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Design of Parasitic Antenna Arrays & Experimentation at AIT's B-WiSE Lab

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AIT & B-WiSE Lab

- **AIT is a self-sustained, non-profit, research and education centre**
- **Has 15 faculty and 45 research staff**
- **Ranked 7th among all Greek institutes in total annual EU fundraising in the area of ICT**
- **Offers two Master programs and a PhD program in collaboration with Aalborg University**
- **Covers 8 distinct research areas**
- **The B-WiSE group covers the broad field of wireless communications**
- ***B-WiSE staff: 2 professors, 3 researchers, 4 PhD students, 1 engineer***

http://www.ait.gr/ait_web_site/research_BWISE.jsp

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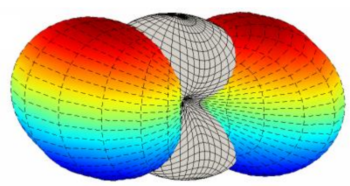
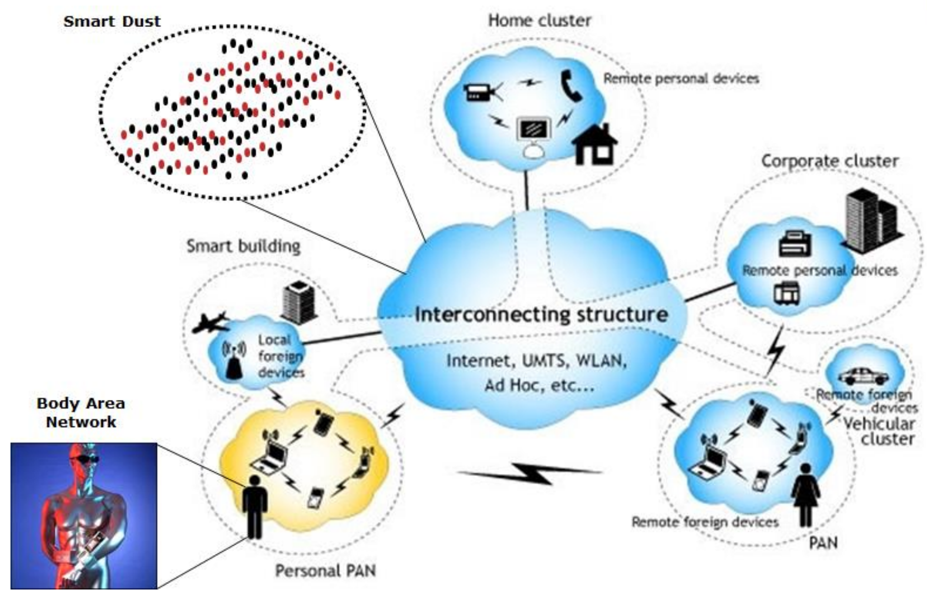
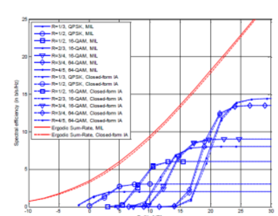
Broadband Wireless & Sensor Networks (B-WiSE) Research Group

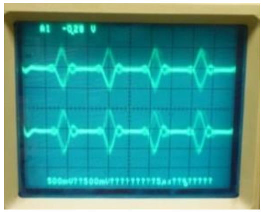


Moto: Smart, Green, Wireless

Contributes to the "Optimally Connected Anywhere, Anytime" global vision, through the investigation, research and development of next generation energy-efficient broadband and sensor wireless communication techniques, devices & networks







B-WiSE Research Agenda

- **Next G Communications**
  - Interference Handling Techniques for next generation networks
  - Wireless / wireline integration
  - Mobile Ad-hoc & Mesh Networks
  - Re-Configurability, Cross-layer Optimization
- **Broadband Air Interfaces**
  - Multi-antenna networks
    - capacity analysis; communication; scheduling/routing
  - Compact antenna systems
  - Cognitive Radio
- **Sensor Devices & Networks**
  - Advanced protocols for smart sensor networks
  - Directional multi-hop communication & positioning
- **Applications**
  - LTE ++
  - IEEE 802xx
  - eHealth (Remote patient monitoring; Human body communication)
  - VANETs
  - Smart grid
  - Location based services
  - Indoor positioning / communication
  - Environmental monitoring

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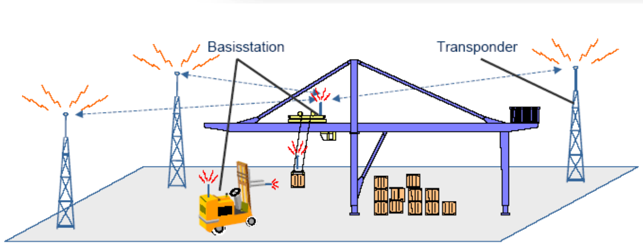
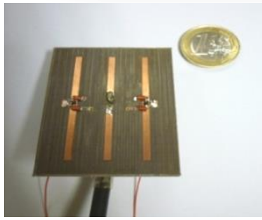
Expertise in Parasitic Arrays & Relevant Projects

