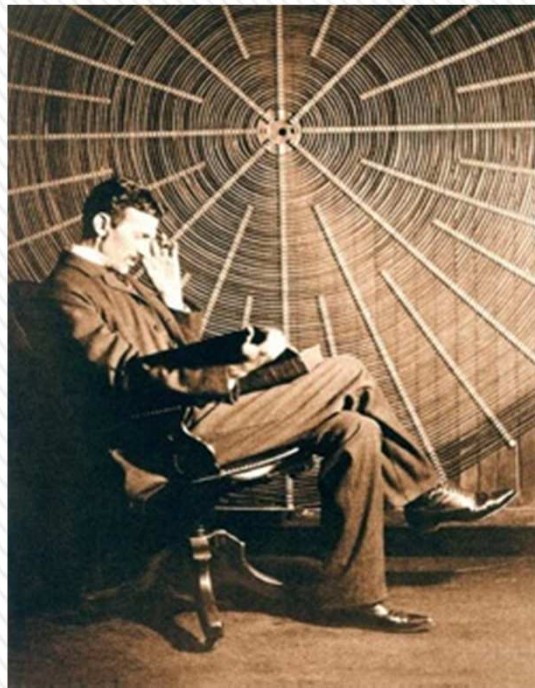




UNIVERSITY OF NICOSIA  
ΠΑΝΕΠΙΣΤΗΜΙΟ ΛΕΥΚΩΣΙΑΣ



# Propagation Modeling and Planning of Battery- less Tags Networks

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



28 September 2014, Toulouse

cost



cost  
EUROPEAN COOPERATION  
IN SCIENCE AND TECHNOLOGY



# Related Projects

- » Sensor Networks
- » RFIDs



# Blase – Precision Agriculture

The screenshot shows the website for the Blase project. The browser address bar displays `blase.tuc.gr/index.php/en/`. The website header features the Blase logo and the tagline "Backscatter Networks for Large-Scale Environmental Sensing". A navigation menu includes "BLASE PROJECT", "PUBLICATIONS & RESEARCH", "STAFF", "DEMOS", and "CONTACT". Below the menu is a row of four images: a tree with a sensor, a close-up of the sensor on a tree, a close-up of the sensor on a plant stem, and a close-up of the sensor on a tree trunk. A search bar is visible on the right side of the image row.

The diagram titled "TUC Prototype Technology: Backscatter Radio (Prof. A. Bletsas)" illustrates the system architecture. It shows a "Carrier Emitter" sending a signal to a "Plant Communicator = Switch", which is connected to a "Software Receiver". The diagram also includes a small image of a tree with a sensor attached to its trunk.

With **Prof. Bletsas** from  
Technical University of  
Crete

# Aquanet – Water Management

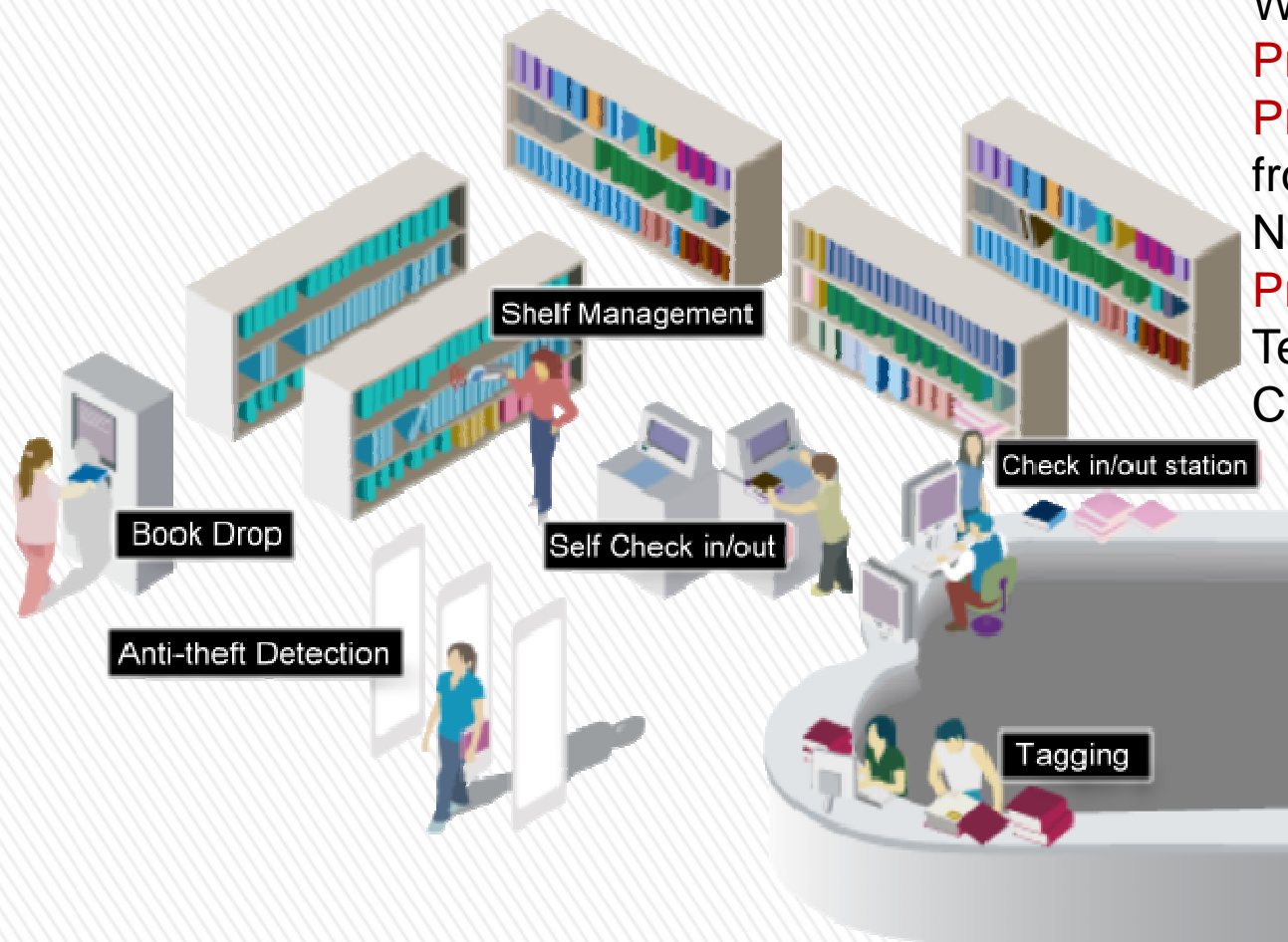
The screenshot shows the homepage of the Aquanet Project website. The browser address bar displays 'aquanet.tuc.gr'. The website has a blue header with the 'AquaNet' logo on the left and a search bar and 'Main pages' dropdown on the right. Below the header, there are links for 'Log in' and 'Register'. The main content area is titled 'Home' and contains a welcome message in both English and Greek. The English text reads: 'Welcome to Aquanet Project website. Aquanet Project aims the design and development of a smart, autonomous, self-powered and low-cost pilot wireless sensor network (WSN) for city-wide water management systems. Aquanet Project is supported by GSRT. You can find more information in English following the link below. Aquanet Project'. The Greek text reads: 'Καλωσήρθατε στην ιστοσελίδα του AquaNet Project. Το AquaNet Project σκοπεύει στη σχεδίαση και ανάπτυξη ενός έξυπνου, αυτόνομου, αυτοτροφοδοτούμενου, χαμηλού κόστους πιλοτικού ασύρματου δικτύου αισθητήρων για την διαχείριση νερού σε επίπεδο πόλης. Το AquaNet Project υποστηρίζεται από την Γενική Γραμματεία Έρευνας και Τεχνολογίας (ΓΓΕΤ), το αναπτυξιακό πρόγραμμα ΕΣΠΑ (2007-2013), και το Ευρωπαϊκό Ταμείο Περιφερειακής Ανάπτυξης. Μπορείτε να βρείτε επιπλέον πληροφορίες στα Ελληνικά, ακολουθώντας το παρακάτω σύνδεσμο. Το AquaNet Project'. Below the text are three photographs: two showing arched underground water tunnels and one showing a long, narrow underground passage with a person in the distance.

