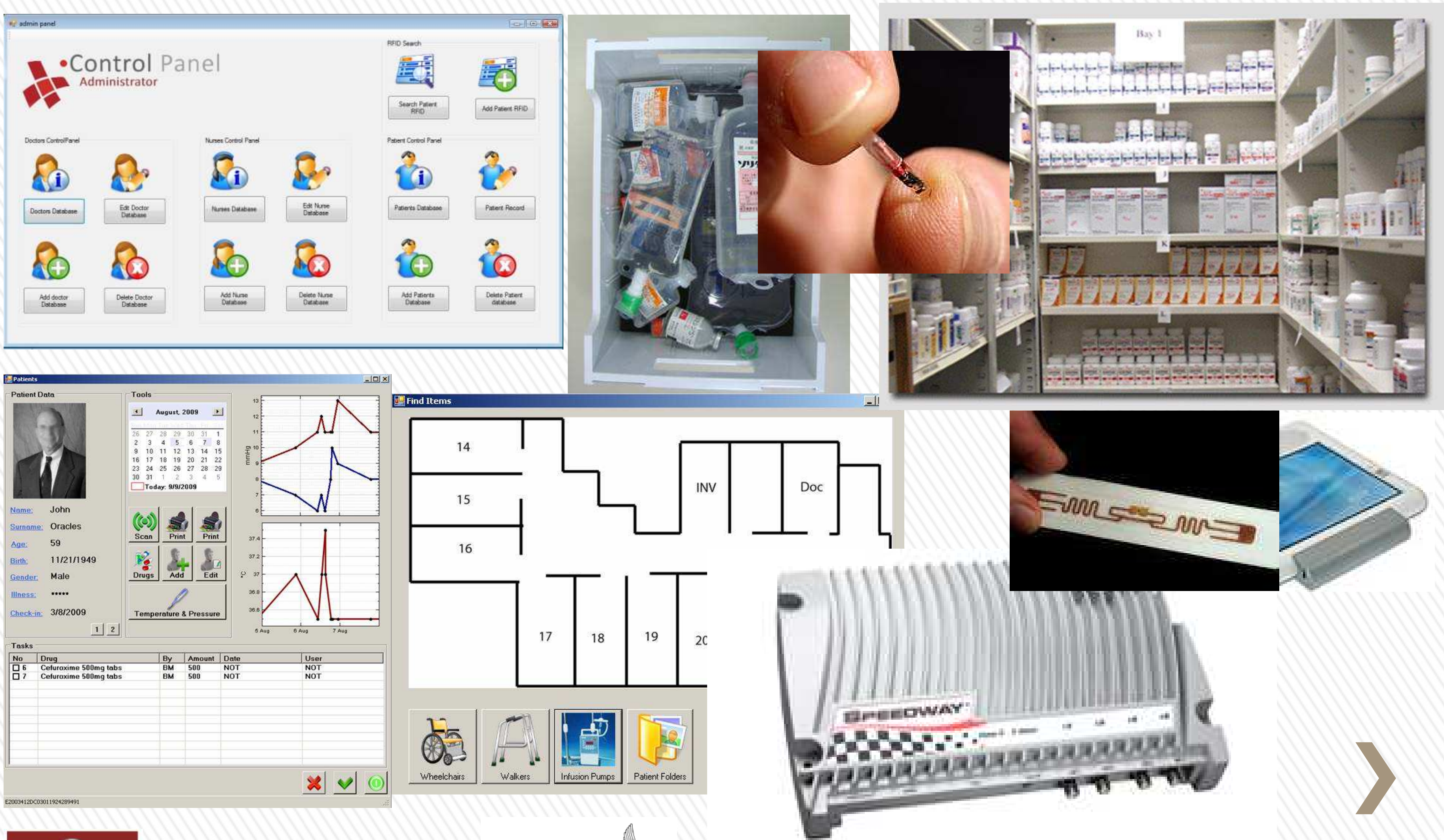
cost

RFID in Healthcare



Outline – Propagation & Planning

» Objective – Prior Art

» Key Points / Innovations

» Analytical Presentation

  > Part I:

    + Propagation Model

    + Evaluation and Results

  > Part II

    + Automated Planning Model

    + Evaluation and Results

» Conclusions

Objective

» Facility Problem - Automated method to select antenna positions such that a network of passive tags are powered-up

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Presentation of Key Points / Innovations

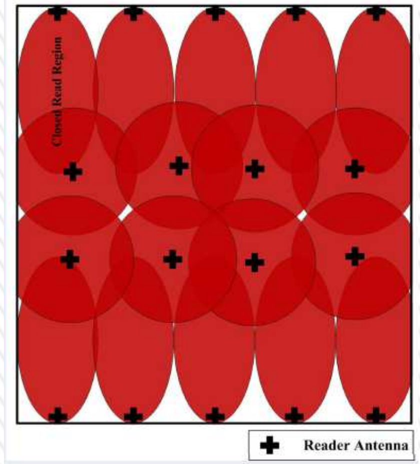
Presentation of Key Points (1/3)

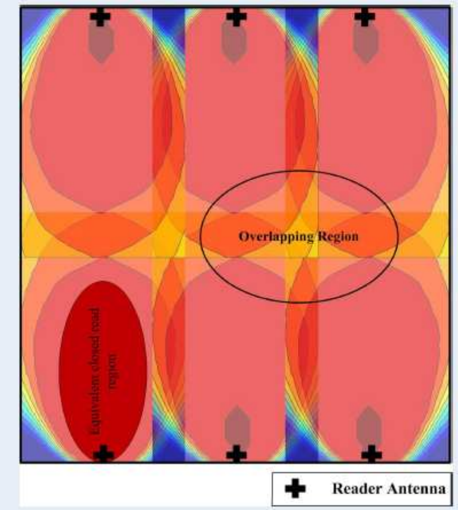
» Existing read-region propagation models, employed in automated planning, define closed read-regions

» Interaction between different antennas in overlapping coverage zones is not treated

» Which leads to solutions with redundant equipment and increased cost

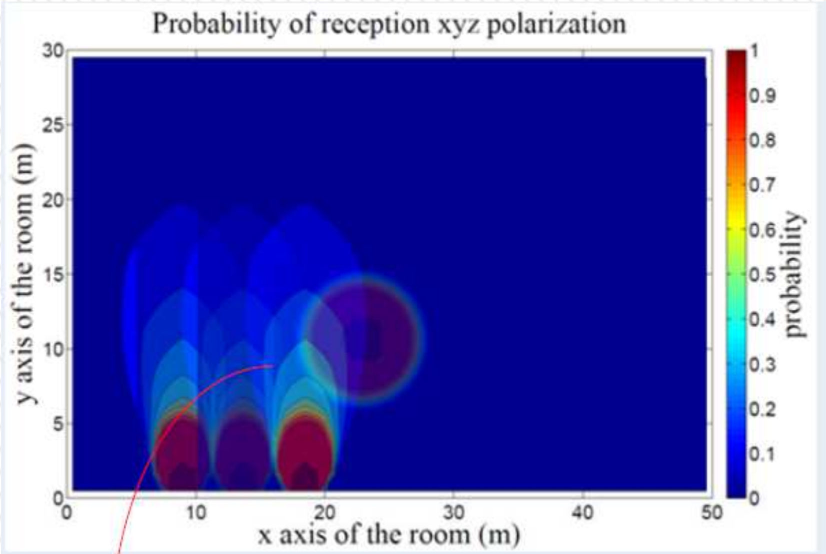
» The computational constraints force the deployment of simple propagation models.