WiseSPOT



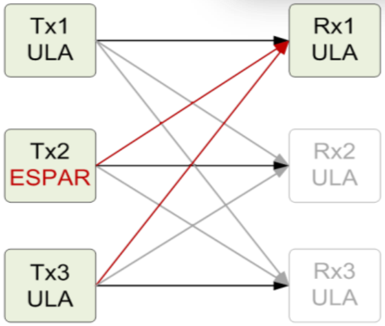
Directive fractal antennas for node localization

CROWN



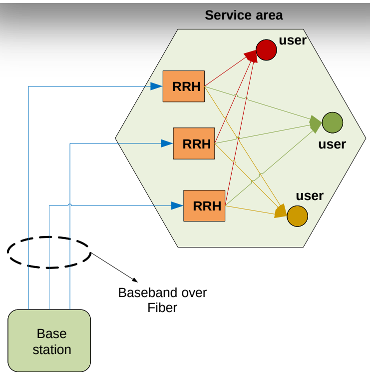
Compact antennas for Cognitive Radio

HiATUS



ESPAR arrays for Interference Alignment

HARP



Remote Radio Heads with parasitic arrays

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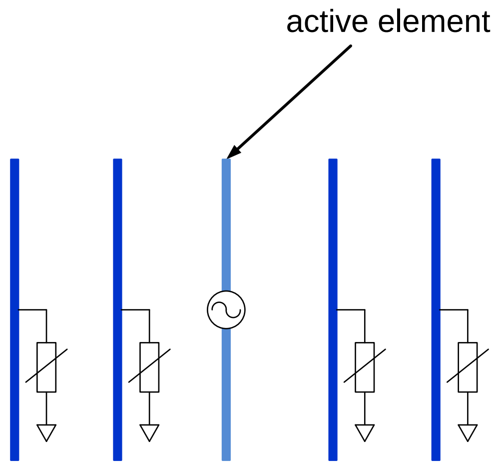
Basics of Parasitic Antenna Arrays

- **Only one element is active -> Single RF chain**
- **Complex loads are connected to the parasitic elements**
- **By changing the load values one can adjust the currents on the elements**
- **Beam-shaping abilities, as well as, more recently, spatial multiplexing and other types of Tx precoding**

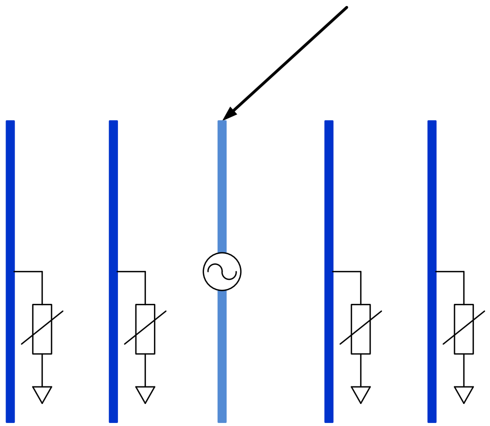


Planar, i.e. 2D geometry

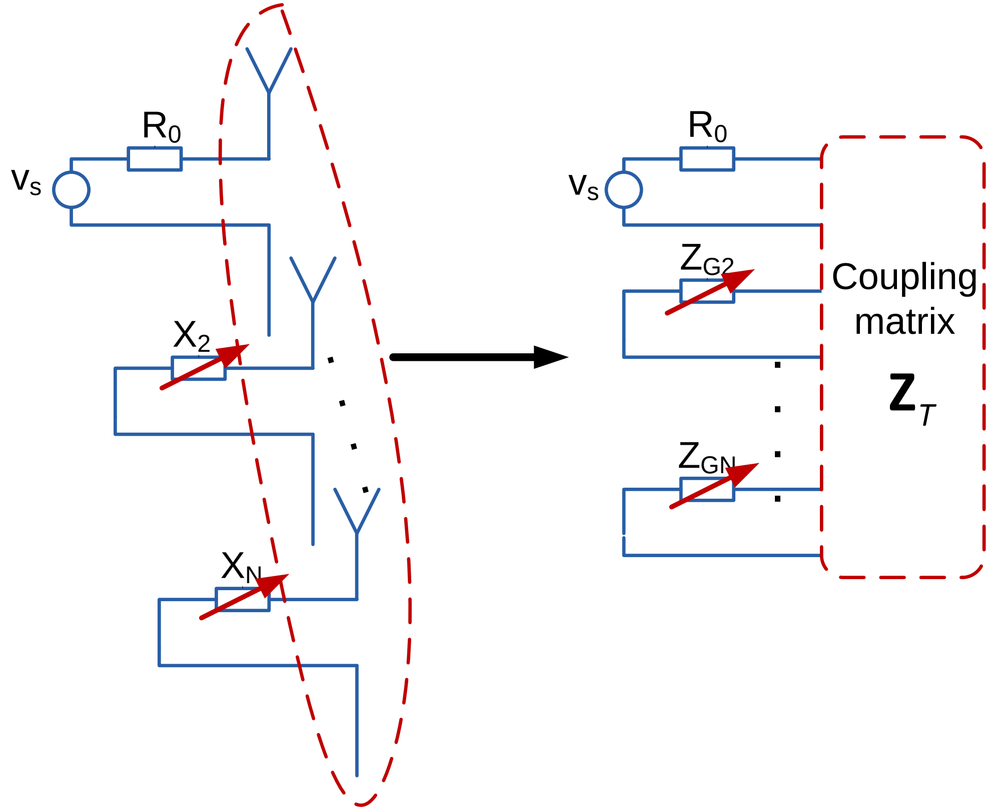
Current generation mechanism: mutual coupling