With **Prof. Bletsas** from  
Technical University of  
Crete

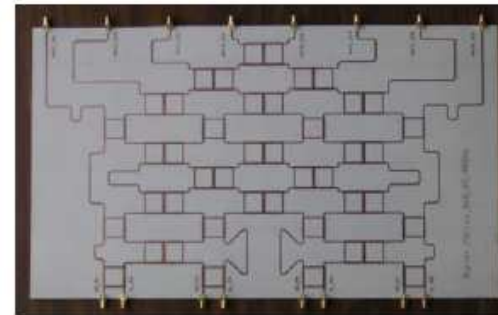
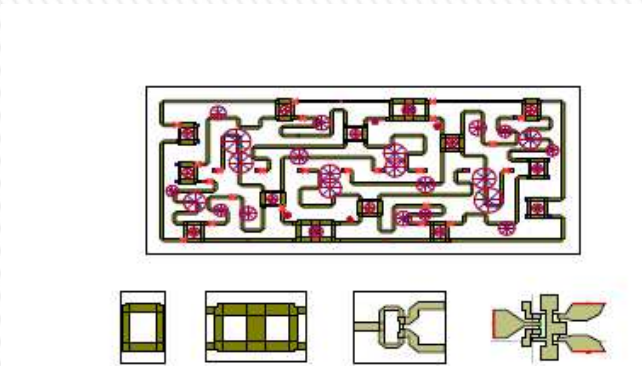


# Intelligent Library Management System Using RFIDs

With  
**Prof. Sahalos** and  
**Prof Polycarpou**  
from the University of  
Nicosia and  
**Prof. Bletsas** from  
Technical University of  
Crete



# Development of RF/RFID systems for COntrol and REgistration of goods and personnel



With  
**Prof. Sahalos** and  
**Prof Polycarpou**  
from the University of  
Nicosia and  
**Prof. Bletsas** from  
Technical University of  
Crete




# RFID in Healthcare



**Patients**

**Patient Data**



Name: John  
Surname: Oracles  
Age: 59  
Birth: 11/21/1949  
Gender: Male  
Illness: \*\*\*\*\*  
Check-in: 3/8/2009

**Tools**

August, 2009

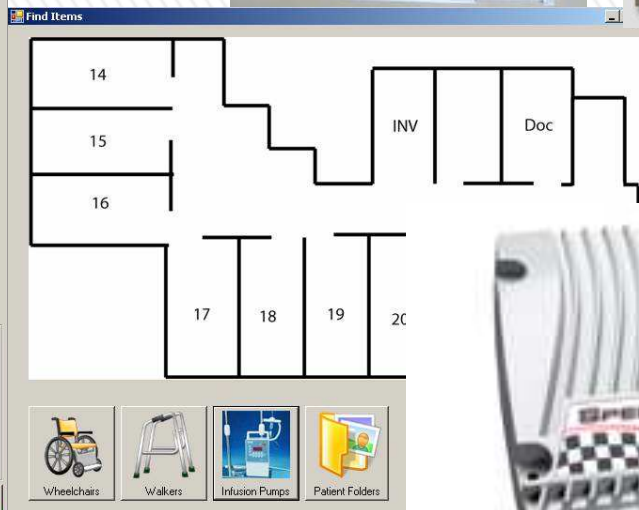
26	27	28	29	30	31	1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

Today: 8/8/2009

Temperature & Pressure

**Tasks**

No	Drug	By	Amount	Date	User
<input type="checkbox"/> 6	Cefuroxime 500mg tabs	BM	500	NOT	NOT
<input type="checkbox"/> 7	Cefuroxime 500mg tabs	BM	500	NOT	NOT



# Outline – Propagation & Planning

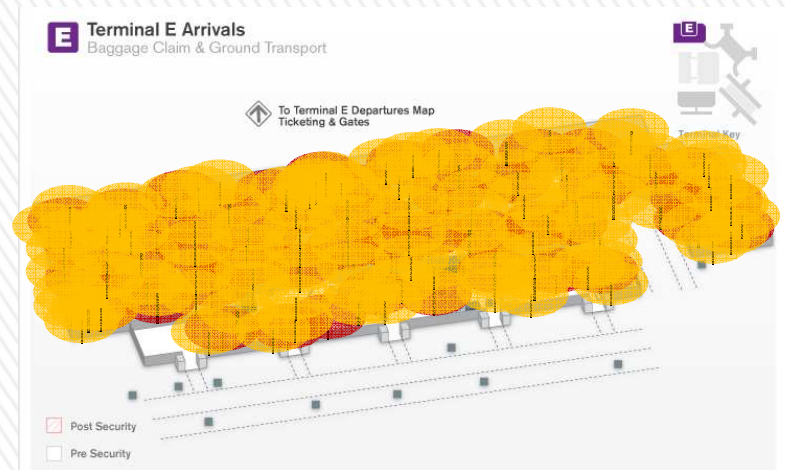
- » Objective – Prior Art
- » Key Points / Innovations
- » Analytical Presentation
  - > Part I:
    - + Propagation Model
    - + Evaluation and Results
  - > Part II
    - + Automated Planning Model
    - + Evaluation and Results
- » Conclusions





# Objective

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

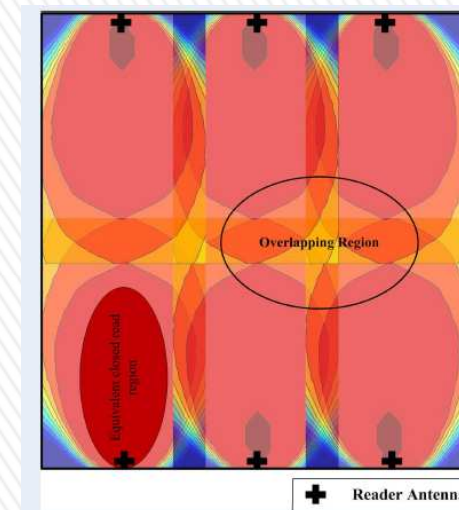
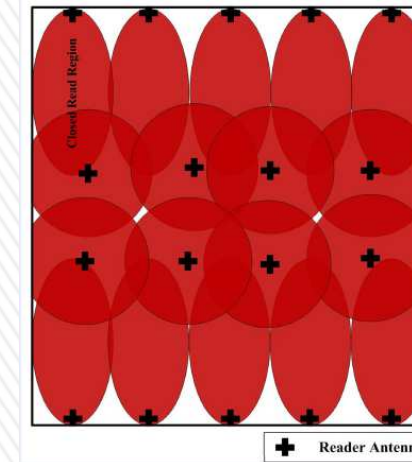


# **Presentation of Key Points / Innovations**



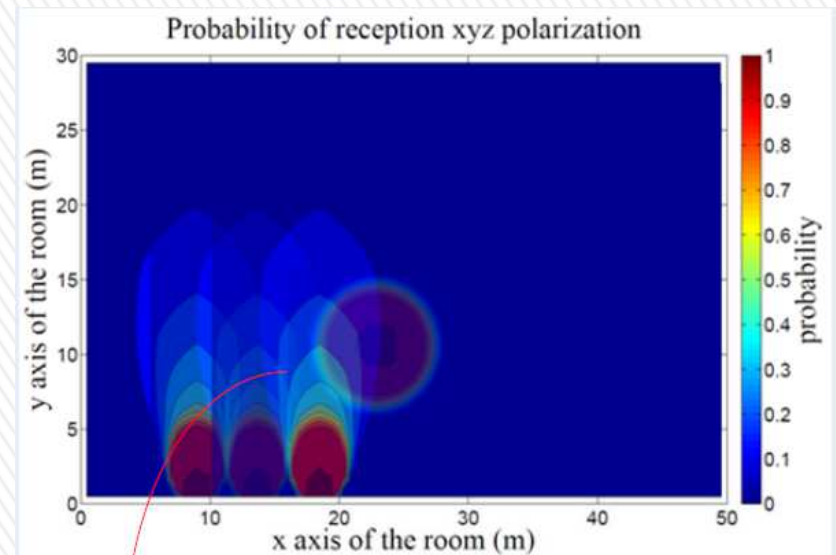
# Presentation of Key Points (1/3)

- » 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**



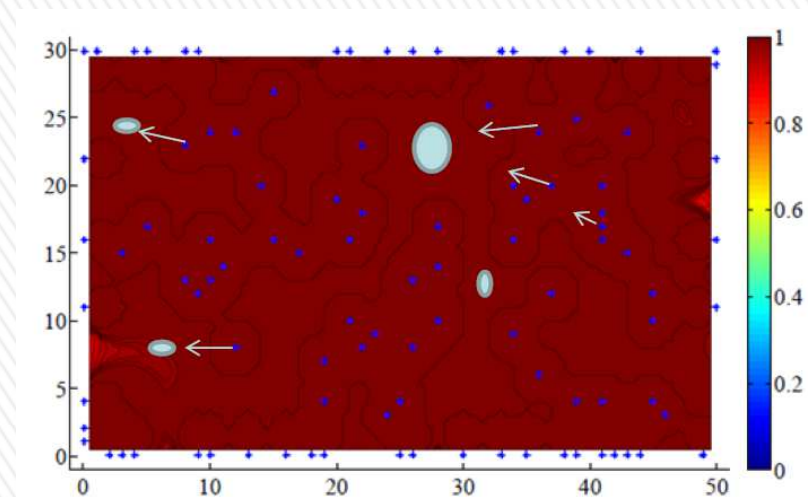
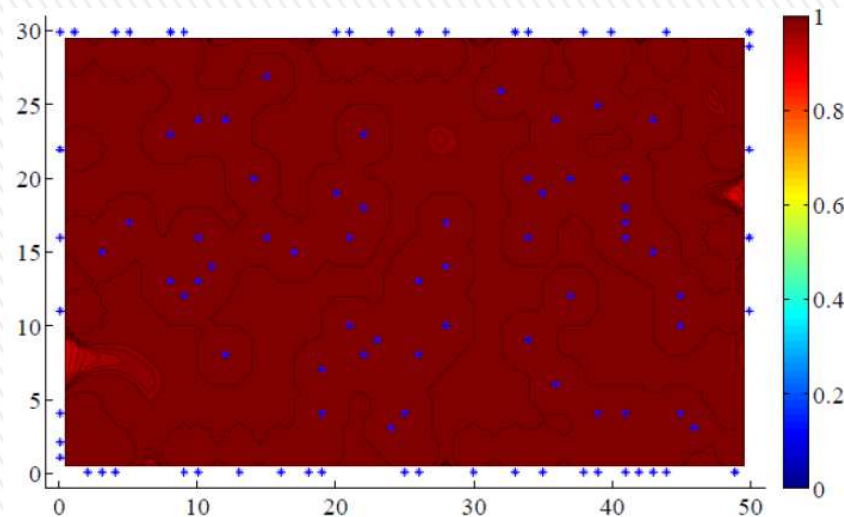
$$p_i = 1 - \prod_{j \in A} (1 - p_{ij} x_j)$$



