FIRE workshop 1: Experimental validation of cognitive radio/cognitive networking solutions

Enhancing Future Networks with Radio Environmental Information

FARAMIR project

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RADIO ENVIRONMENTAL MAPS

- The basic idea is to generate high-resolution spatio-temporal empirical models (and true maps) on the radio environments
  - These maps can be used to data-mine useful regularities, and e.g. estimate probabilities of spectrum holes

- Opens up many exploitation possibilities
  - Localization by finger printing
  - Smart interference minimization and cancellation
  - Radio environment based policy changes
  - Radio environment based optimization decisions

FARAMIR has strong focus on applications beyond dynamic spectrum access, especially within existing and future cellular networks

GENERATING AND EXPLOITING REM

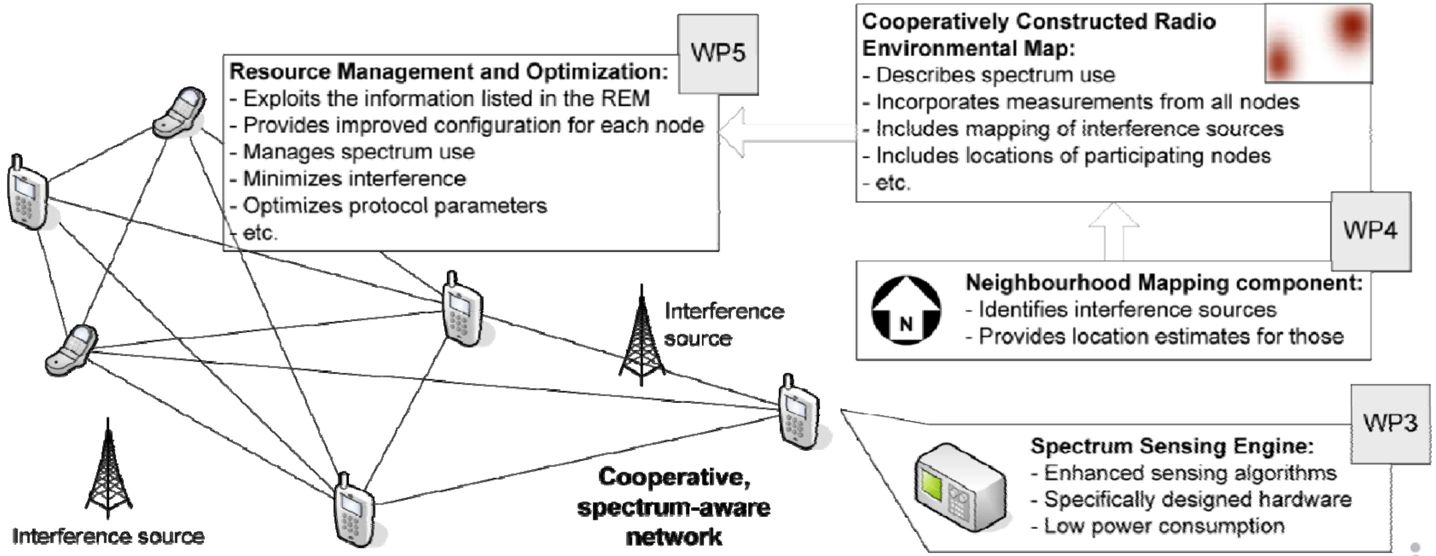
- **Context acquisition and recognition**
  - Using radio finger-prints to quickly understand where and in which condition cognitive radio is
  - Deploying novel hardware solutions for gathering spectrum use information
  - Considering indoor and precision localization techniques
  - Using advanced classifiers to recognize **the state of the system**

- **Context-based optimization and adaptation**
  - RRM can decide appropriate optimizers and state transitions only if it knows the context of the decision making
  - Location and propagation information are currently one of our key context parameters