$$\mathbf{i} = \left(\mathbf{Z}_T + \mathbf{Z}_G\right)^{-1} \mathbf{v}_{Tx} = \mathbf{D}_{Tx}\mathbf{v}_{Tx}$$

$$\mathbf{v}_{Tx} = \left[v_{T1} \quad 0 \quad \dots \quad 0\right]^T$$



Planar, i.e. 2D geometry



Due to the strong coupling and the tunable loading, the current-voltage relationship is a non-linear one

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Signal Model for ESPAR Arrays

- **However, once the currents have been generated, the relationship between the currents and the received voltage vector at the receiver remains linear, similar to the conventional baseband MIMO link signal model:**

- Input – output equation

$$\mathbf{y} = \mathbf{H}\mathbf{i} + \mathbf{n}$$

$\mathbf{y} : \left(M_R \times 1\right)$ It contains the voltages of the conventional multi-antenna receiver

$\mathbf{H} : \left(M_R \times M_T\right)$ Is the channel matrix. The *(m,n)* entry represents the complex gain between the *m*-th Tx current and the *n*-th Rx antenna element

$\mathbf{i}_{Tx} : \left(M_T \times 1\right)$ Contains the ESPAR's currents: $\mathbf{i}_{Tx} = \left(\mathbf{Z}_T + \mathbf{Z}_G\right)^{-1} \mathbf{v}_{Tx} = \mathbf{D}_{Tx}\mathbf{v}_{Tx}$

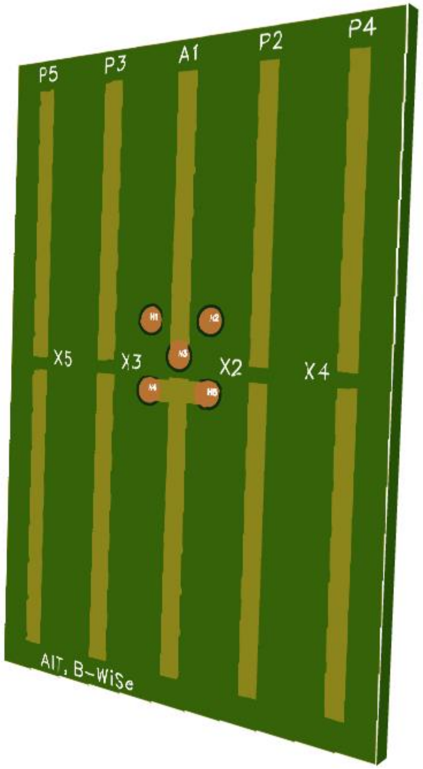
$\mathbf{n} : \left(M_R \times 1\right)$ Additive (typically Gaussian) noise vector

Parasitic Array Design

- Simulation Tool: IE3D
  - It uses the Method of Moments (MoM) or Boundary Element Method (BEM).

- Main parameters for simulation:
  - Element Length: ~λ_0 **/ 2**
  - Inter-element spacing: **~** λ_0 **/16**

- Fabrication Imposed Parameters
  - Dielectric: FR4 (**e_r = 4.45**, **tanδ = 0.017**)
  - Substrate thickness: **0.8 or 1.6 mm**
  - Copper trace thickness **35 μm**