# Presentation of Key Points (3/3)

## » Particle Swarm Optimization

- > Typical Algorithm
- > Hybrid Approach (Clustering)



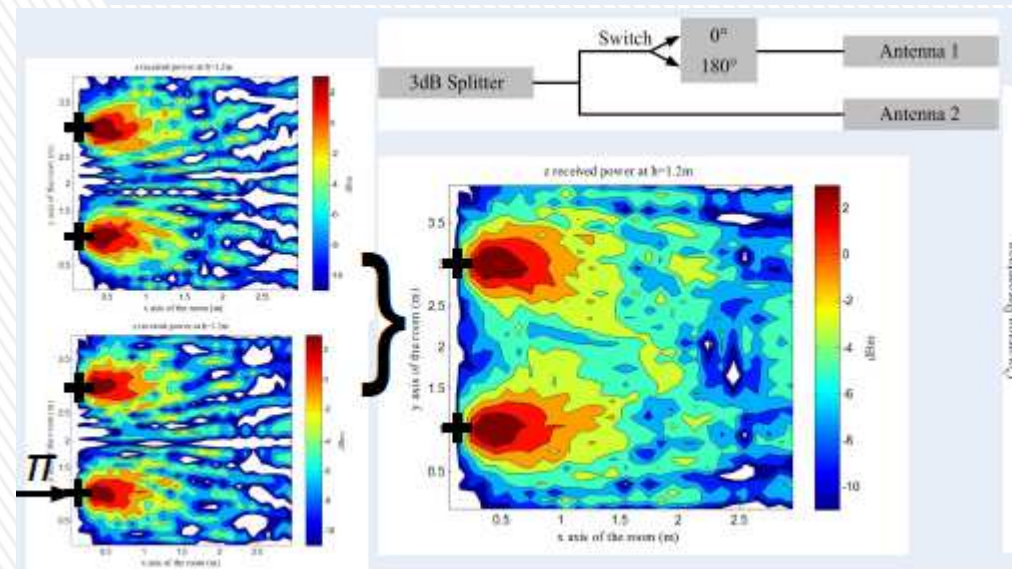
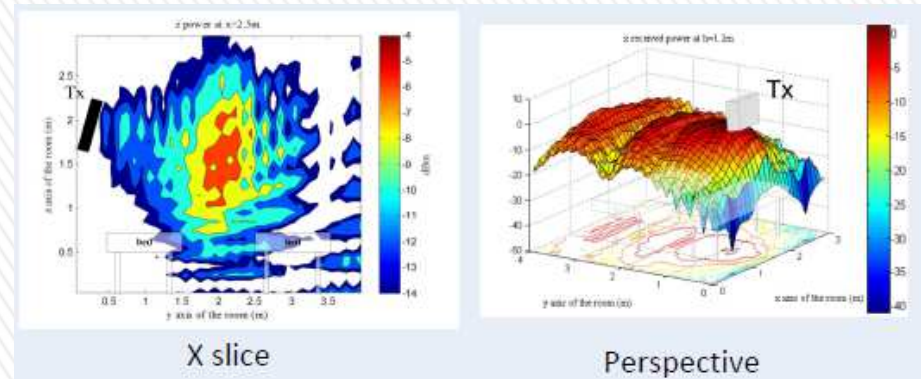
# Part I – Probabilistic Propagation

## 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

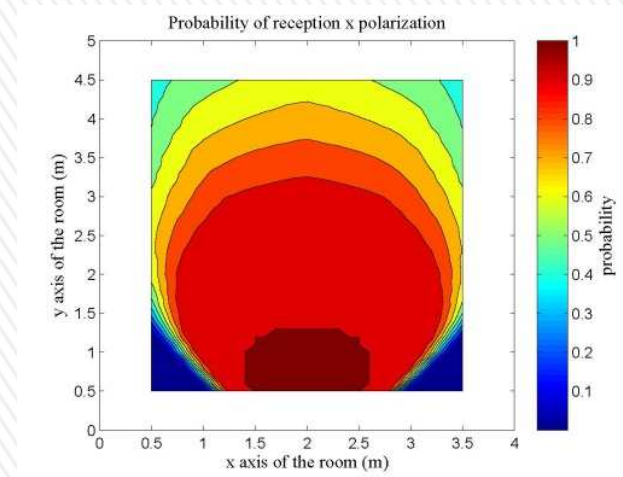
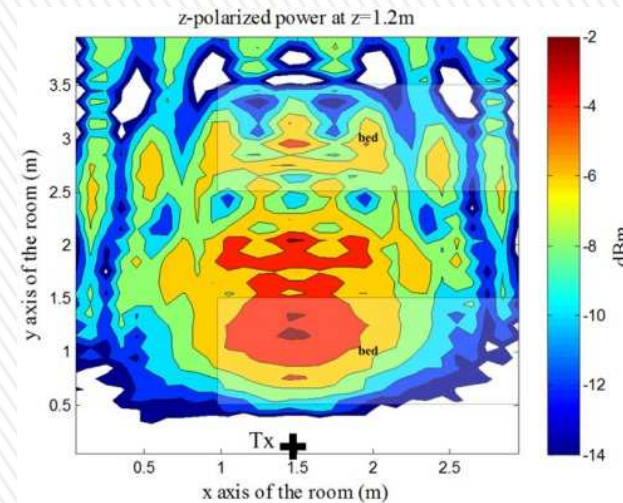


Antonis G. Dimitriou, Aggelos Bletsas, and John N. Sahalos, "Room Coverage Improvements of UHF RFID with Commodity Hardware," IEEE Antennas and Propagation Magazine, vol. 53, no. 1, February 2011.

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**”?

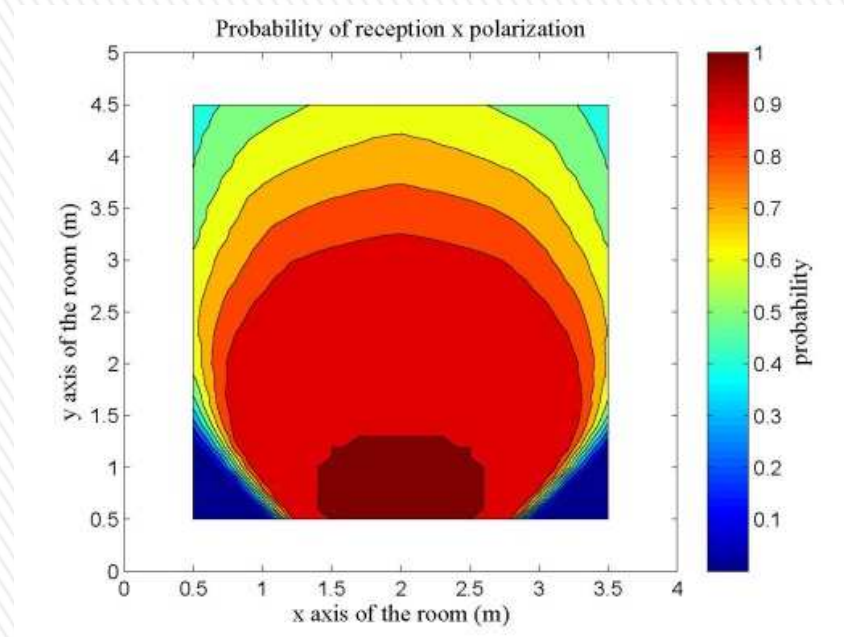




# Probabilistic Model - Goals

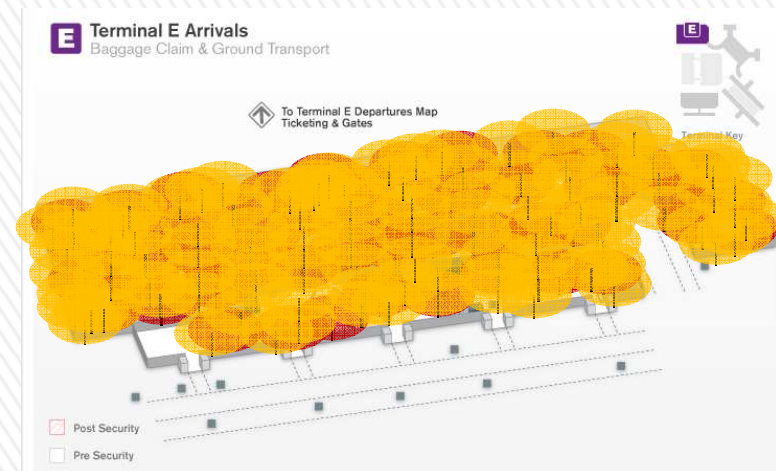
## » Site Specific Propagation Model for Passive Tags