Presentation of Key Points (2/3)

- Probabilistic Propagation Model, assuming Rician fading, considering
  - radiation pattern
  - geometry & materials of surrounding walls
  - polarization of reader and tags
- Proving different probability density function for each point.
- Having calculated the probability of successful powering-up by each antenna, we can calculate the desired probability for the entire network, assuming independence – **Overlapping region problem is solved**

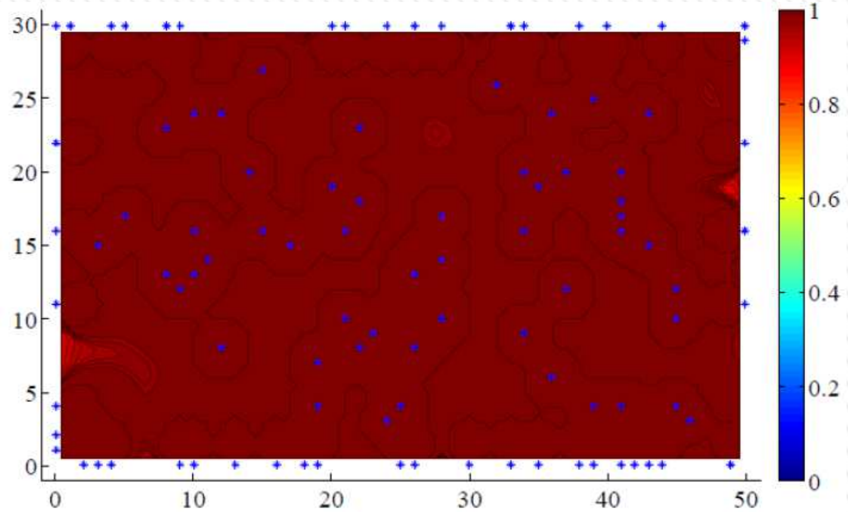


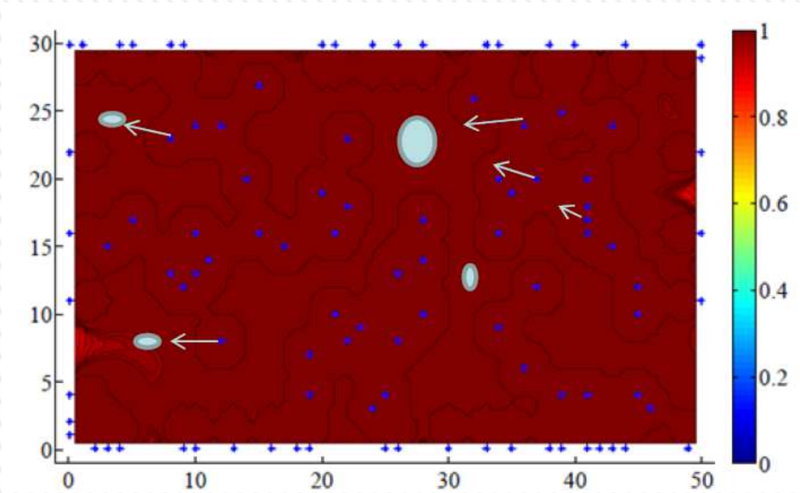
$$p_i = 1 - \prod_{j \in A} (1 - p_{ij} x_j)$$

Presentation of Key Points (3/3)

» Particle Swarm Optimization

- > Typical Algorithm
- > Hybrid Approach (Clustering)

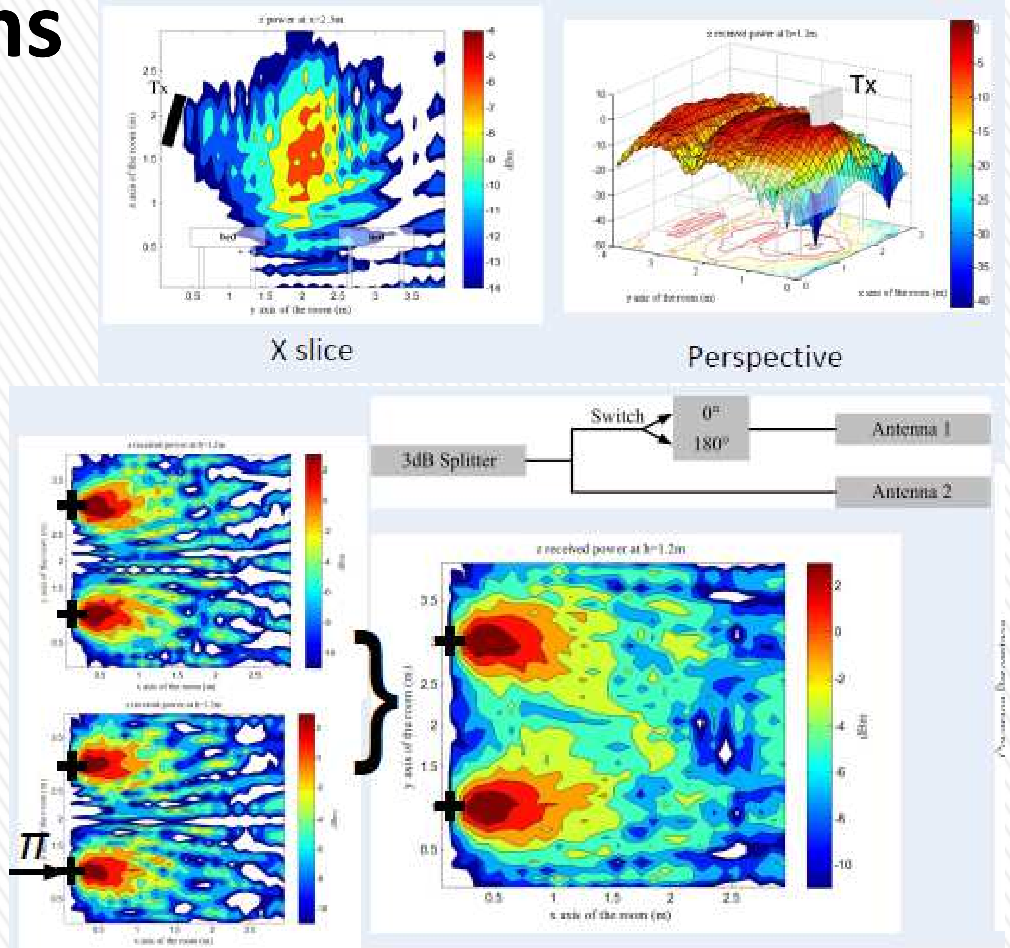




Part I – Probabilistic Propagation Model

Prior Experience on Propagation for Battery-less systems

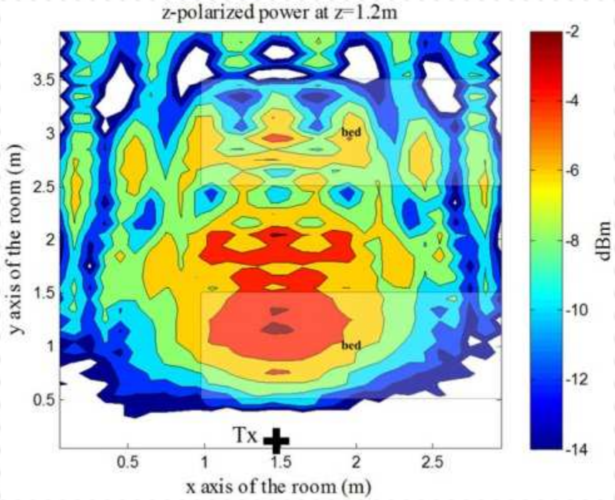
» Analytical Propagation Models & Measurements to evaluate the performance gains by
  > Implementing tag's polarization diversity
  > Multiple antennas in the time-domain
  > Multiple antennas, introducing phase shifters to dislocate the minima

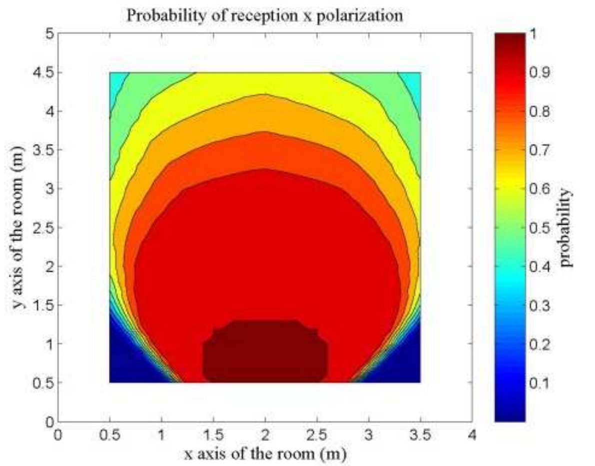


Antonis G. Dimitriou, Aggelos Bletsas, and John N. Sahalos, "Room Coverage Improvements of UHF RFID with Commodity Hardware," IEEE Antennas and Propagation Magazine, vol. 53, no. 1, February 2011.
Antonis G. Dimitriou, Aggelos Bletsas, Anastasis Polycarpou, and John N. Sahalos, "Theoretical Findings and Measurements on Planning a UHF RFID System inside a Room," Radioengineering Journal - Towards EuCAP 2012: Emerging Materials, Methods, and Technologies in Antenna & Propagation, Vol. 20, no. 2, June 2011, pp. 387-397.

Why Probabilistic?

- Analytical Models present a screenshot of reality
- What happens in time?
- What about modeling inaccuracies?
  - Geometry
  - Materials
- Instead of searching for a specific "hole", we ask ourselves "**What is the probability that such a hole might exist**"?