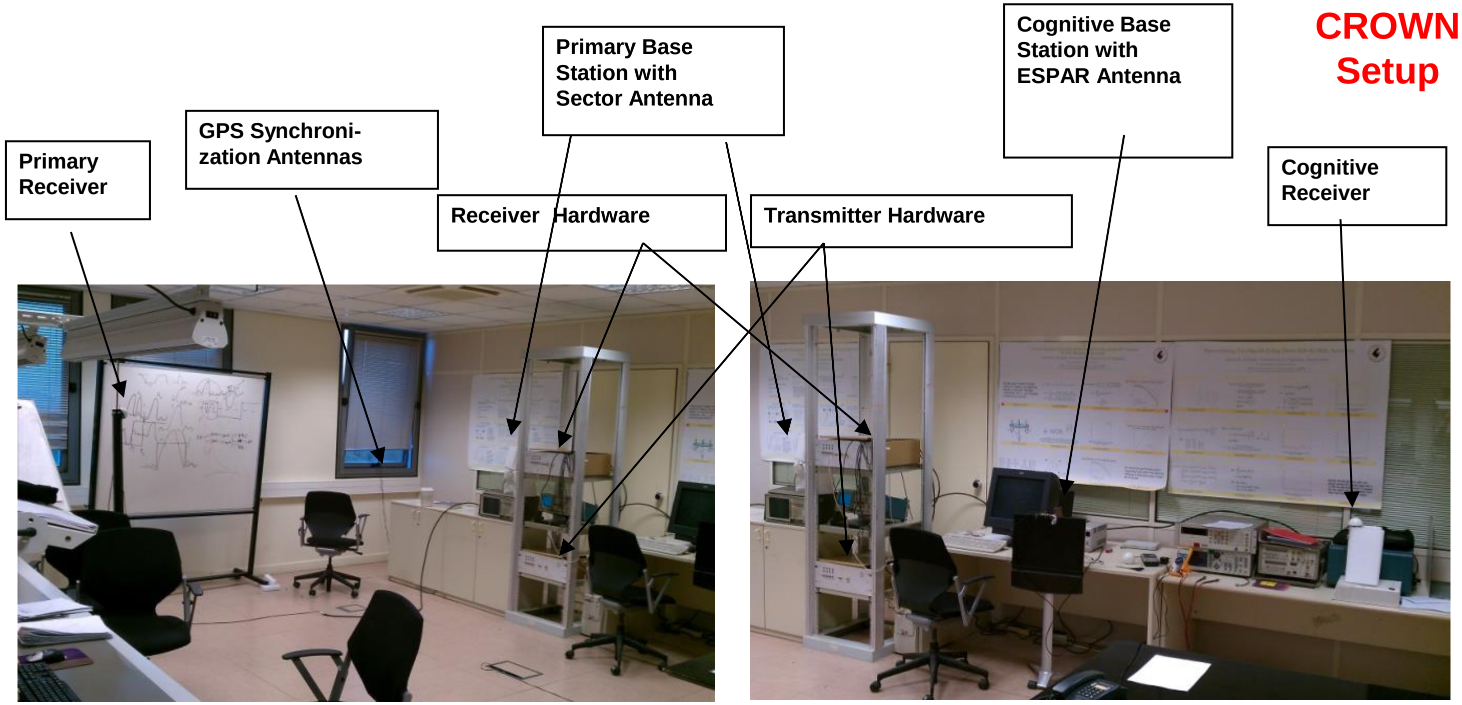
MIMO Testbed Overview

- 2 MMDS Transmitter RF modules
- 2 MMDS Receiver RF modules
- Carrier Frequency, 2.5 to 2.7 GHz (MMDS Band)
- Signal Bandwidth up to 1 MHz
- GPS synchronization unit
- Stores gathered data into a computer, connected via 10 BaseT Ethernet.

Example MIMO Testbed Activities

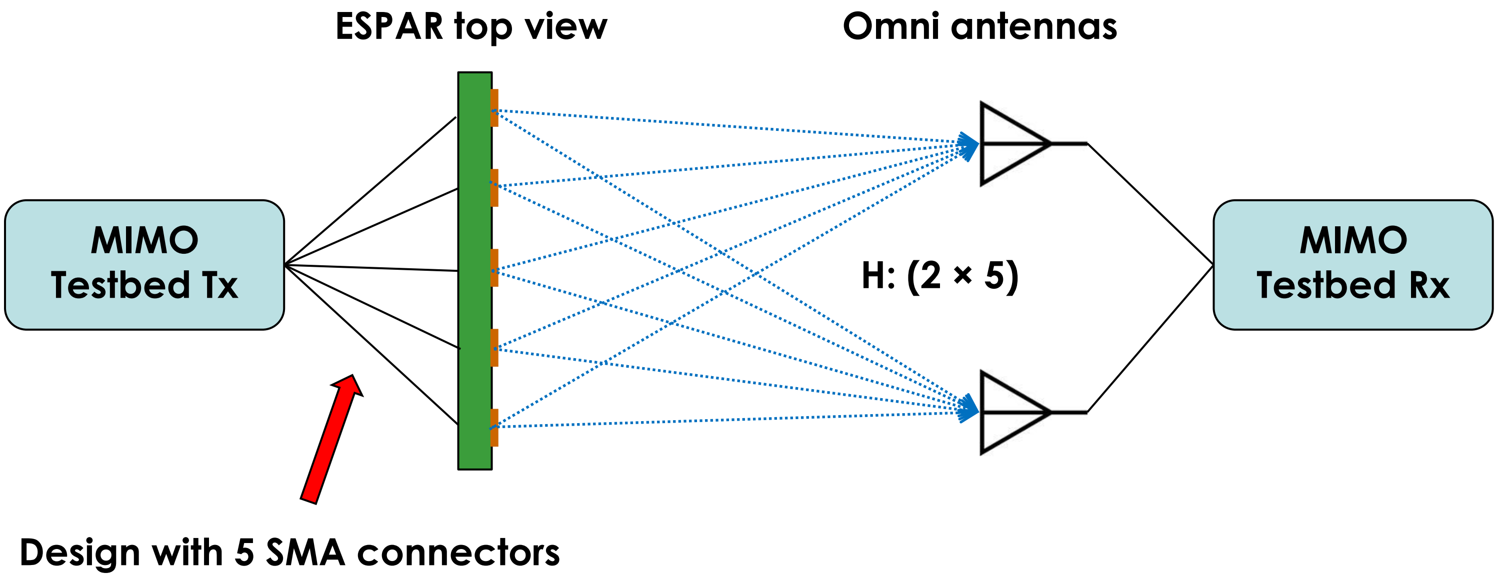
- **16-QAM MIMO transmission (MSc Thesis)**
- **OFDM transmission (Student project)**
- **1st ever over-the-air demo of spatial multiplexing with ESPARs *(IEEE Comm. Lett., Feb. 2011)***
- **Beam nulling in the context of CROWN**