- > Space geometry
- > Materials
- > Polarization
- > Antennas



# 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  $\sim 35\text{dBm}$
- Battery-less tag needs  $\sim -18\text{dBm}$
- 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

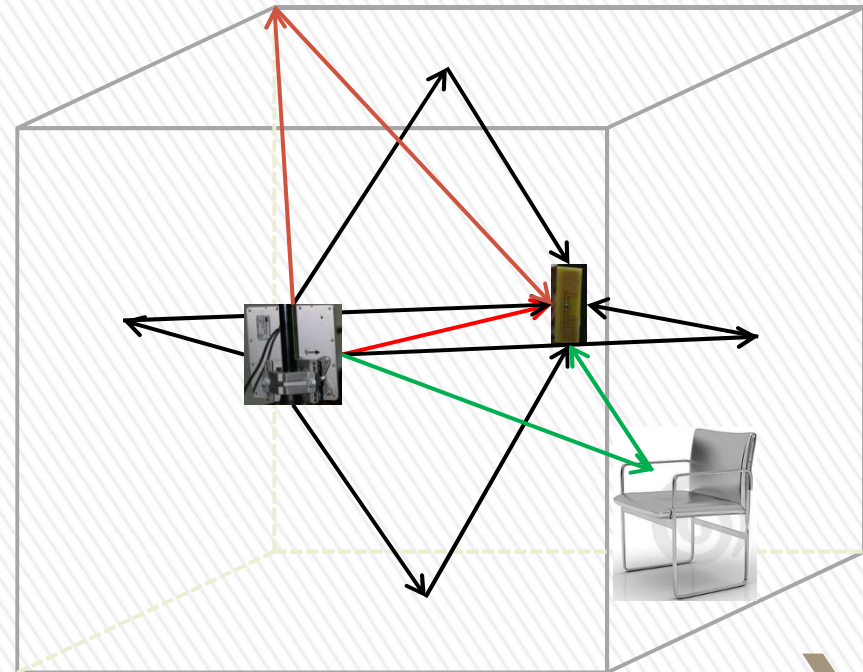


# Propagation inside a room

- » 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: 
$$f(x|v, \sigma) = \frac{x}{\sigma^2} e^{\left[ \frac{-(x^2+v^2)}{2\sigma^2} \right]} I_0 \left( \frac{xv}{\sigma^2} \right)$$

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

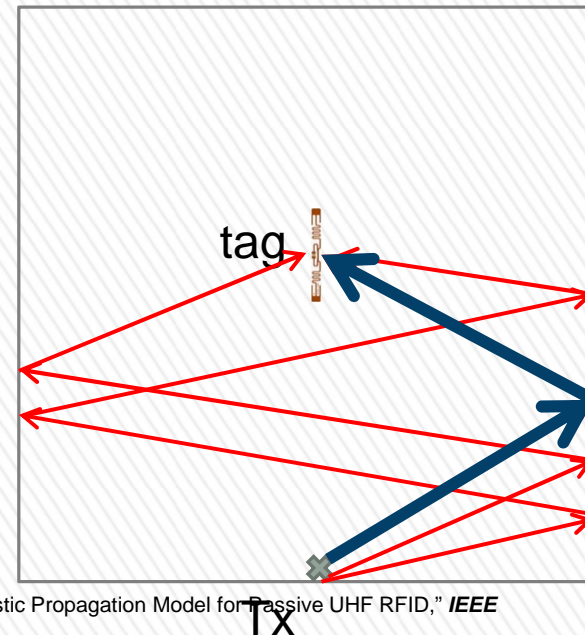


# Rays Clustering

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

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

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



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.

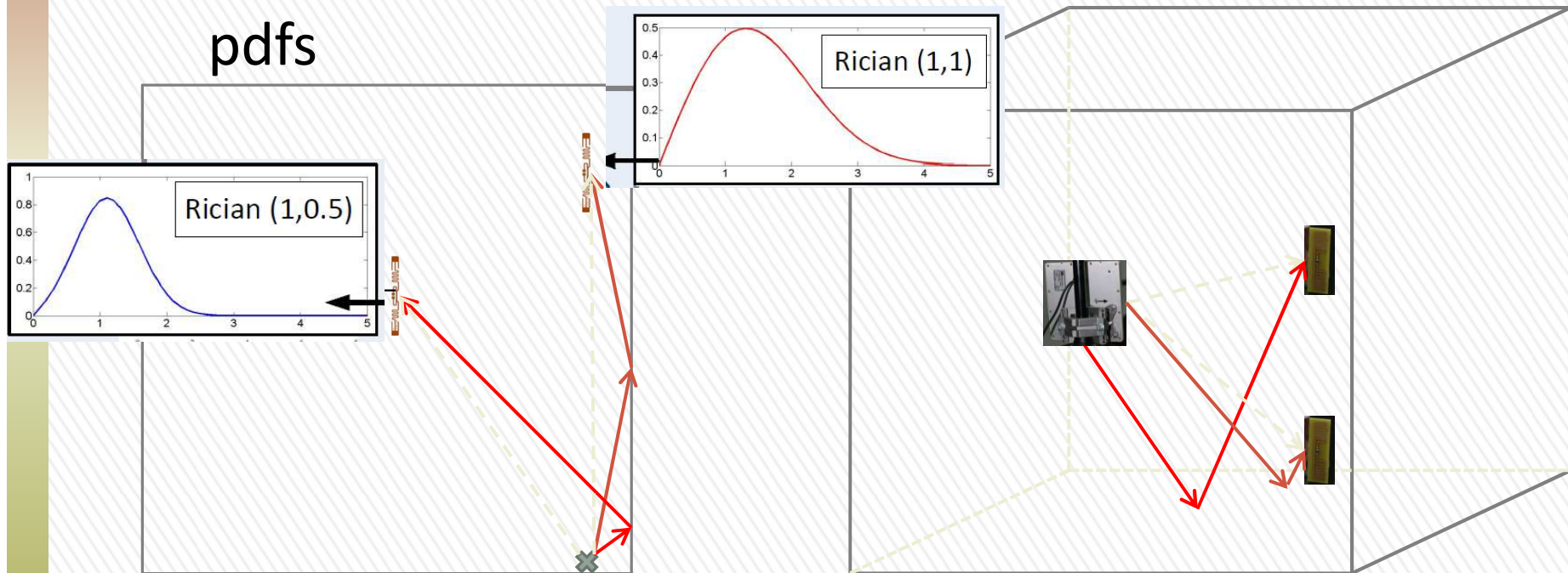
Antonis G. Dimitriou, Stavroula Siachalou, Aggelos Bletsas, and John N. Sahalos, "Site-specific stochastic propagation model for automated RFID network planning," *2013 International Conference on Electromagnetics in Advanced Applications (ICEAA)*, pp. 603-606, Torino, Italy, Sept. 2013.

24/46



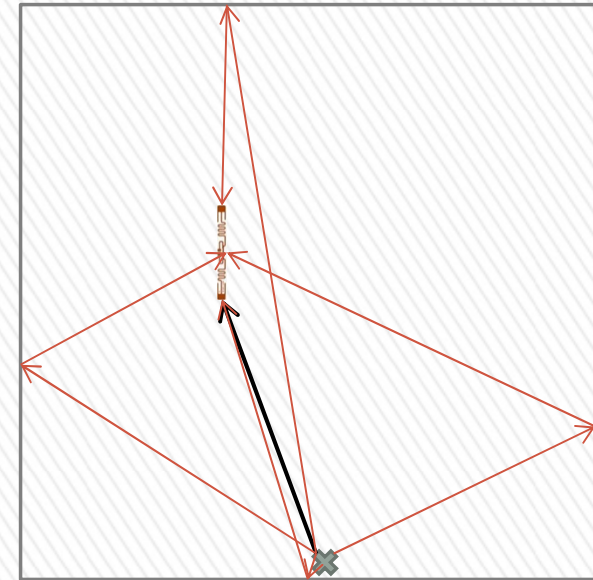
# Detail of the Model

- » 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 1<sup>st</sup> order reflection coeffs on the grid
3. Application of proposed formula for the mean reflected power  $\sigma$
4. Calculation of the probability