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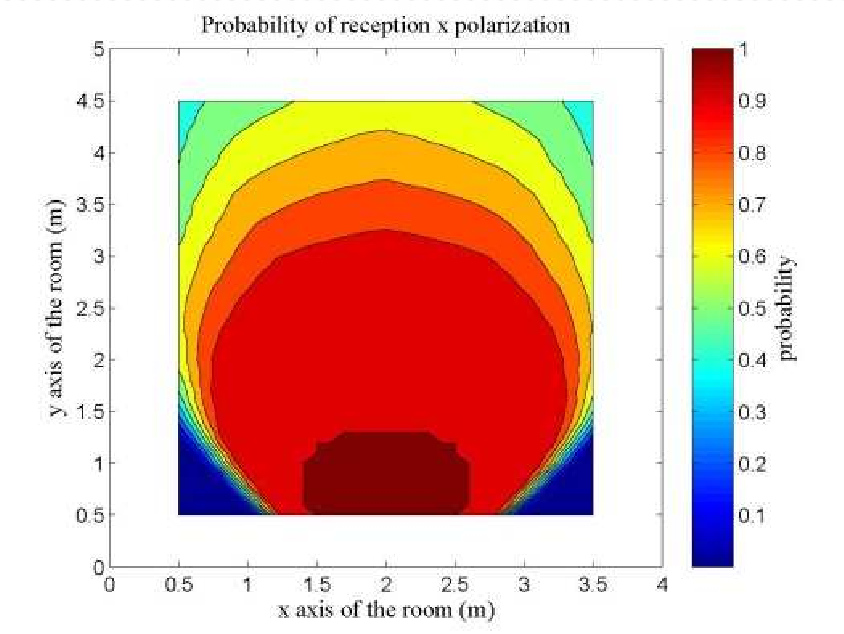
Probabilistic Model - Goals

» **Site Specific** Propagation Model for Passive Tags

> Space geometry
> Materials
> Polarization
> Antennas



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Large-Scale Planning

- Airports, warehouses,…
  - Final network includes tens of antennas
  - Candidate set includes hundreds of antennas
  - For each antenna configuration, we need propagation data
  - Running-time should be small

- Max EIRP ~35dBm
- Battery-less tag needs ~-18dBm
- Range is in the order of 10m

Objective

» **Computationally Inexpensive** Site Specific Propagation Model for Passive Tags

> Space geometry
> Materials
> Polarization
> Antennas

» Target Apps:

> Large scale (automated) network planning

Prior-Art

» Computational Electromagnetics

» Analytical Ray tracing

A. G. Dimitriou, A. Bletsas, and J. N. Sahalos, ”Room coverage improvements of UHF RFID with commodity hardware,” IEEE Antennas Propag. Mag., vol. 53, pp. 175-194, Feb. 2011

» Simple Propagation Model

> Friis equation

> Two slope model + Stochastic fading

M. F. Iskander and Z. Yun, ” Propagation prediction models for wireless communication systems,” IEEE Trans. Microw. Theory Techn., vol. MTT- 50, pp. 662-673, March 2002.
A. Lazaro., D. Girbau, and D. Salinas, ”Radio link budgets for UHF RFID on multipath environments”, IEEE Trans. Antennas Propag., vol. AP-57, pp. 1241-1251, April 2009.

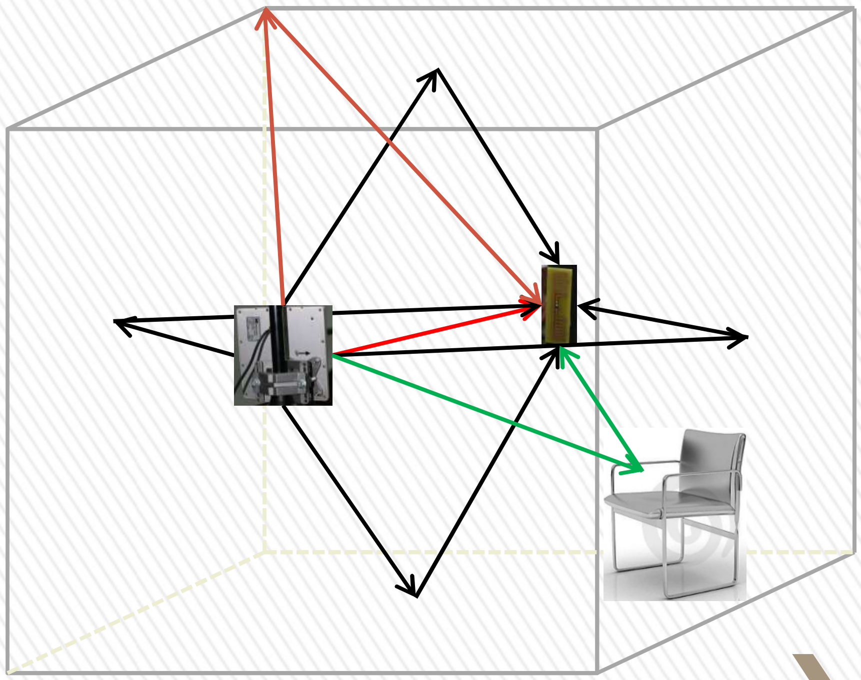
> Two-ray model – reliable reading region

G. Marrocco, E. Di Giampaolo, and R. Aliberti., ”Estimation of UHF RFID reading regions in real environments”, IEEE Antennas Propag. Mag., vol. 51, pp. 44-57, Dec. 2009.

Derivation of the Proposed Model

Propagation inside a room

- Direct Ray
- Multiple Reflections
- Diffraction at corners
- Scattering from objects



- What is the probability of successful reception?
  - Received power should be above threshold

$P(X \geq \gamma)$

Rician Fading

» The strong LOS path should be present

Rice pdf: $$f(x|v,\sigma) = \frac{x}{\sigma^2} e^{\left[\frac{-(x^2+v^2)}{2\sigma^2}\right]} \mathrm{I}_0\left(\frac{xv}{\sigma^2}\right)$$

where v^2 is the power of the LOS path and $2\sigma^2$ is the average power of all other contributions

Rice cdf: $$F_x(x|v,\sigma) = 1 - Q_1\left(\frac{v}{\sigma},\frac{x}{\sigma}\right)$$

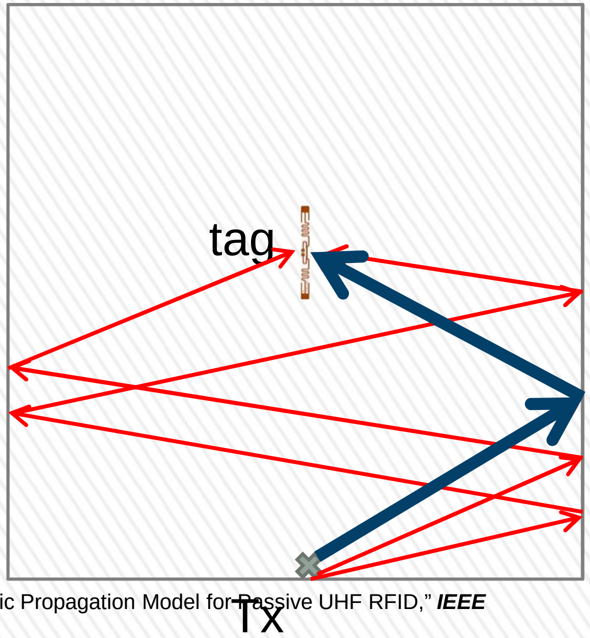
Successful power-up: $$P(X > \gamma) = 1 - F_x(x|v,\sigma)$$

Rays Clustering

For $E = \sum_m E_m e^{i\theta_m}$, where θ_m are independent random variables uniformly distributed in (0,2π) then the power is proportional to the sum of the squares of E_m.

$$P_{\eta_0} = A cos^2(\psi) \sum_m \frac{(|\Gamma^{\perp}|^2)^m}{r_m^2}$$

$$P_{\varepsilon_0} = A sin^2(\psi) \sum_m \frac{\left(|\Gamma^{\parallel}|^2\right)^m}{r_m^2}$$