CROWN Setup



Parasitic Channel Measurement Experiment

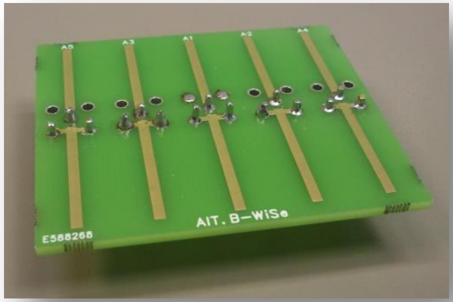
<u>Motivation for the experiment</u>:
To characterize the parasitic channel in a decoupled way from the current generation mechanism, as per the model: $\mathbf{y} = \mathbf{H}\mathbf{i} + \mathbf{n}$



Primary Goal: to characterize H !!

Antenna Designed for the Channel Measurement

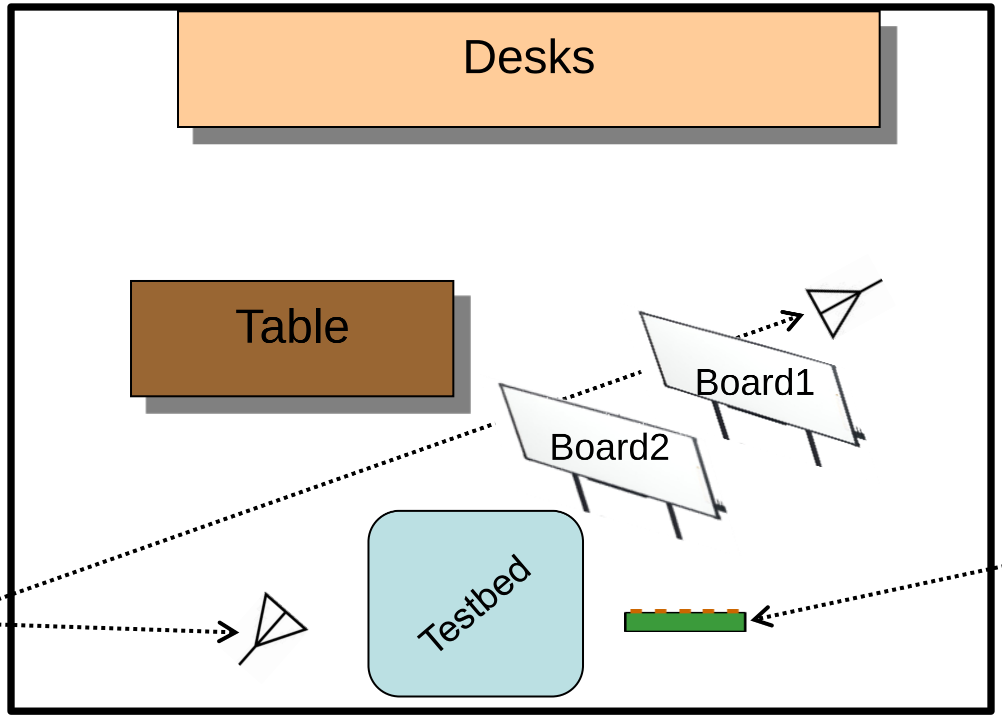
- Design process as described before
- Inter-element spacing λ/12
- Measurement frequency 2.67 GHz
- Since the testbed TXs are only 2, each element will be driven in turn
- Each channel measurement requires to run the testbed 5 times



Experiment Setup

Configuration Top View

The two Rx were moved around the room in random positions. Not every realization involved LoS and they were always around the same height level with the Tx.



The Tx was moved only in the azimuthal plane and was kept at the same height level throughout all the realizations of the experiment.

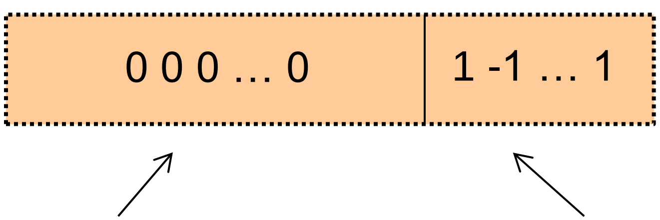
Frame structure

- **The signal is composed of 2048 samples with a baseband sampling frequency of 500 kHz.**