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

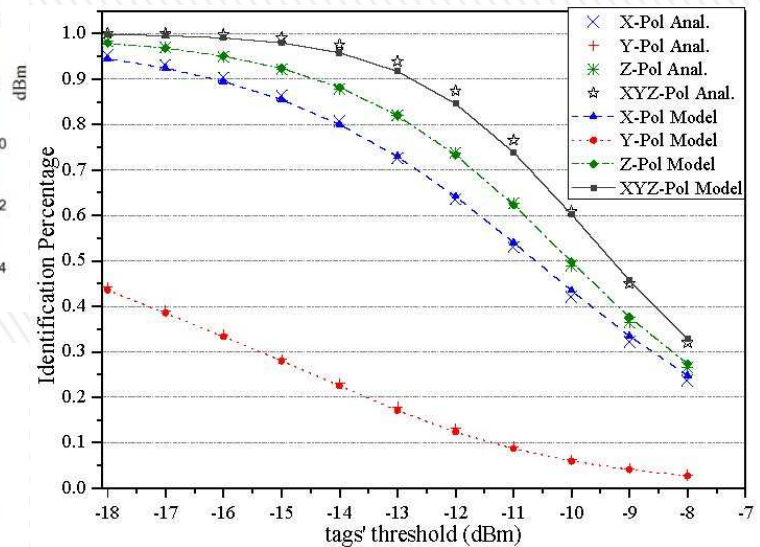
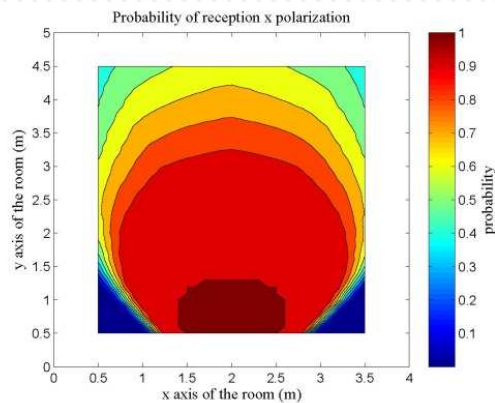
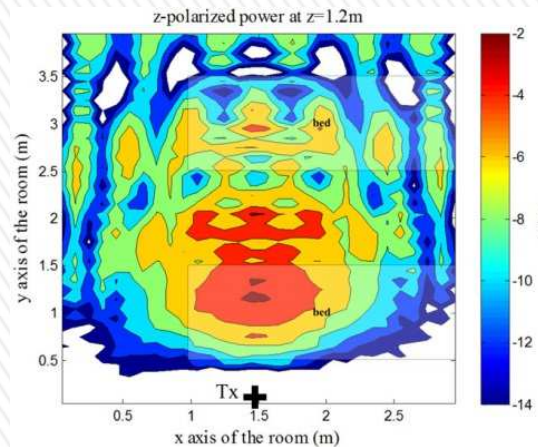
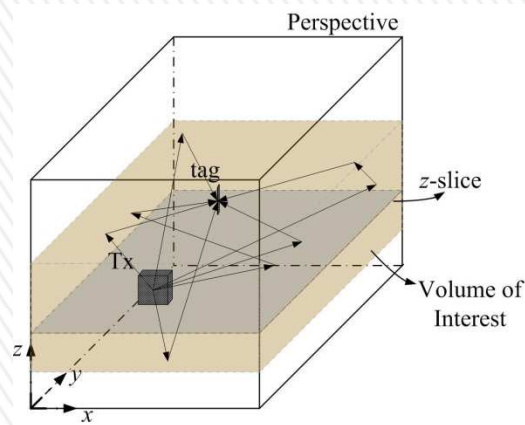
where  $\gamma$  is the wake-up power threshold of the tag



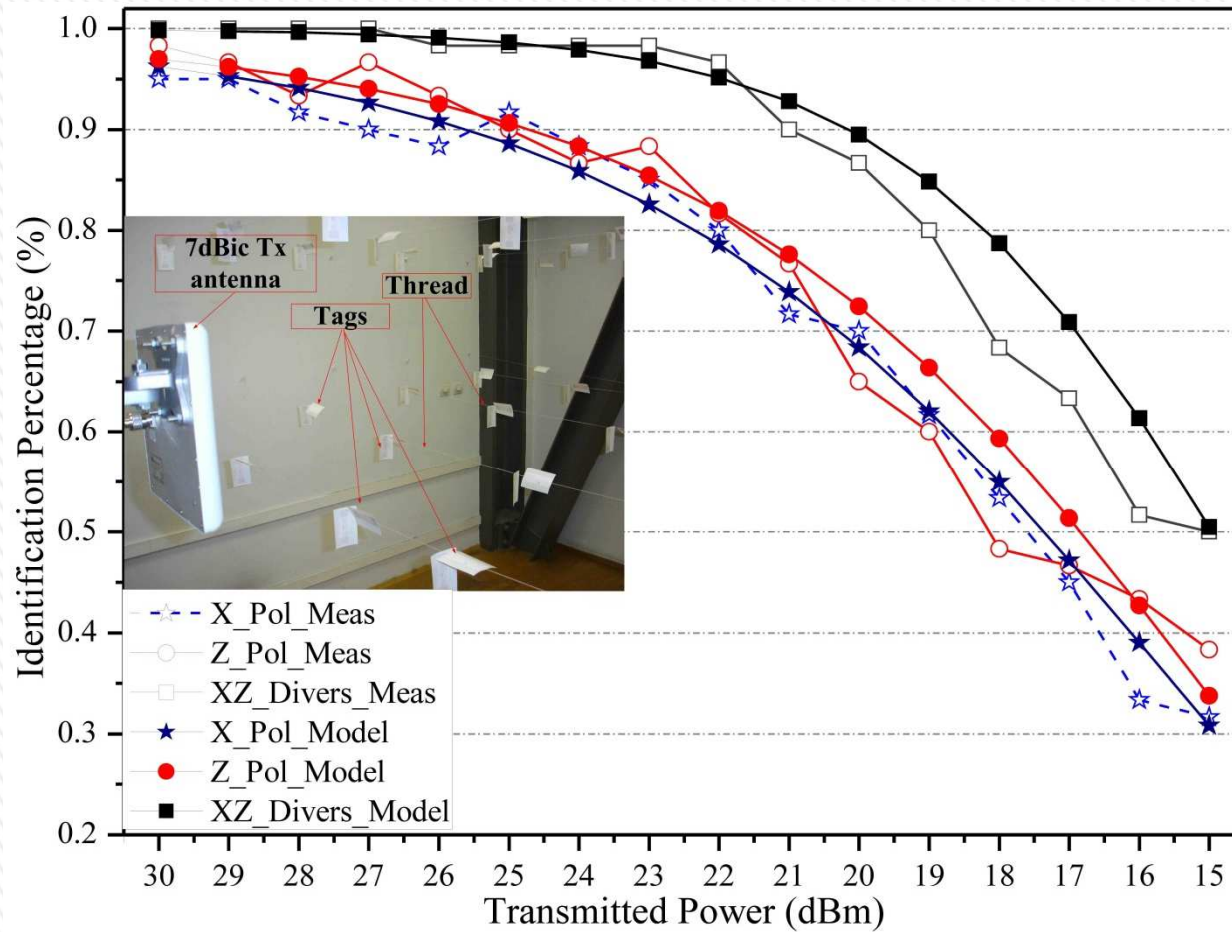
# Results



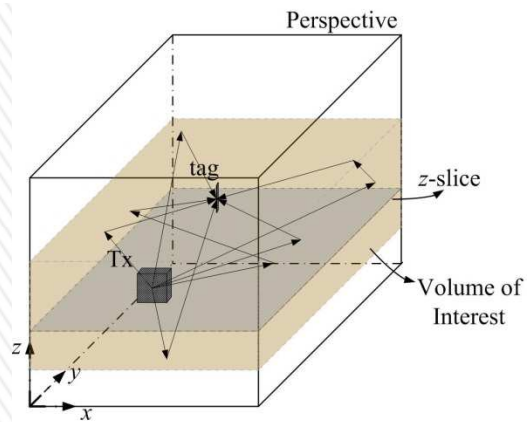
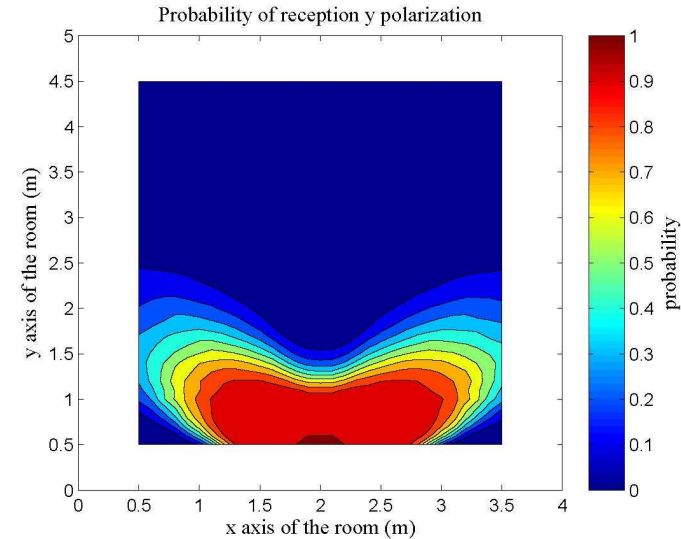
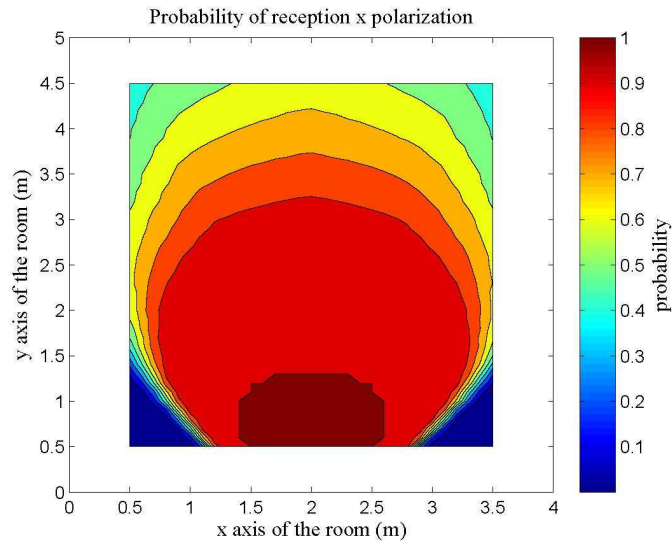
# Comparison with Analytical Ray-Tracing Data