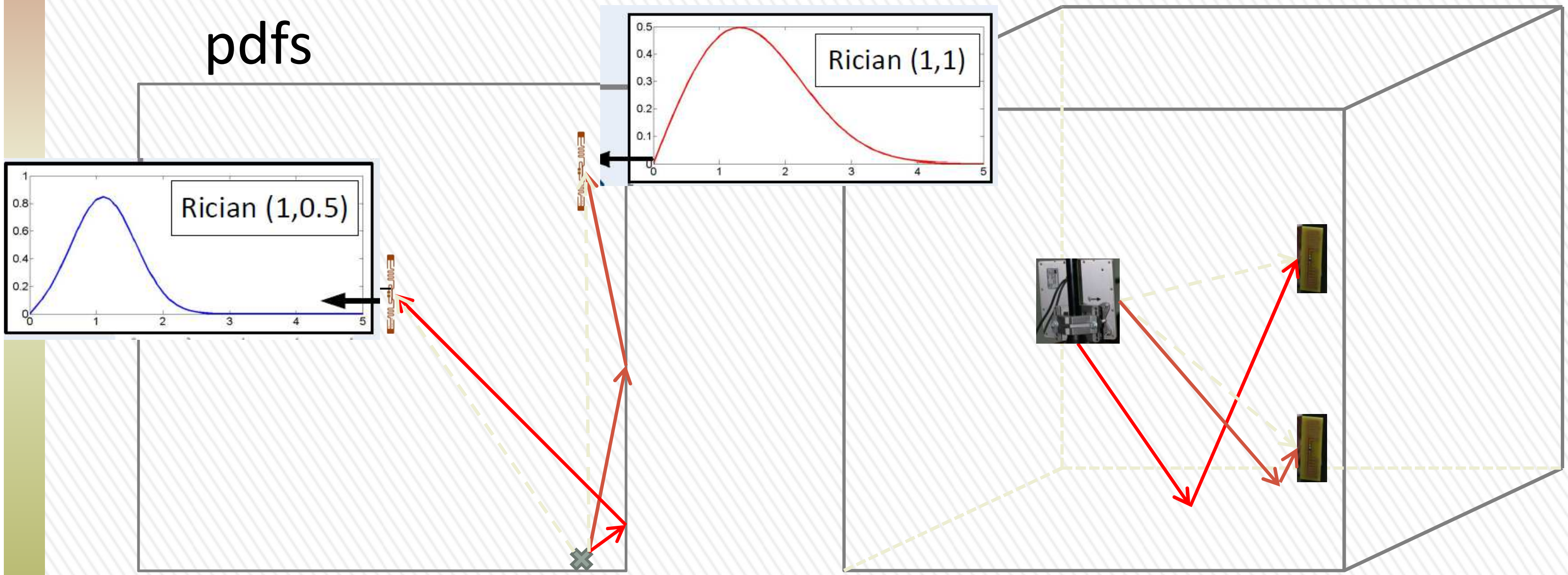


Antonis G. Dimitriou, Stavroula Siachalou, Aggelos Bletsas, and John N. Sahalos,,"A Site-Specific Stochastic Propagation Model for Passive UHF RFID," ***IEEE Antennas and Wireless Propagation Letters***, March 2014.

Antonis G. Dimitriou, Stavroula Siachalou, Aggelos Bletsas, and John N. Sahalos,, "Site-specific stochastic propagation model for automated RFID network planning," ***2013 International Conference on Electromagnetics in Advanced Applications*** (ICEAA), pp. 603-606, Torino, Italy, Sept. 2013.

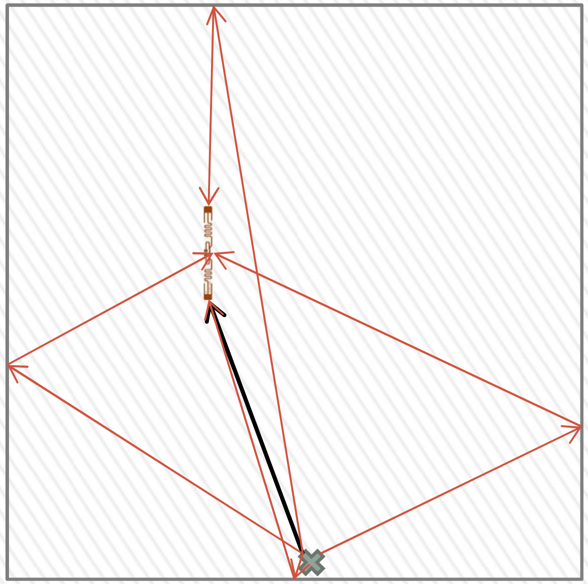
Detail of the Model

» We claim that each reception point suffers different fading; hence, we extract different pdfs



Calculation of Probability that a tag is powered up

1. Calculation of direct field v
2. Calculation of 1st order reflection coeffs on the grid
3. Application of proposed formula for the mean reflected power σ
4. Calculation of the probability

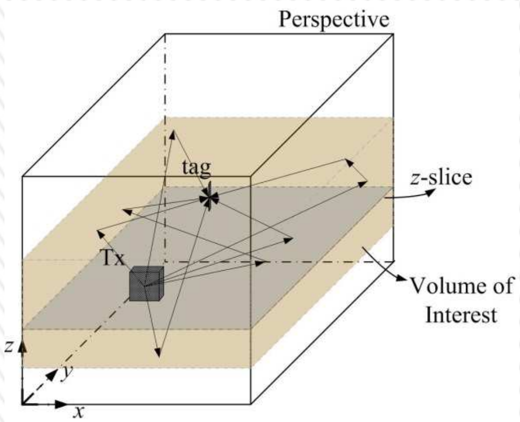


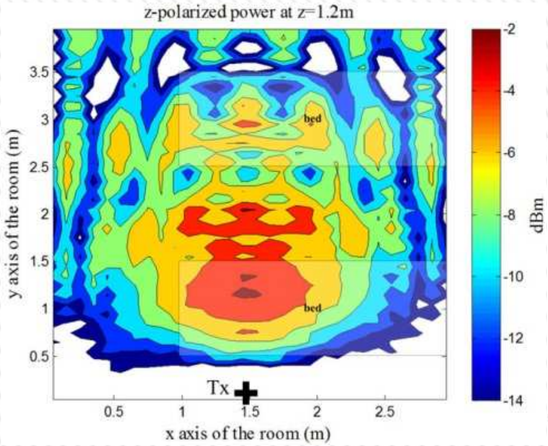
$$P(X > \gamma) = 1 - F_x(x|v, \sigma)$$

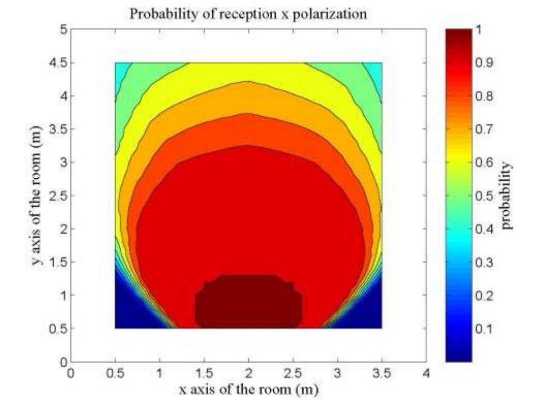
where γ is the wake-up power threshold of the tag