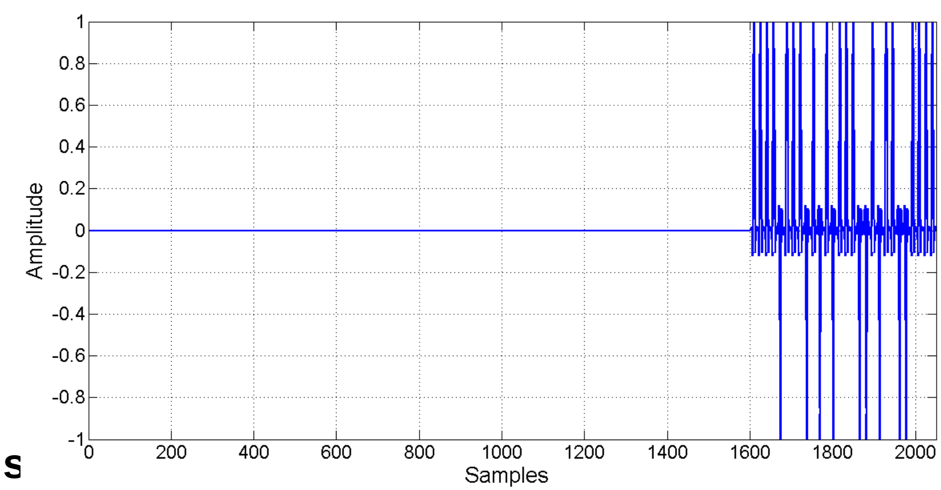
- **The number of transmitted symbols is 128 and consists of 100 zeros and 28 BPSK symbols**

- **Raised cosine pulse shaping was used, with 16 samples per symbol.**

Frame Size: 128 symbols



100 zero symbols **28 BPSK symbols**



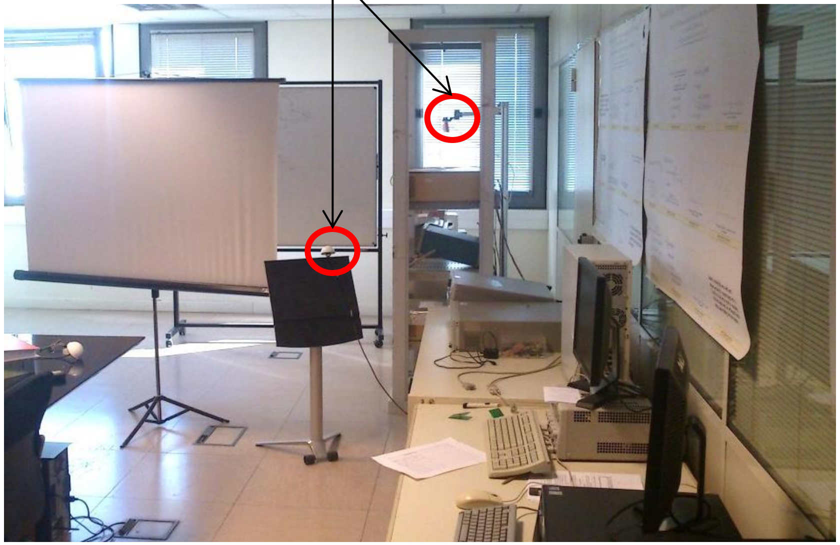
Channel Estimation at the Receiver

- **50 different configurations were measured (250 measurements) and for each one of them a channel matrix H was calculated.**