# Comparison with Measurements

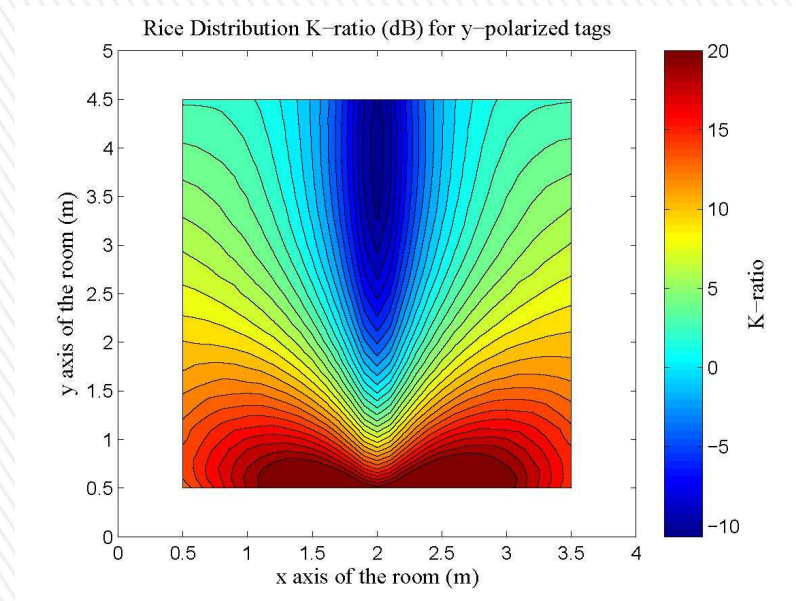
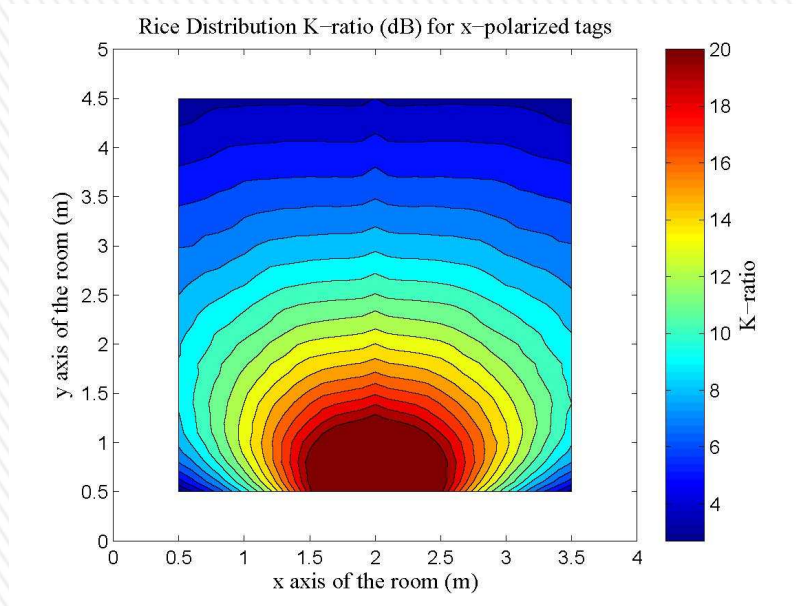


# Probability results



# K-ratio (dB)

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



# Running Time

- » Less than 6s on a laptop for 13981 calculation points
- » Can be implemented in large-scale optimization problems





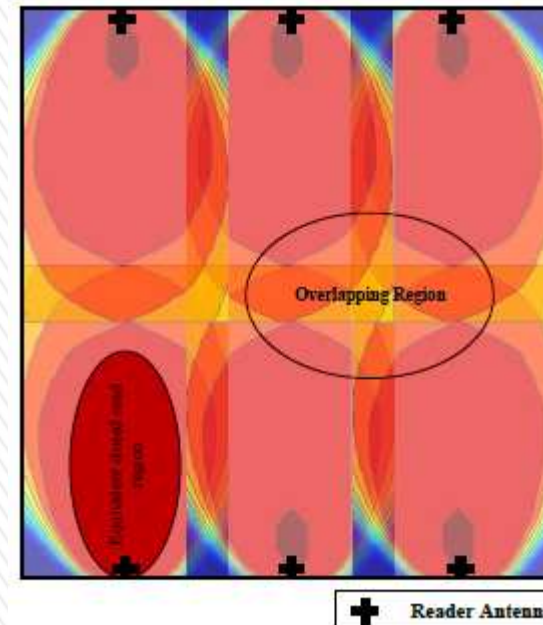
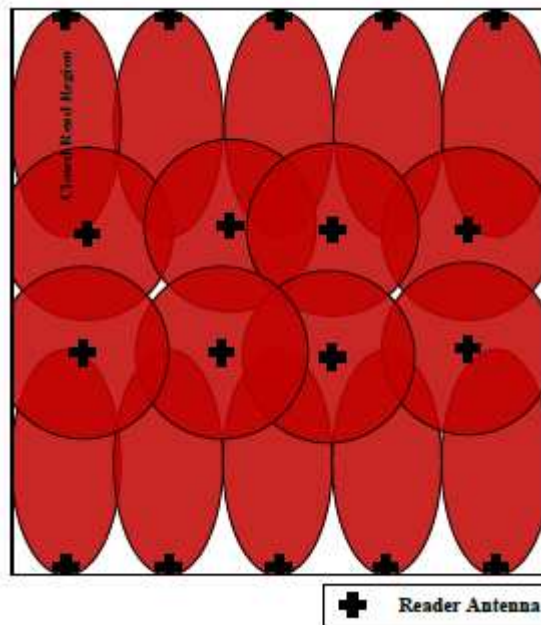
# Part II – Automated Planning

## Algorithm



# Prior Art

- » Simplified Fixed Path-Loss Model
- » Incapable to consider interaction between different antennas in overlapping zones



# Optimization Problem

» Minimize reader-antennas

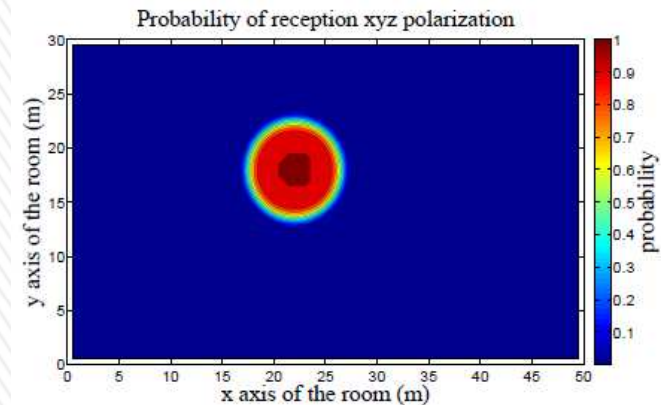
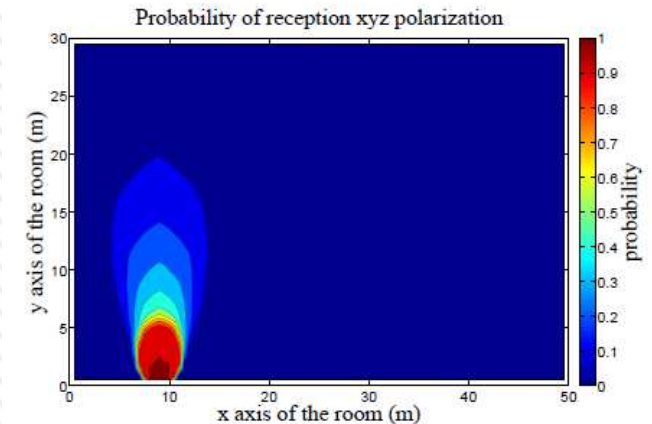
$$\min \sum_{j \in A} x_j, \text{ subject to}$$