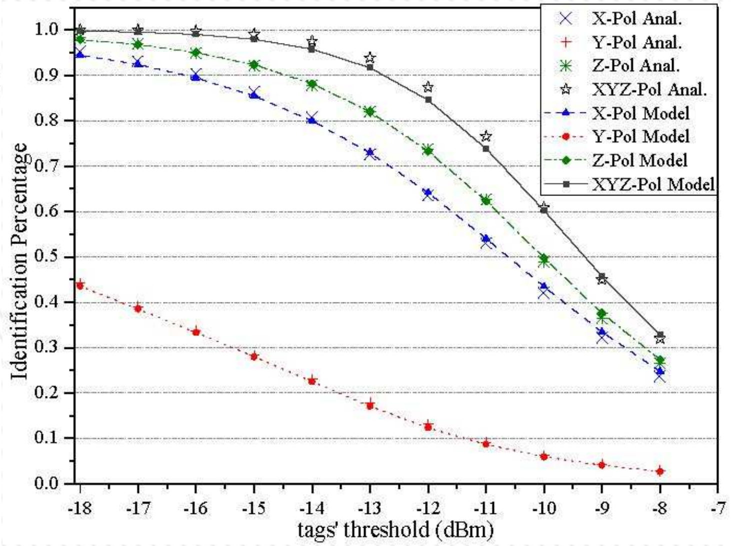
Results

Comparison with Analytical Ray-Tracing Data









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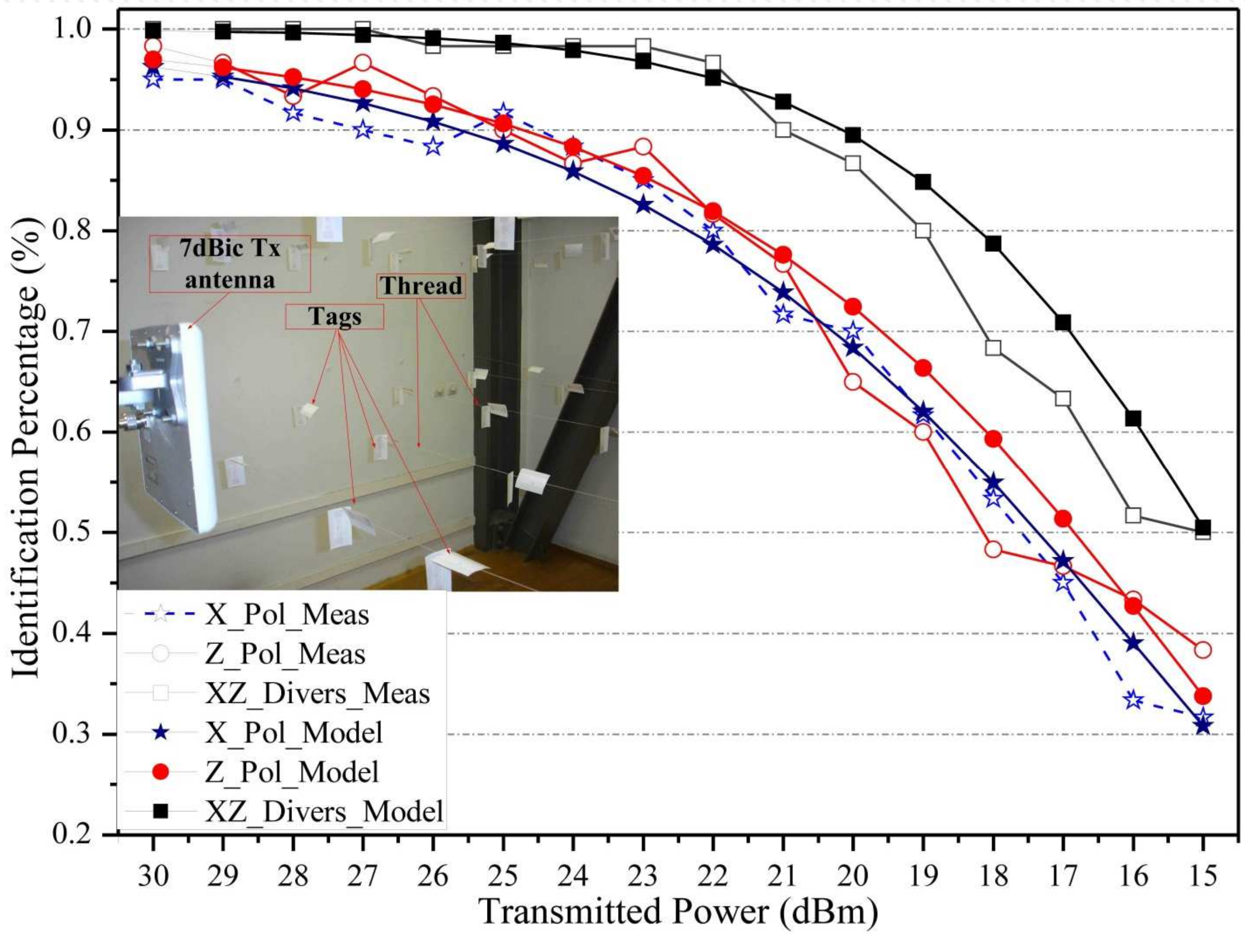
Comparison with Measurements



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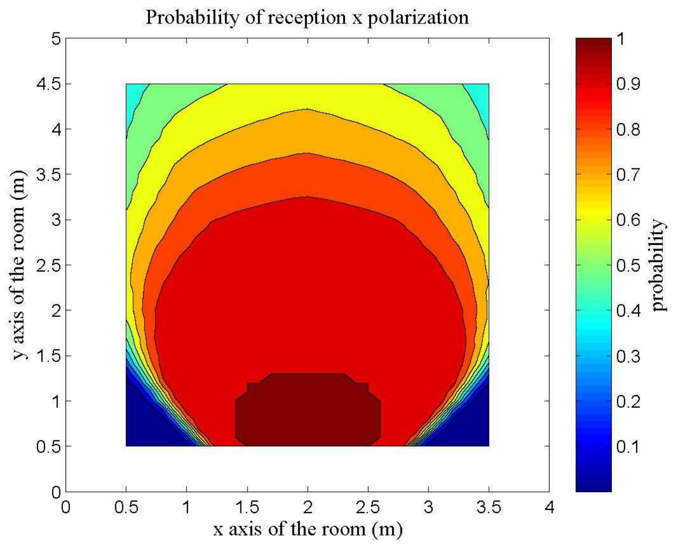
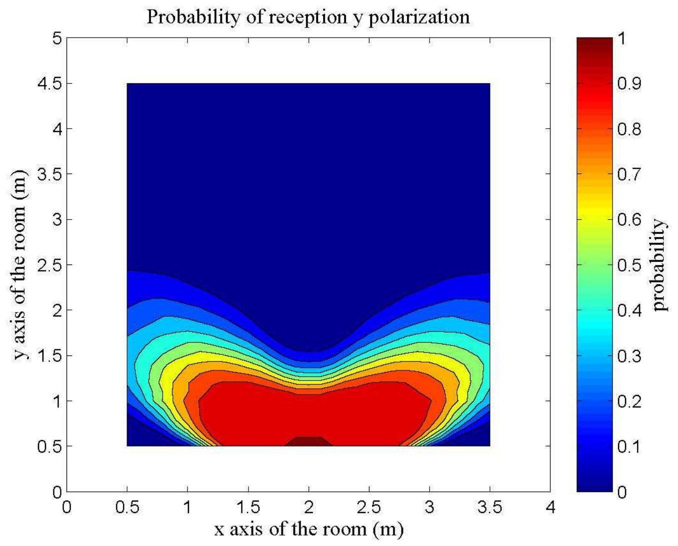
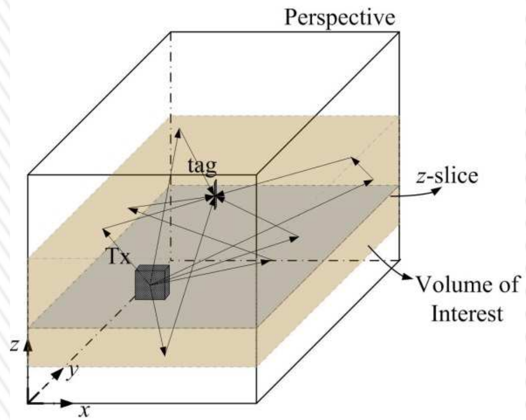
Probability results







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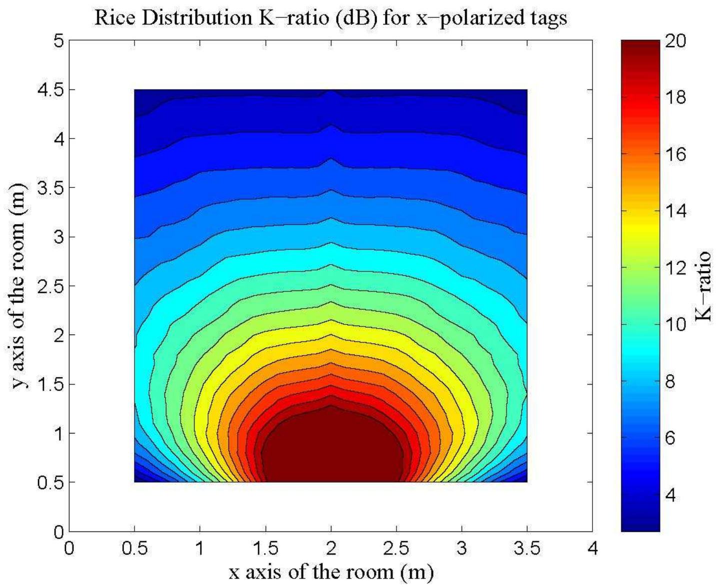
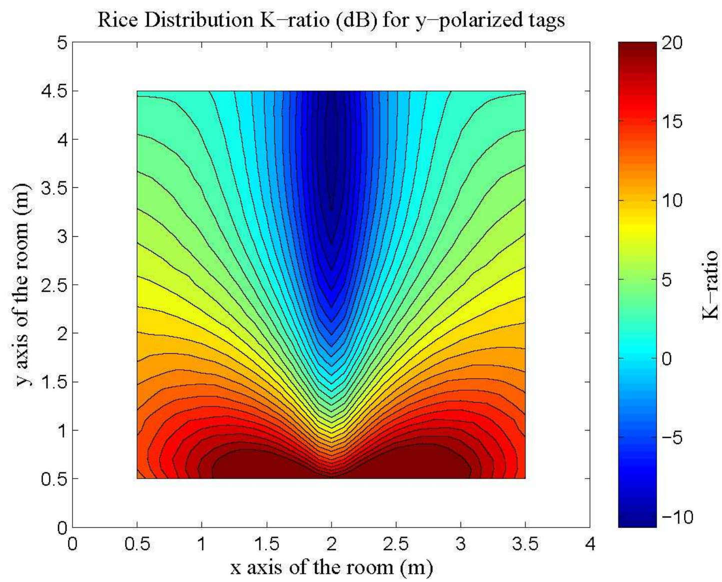
K-ratio (dB)