- **Least squares estimate:** $H = Y*X^{T}*(X*X^{T})^{-1}$

X: (1x28) BPSK training symbols
Y: (1x28) Received symbols

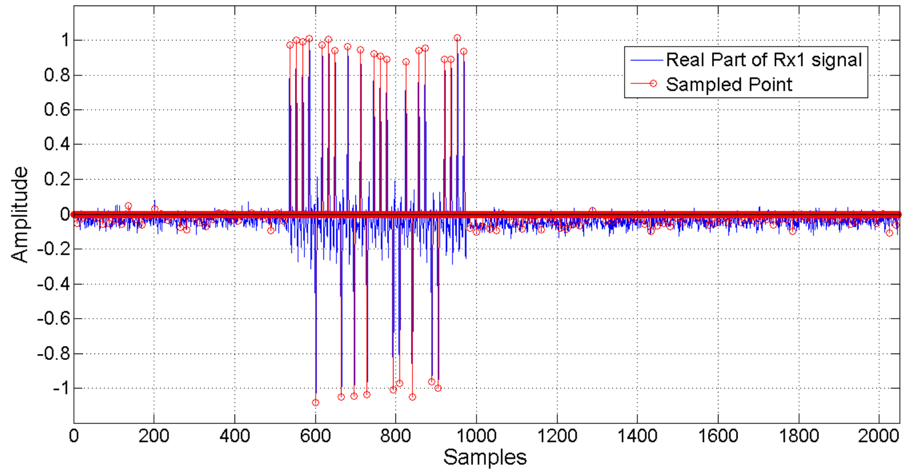
Rx Antennas

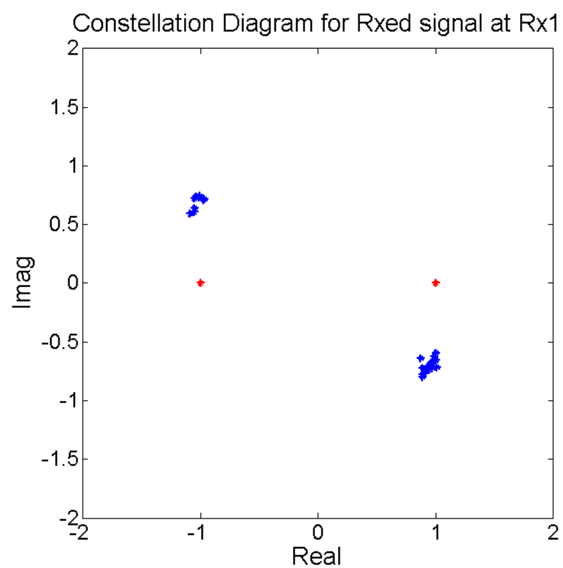


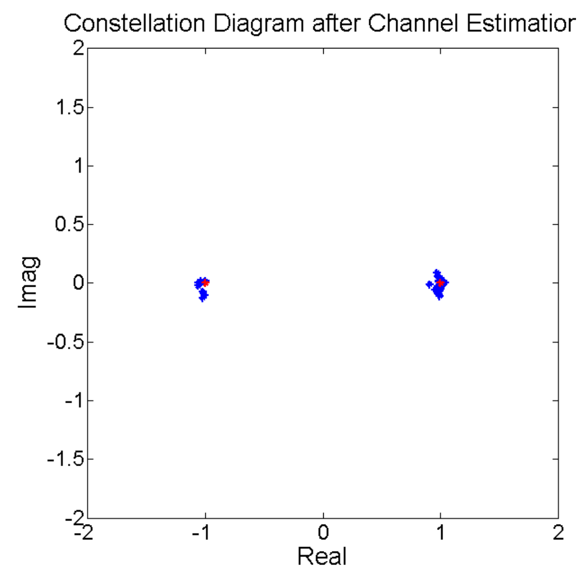
The spatial scenario involved scatterers (whiteboard, chairs, meeting table, drawers) and in most occasions there was no LoS component.

Early Results(1/3)

- **Received signal in Rx1 (top) and constellation diagrams before and after the channel estimation (bottom), for one out of the 50 measurements and for one out of the 5 elements.**







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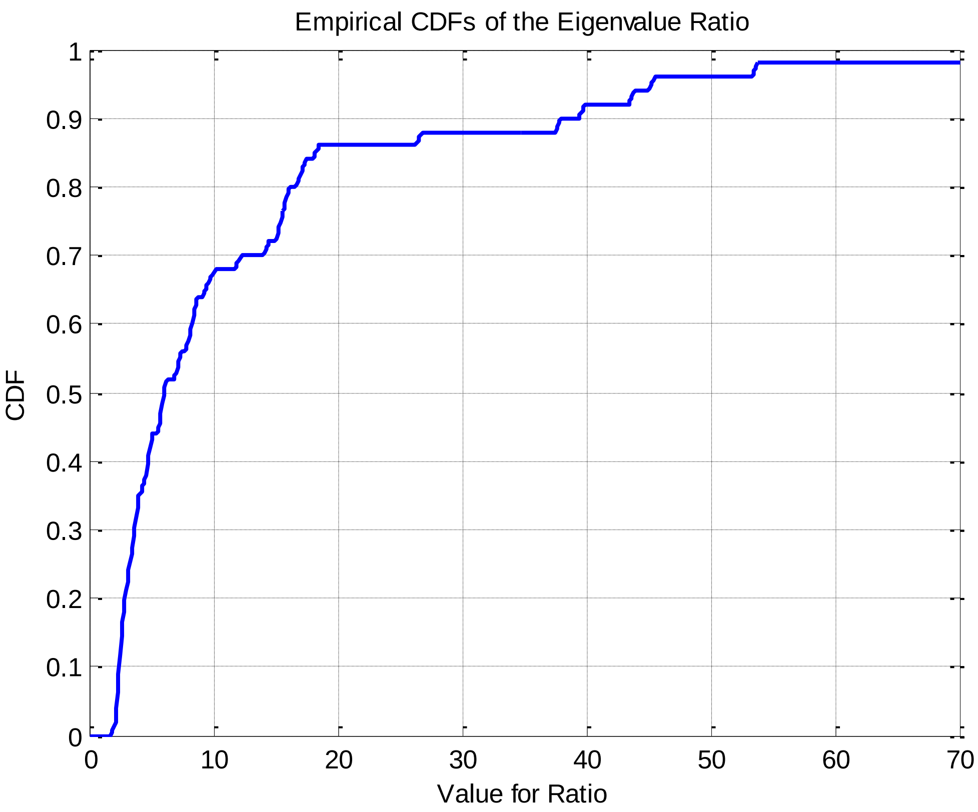
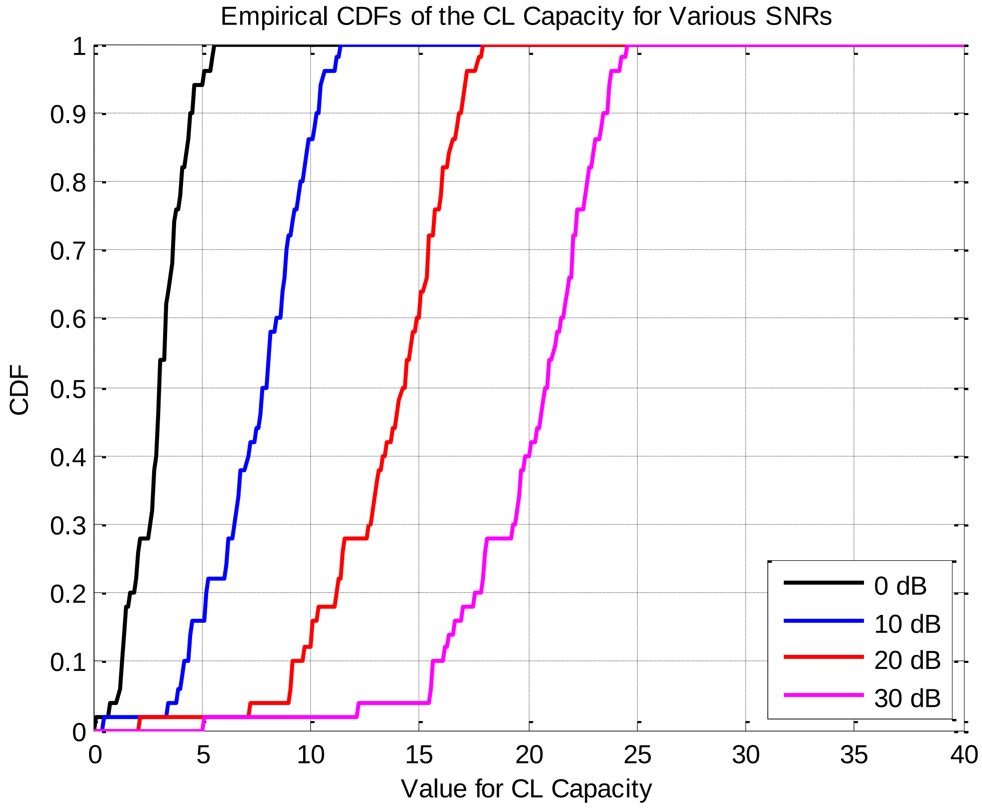
Early Results(2/3)