» Each location is powered-up with desired probability

$$\sum_{i \in T} q_i = 0$$

$$q_i = \begin{cases} 1, & p_i \leq d_i \\ 0, & \text{otherwise.} \end{cases}$$

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



# 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

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

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

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

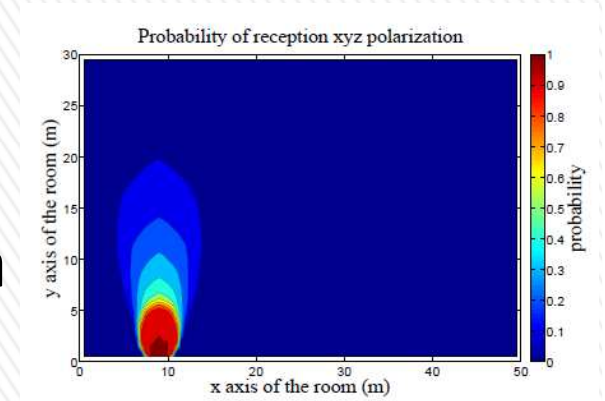
$$V(k) = \begin{bmatrix} V_{11}(k) & \cdots & V_{1L}(k) \\ \vdots & \vdots & \vdots \\ V_{K1}(k) & \cdots & V_{KL}(k) \end{bmatrix}$$

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

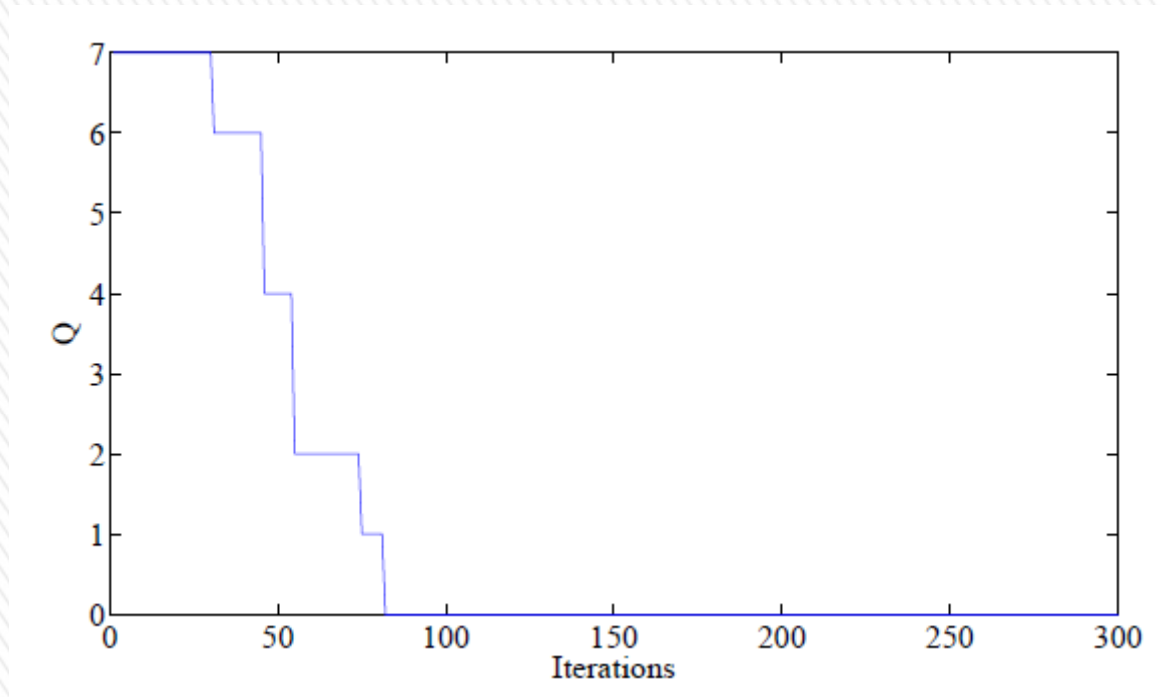


# Application Example

- » 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



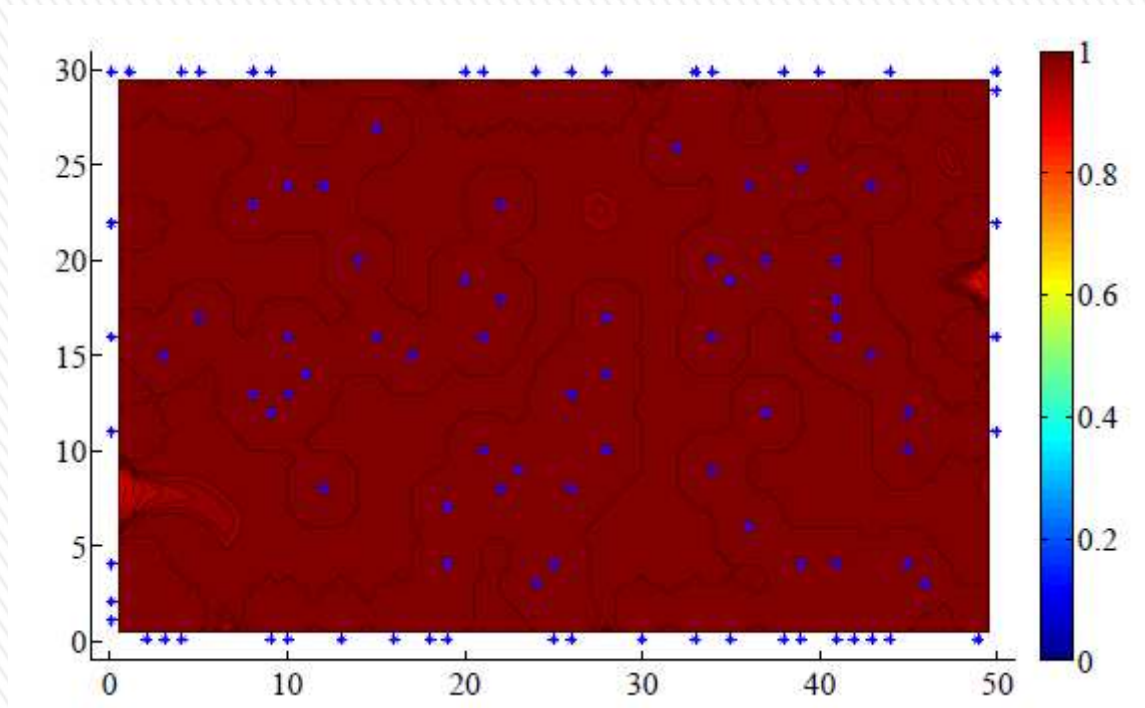
# Results



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  $p$

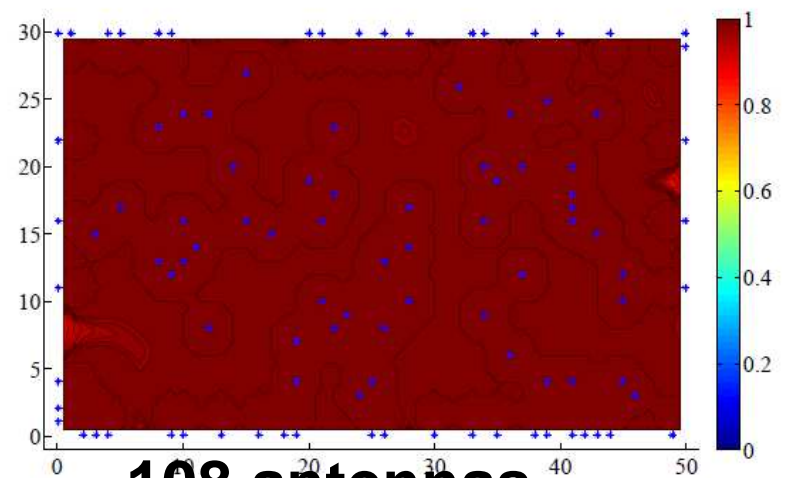
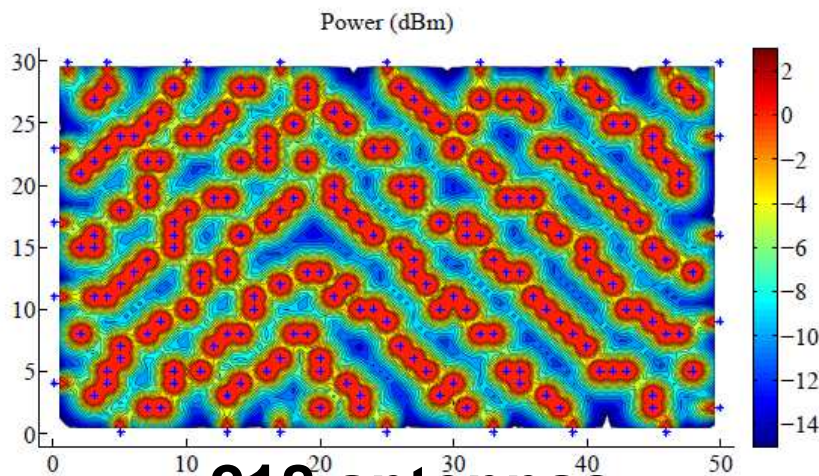
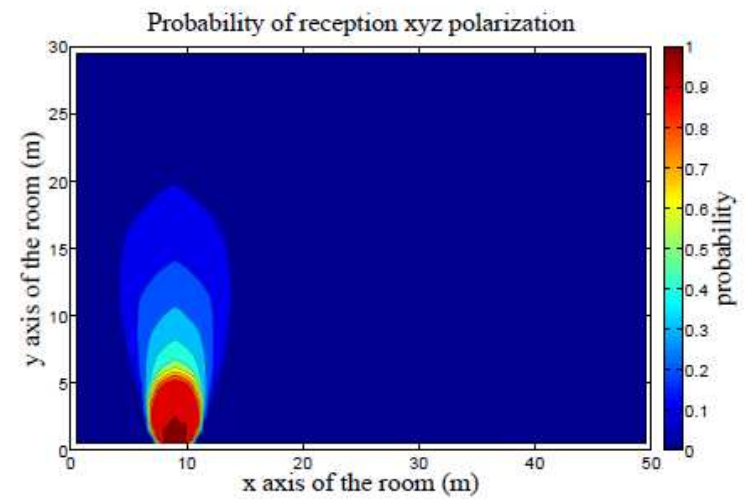
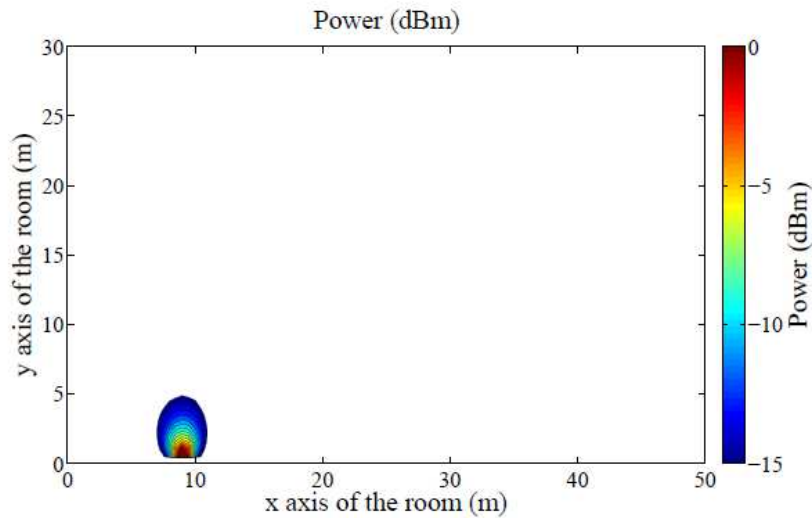
$$P(X \geq P_i) = p_i \Leftrightarrow 1 - P(X \leq P_i) = p_i \Leftrightarrow \\ \Leftrightarrow P(X \leq P_i) = 1 - p_i$$