$$K = 10log_{10}(v^2/2\sigma^2)$$





Running Time

» Less than 6s on a laptop for 13981 calculation points

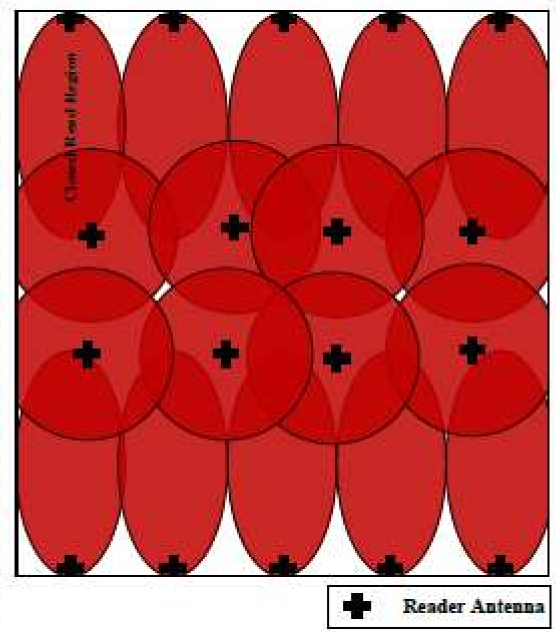
» Can be implemented in large-scale optimization problems

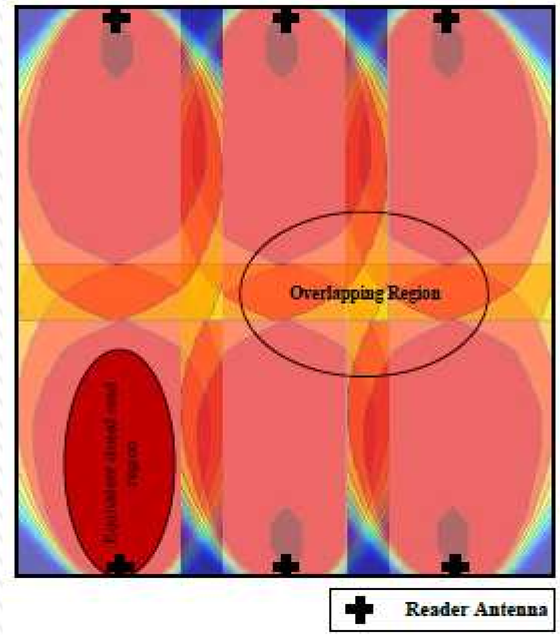
Part II – Automated Planning Algorithm

Prior Art

» Simplified Fixed Path-Loss Model

» Incapable to consider interaction between different antennas in overlapping zones





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Optimization Problem

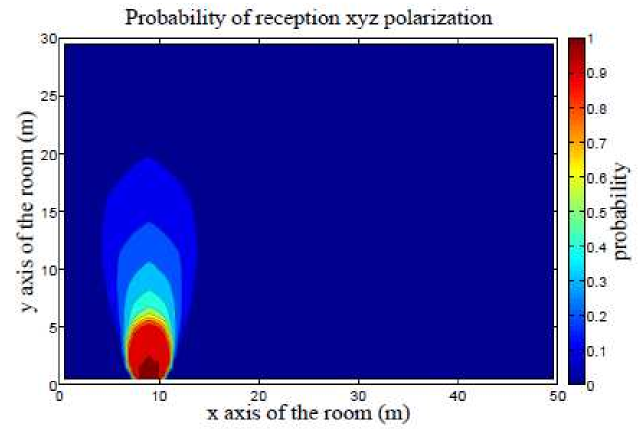
» Minimize reader-antennas

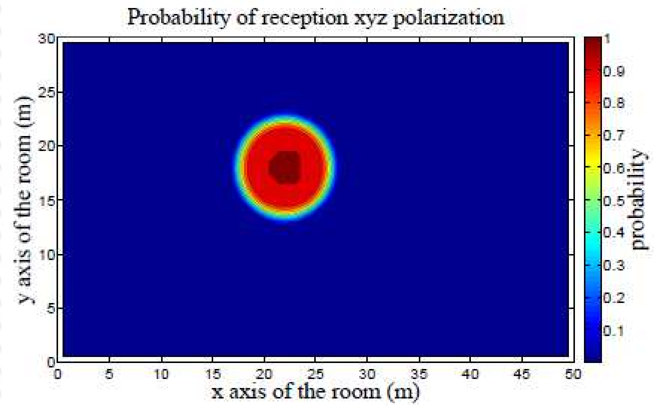
$$\min \sum_{j \in A} x_j, \text{ subject to}$$

» Each location is powered-up with desired probability

$$\sum_{i \in T} q_i = 0 \qquad q_i = \begin{cases} 1, & p_i \leq d_i \\ 0, & \text{otherwise.} \end{cases}$$

$$p_i = 1 - \prod_{j \in A} (1 - p_{ij} x_j).$$





Particle Swarm Optimization

» Each particle is a set of reader-antenna locations.

» Each particle “flies” towards its best previous “best experience” and by the overall best experience of the group.

» Particles tend to move towards a promising area.

Particle Swarm Optimization

$$Q = \sum_{i \in T} q_i.$$

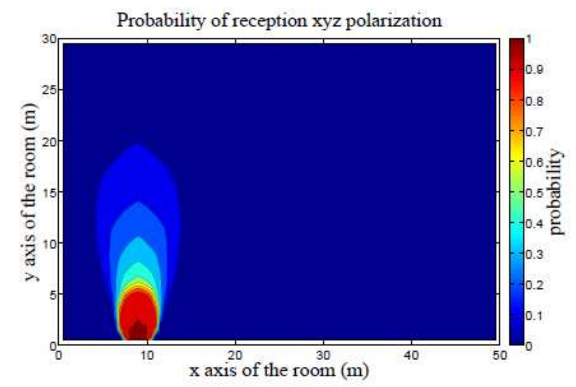
$$X(k) = \begin{bmatrix} X_{11}(k) & \cdots & X_{1L}(k) \\ \vdots & \vdots & \vdots \\ X_{K1}(k) & \cdots & X_{KL}(k) \end{bmatrix} = \begin{bmatrix} X_1(k) \\ \vdots \\ X_K(k) \end{bmatrix}$$

$$X(k+1) = X(k) + V(k),\ k \geq 0, \text{where}$$

$$V(k) = \begin{bmatrix} V_{11}(k) & \cdots & V_{1L}(k) \\ \vdots & \vdots & \vdots \\ V_{K1}(k) & \cdots & V_{KL}(k) \end{bmatrix}$$