- **CDF of the Channel Matrix condition number**
- **Only few extreme values**
- **Seemingly reasonable values for the correlated channel**



Early Results (3/3)

- **CDF of the closed-loop capacity for different SNRs**

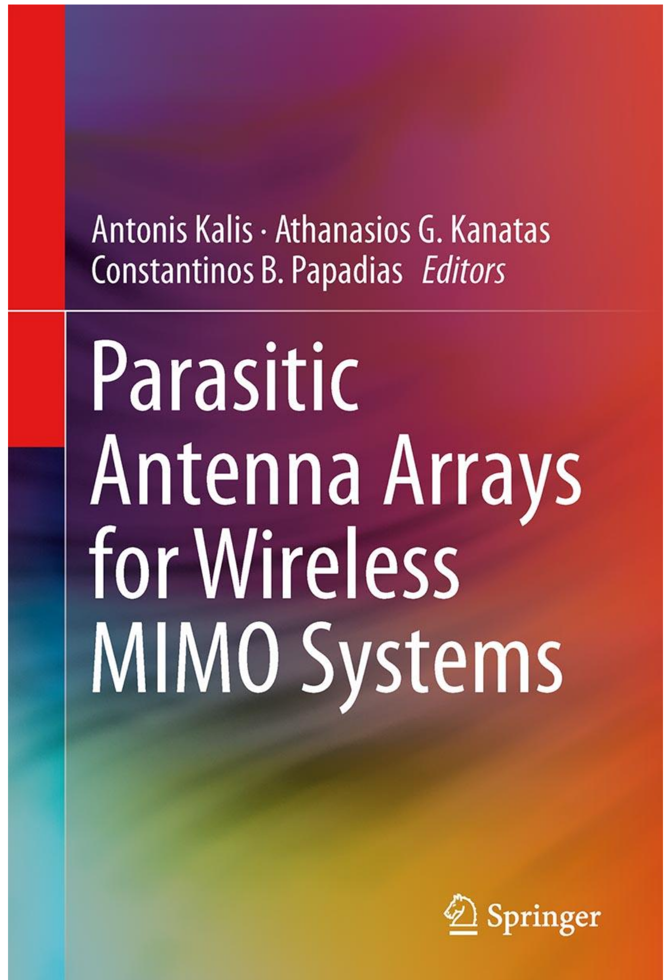


Future work

In the next few months we plan:

- **To develop statistical models for characterizing the parasitic indoor channel**
- **To use the measured channels in order to design appropriate precoders for transmission, e.g. for interference alignment**
- **To verify the performance of the developed precoders over-the-air**

Thank you for your attention!


Antonis Kalis · Athanasios G. Kanatas
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Parasitic Antenna Arrays for Wireless MIMO Systems
Springer