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

- > Successful power up of the tag for 90% of the observation-time is accomplished in the closed volume, where  $P_i > -15\text{dBm}$



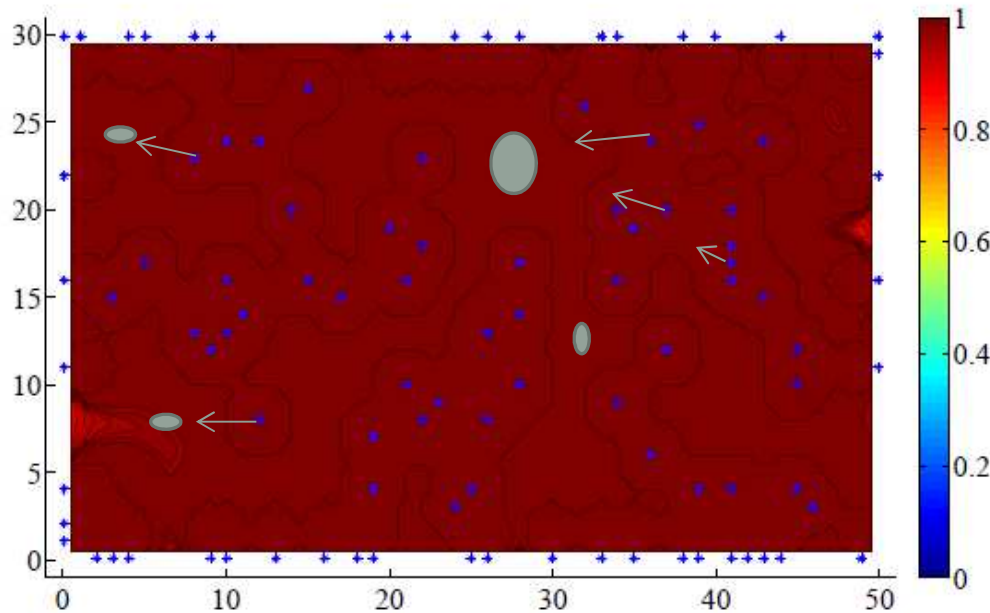
# Comparison with Prior-Art



218 antennas

108 antennas

# Hybrid Approach



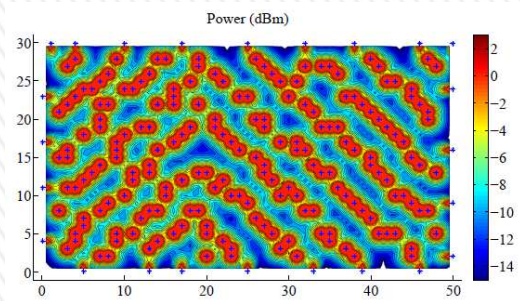
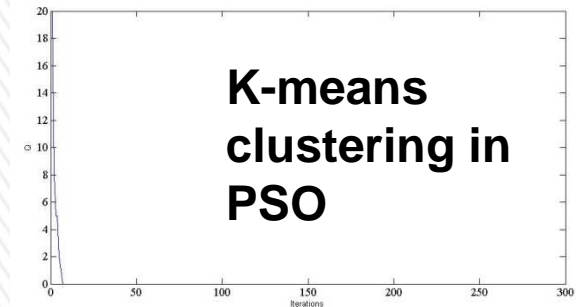
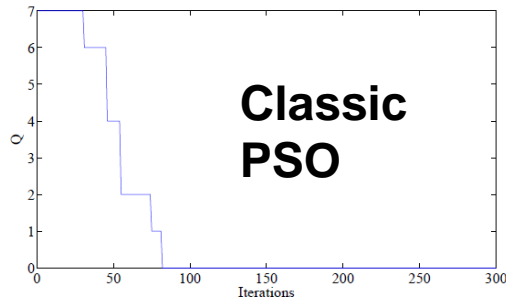
1. K-means creates clusters of poorly powered locations
2. A new velocity vector is added to each particle forcing it to move towards these points
3. The closer one is the faster they move

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

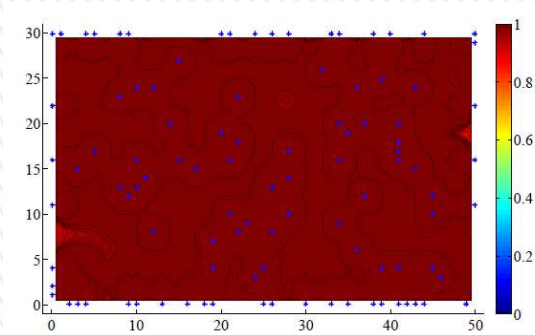


# Comparison with Prior Art

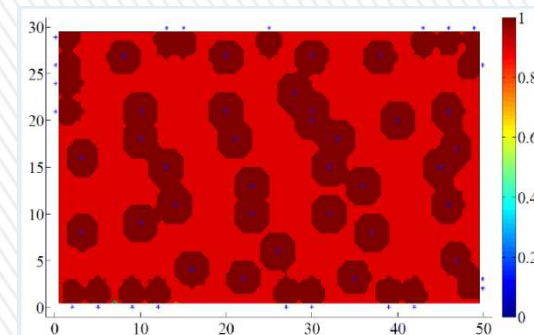
Each antenna  
treated  
separately -  
Classic PSO



218 antennas



108 antennas



55 antennas



# Concluding Key-Remarks

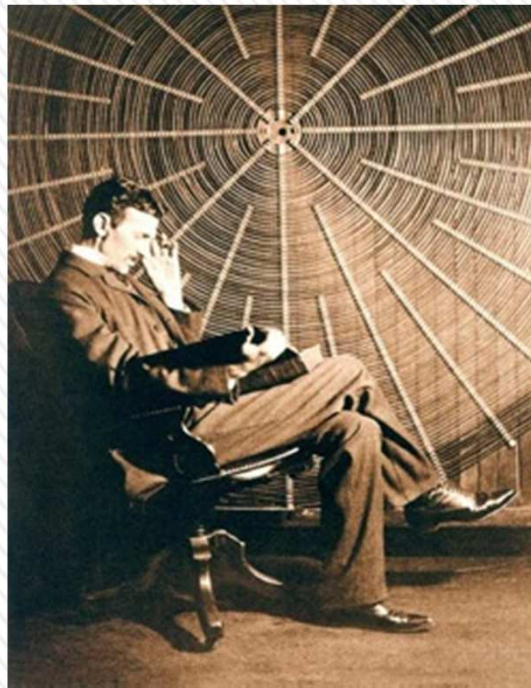
- » Probabilistic modeling allowed for proper consideration of the combined performance of multi antenna network
- » Proposed formulation and the PSO is the only one to consider the network's performance and outperforms prior-art.
- » Finally, a method to reach faster and more “reasonable” planning results 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.





# Propagation Modeling and Planning of Battery- less Tags Networks

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28 September 2014, Toulouse