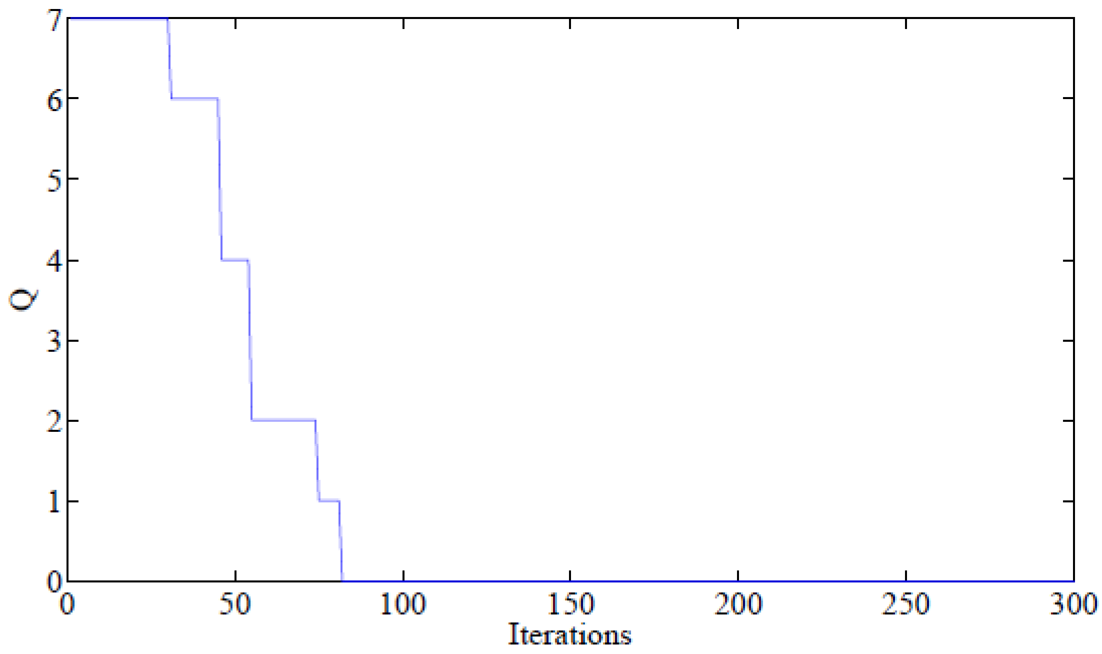
$$V_{ij}(k) = \omega \times V_{ij}(k-1) + c_1 \times rand_{ij}^1(k) \times (PB_{ij}(k) - X_{ij}(k)) + c_2 \times rand_{ij}^2(k) \times (GB_j(k) - X_{ij}(k)), \quad (15)$$

Application Example



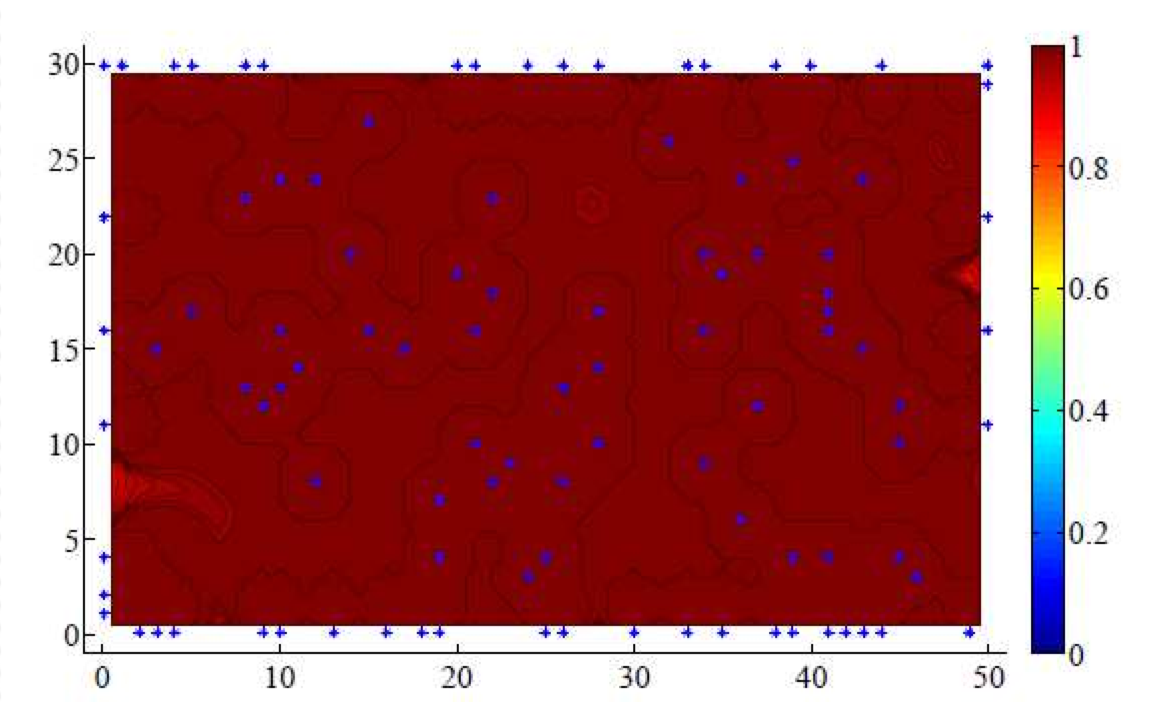
- 50m×30m building
- 7dBic antenna and a dipole antenna
- Polarization diversity
- -15dBm threshold
- 1500 candidate reader-antenna configurations
- 6000 uniformly arranged tag-locations
- Power-up probability >0.9
- 10 particles

Results



When all Rx points satisfy the quality criterion, one reader-antenna is eliminated

Retrieved Solution



The algorithm found a solution with 108 reader antennas

Comparison with Prior Art – We need power instead of probability

» Rician pdf mapping to power level

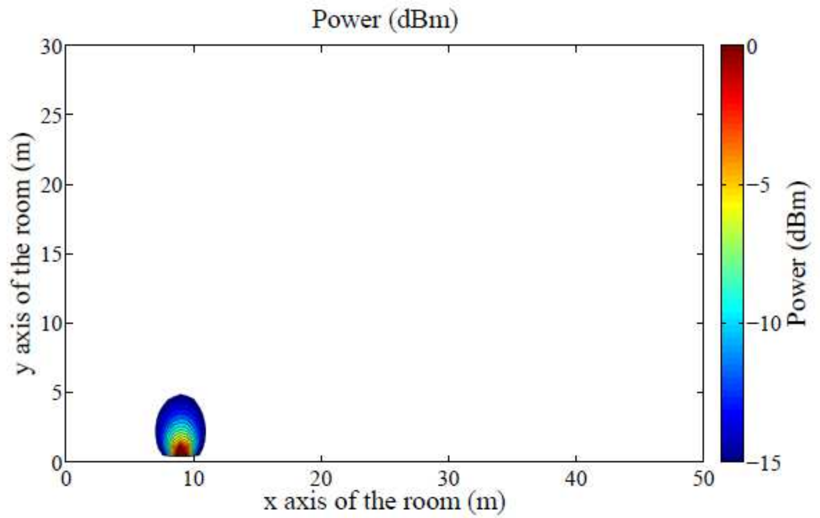
> What is the minimum received power level at each location that ensures “power-up” probability p

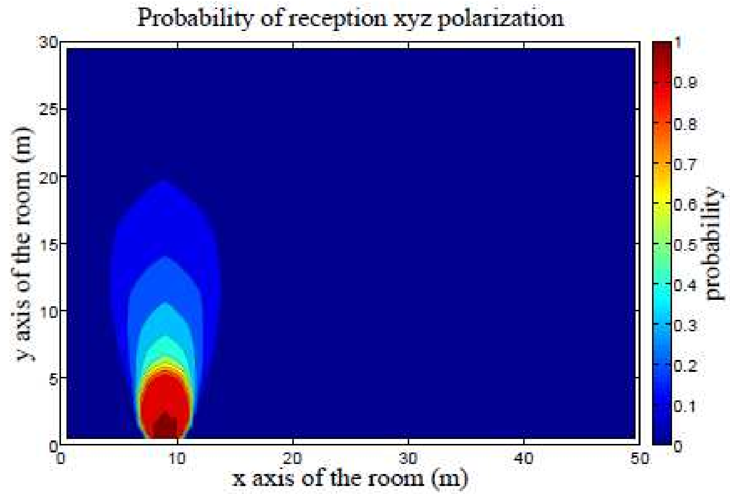
$$P(X \geq P_i) = p_i \Leftrightarrow 1 - P(X \leq P_i) = p_i \Leftrightarrow$$
$$\Leftrightarrow P(X \leq P_i) = 1 - p_i$$

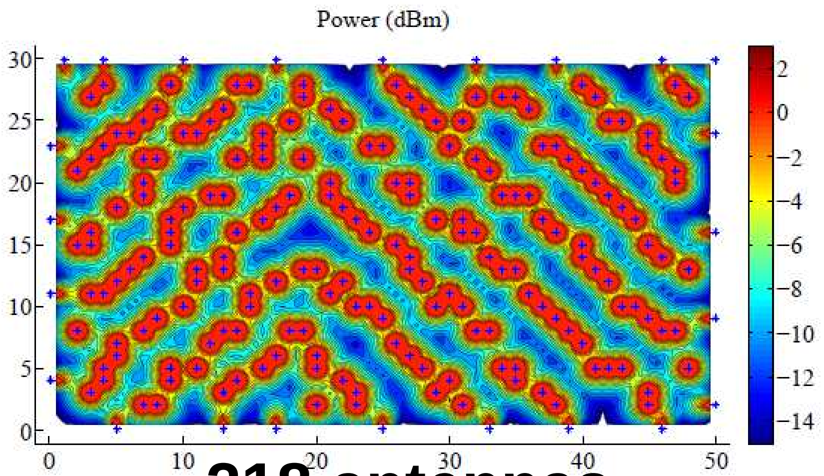
$$P_i = F_x^{-1}(1 - p_i)$$

> Successful power up of the tag for 90% of the observation-time is accomplished in the closed volume, where
Pi>-15dBm

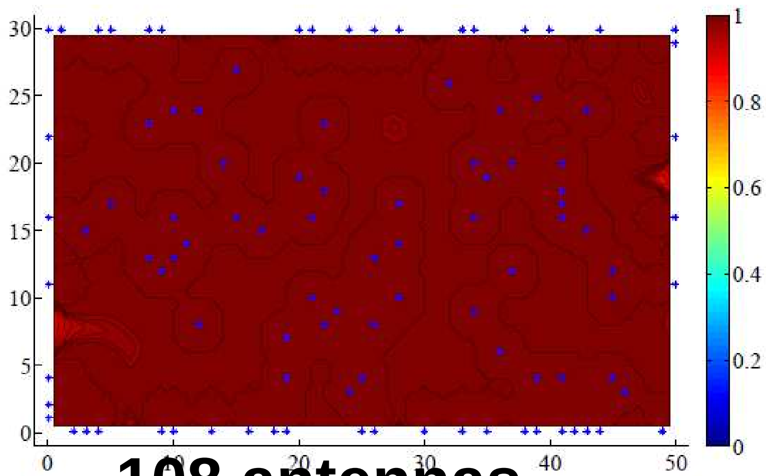
Comparison with Prior-Art







218 antennas



108 antennas

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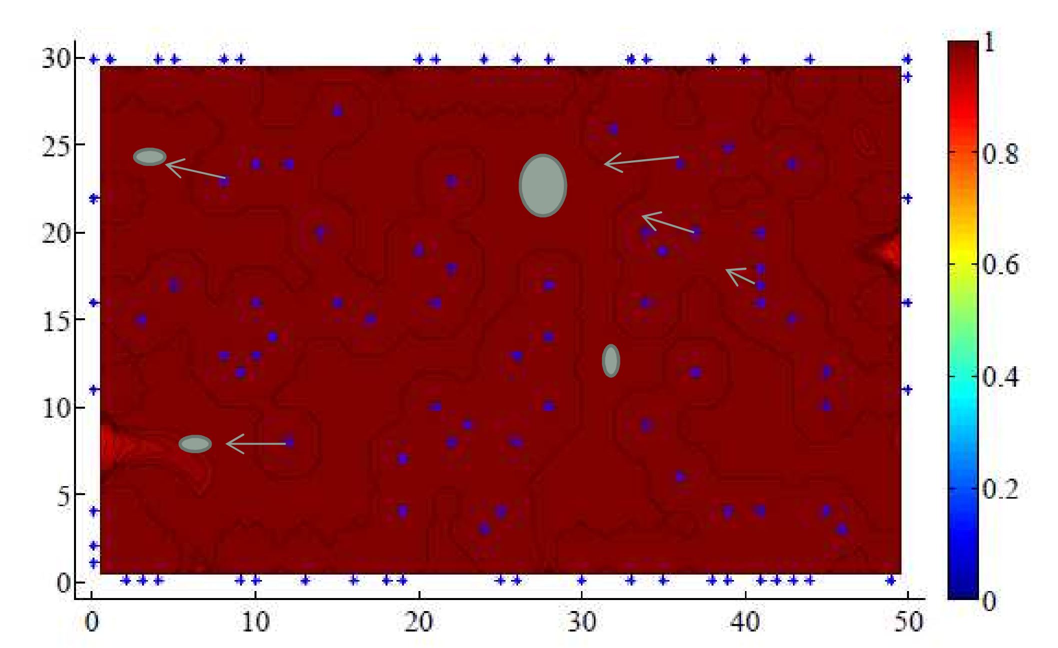
Hybrid Approach



1. K-means creates clusters of poorly powered locations
2. A new velocity vector is added to each particle forcing it to move towards these points
3. The closer one is the faster they move

$$V_{ij}(k) = \omega \times V_{ij}(k-1) + c_1 \times rand_{ij}^1(k) \times (PB_{ij}(k) - X_{ij}(k)) + c_2 \times rand_{ij}^2(k) \times (GB_j(k) - X_{ij}(k)),$$ **+ *Vij***

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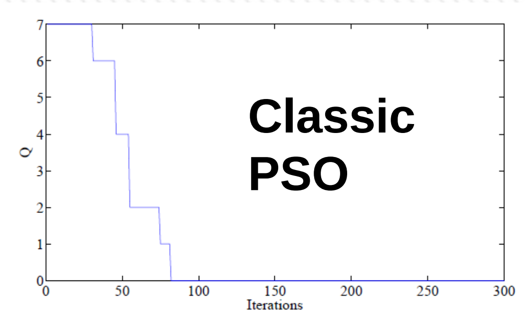
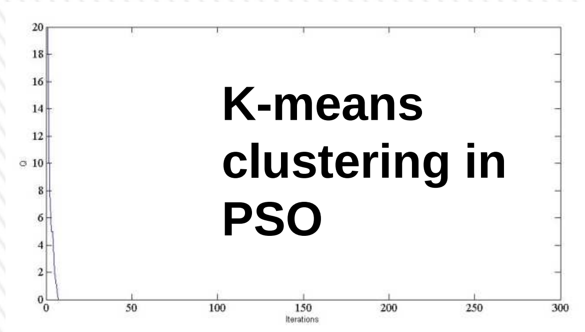
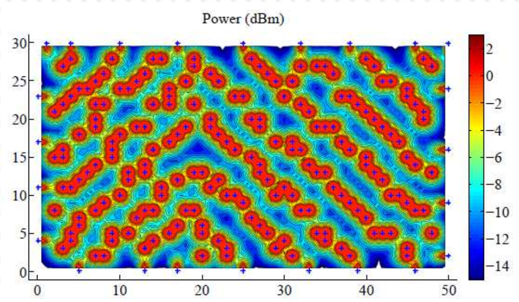
Comparison with Prior Art

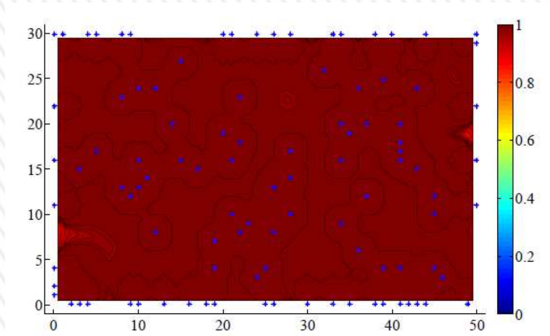
Each antenna treated separately - Classic PSO



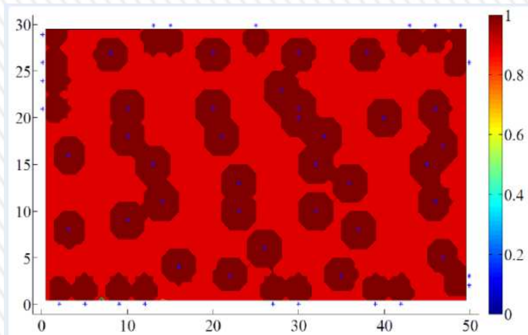




218 antennas



108 antennas



55 antennas

Concluding Key-Remarks

» Probabilistic modeling allowed for proper consideration of the combined performance of multi antenna network

» Proposed formulation and the PSO is the only one to consider the network's performance and outperforms prior-art.

» Finally, a method to reach faster and more "reasonable" planning results is developed, employing k-means clustering and PSO

Publications

1. A. G. Dimitriou, S. Siachalou, A. Bletsas, and J. N. Sahalos,, "Site-specific stochastic propagation model for automated RFID network planning," ***2013 International Conference on Electromagnetics in Advanced Applications*** (ICEAA), pp. 603-606, Torino, Italy, Sept. 2013.

2. Antonis G. Dimitriou, Stavroula Siachalou, Aggelos Bletsas, and John N. Sahalos,," A Site-Specific Stochastic Propagation Model for Passive UHF RFID," ***IEEE Antennas and Wireless Propagation Letters, March 2014***.

3. Antonis G. Dimitriou, Stavroula Siachalou, Aggelos Bletsas, and John N. Sahalos,," Automated RFID Network Planning with Site-Specific Stochastic Modeling and Particle Swarm Optimization," ***IEEE RFID TA***, September 2014.

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Propagation Modeling and Planning of Battery-less Tags Networks

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28 September 2014, Toulouse

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