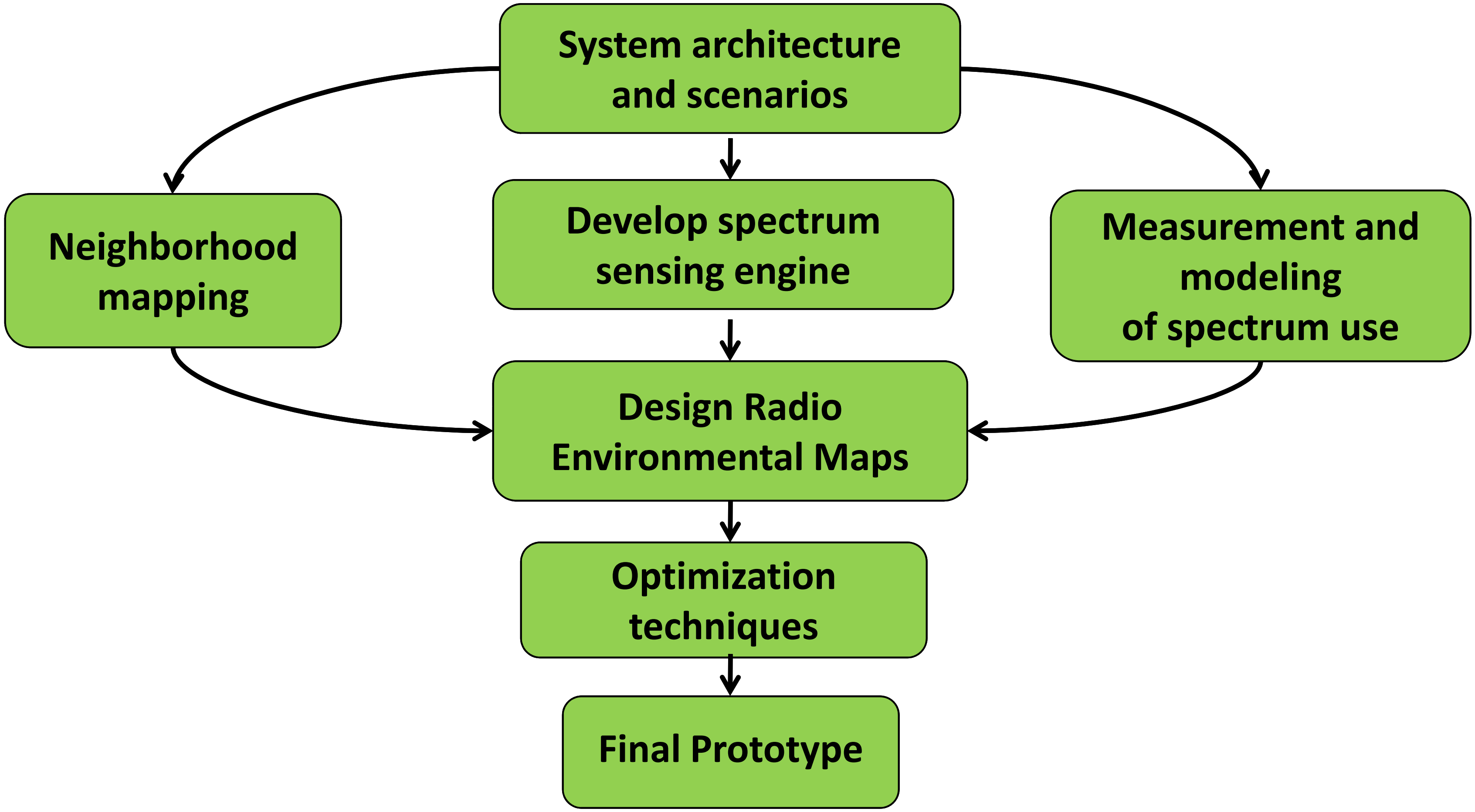
FARAMIR AT A GLANCE

- Objective of the project is to research and develop techniques to increase radio environmental and spectral **awareness** of future wireless systems
  - Spectrum sensing hardware efficiently integrated to handheld devices
  - Measurements performed at multiple nodes in a cooperative fashion on a network level

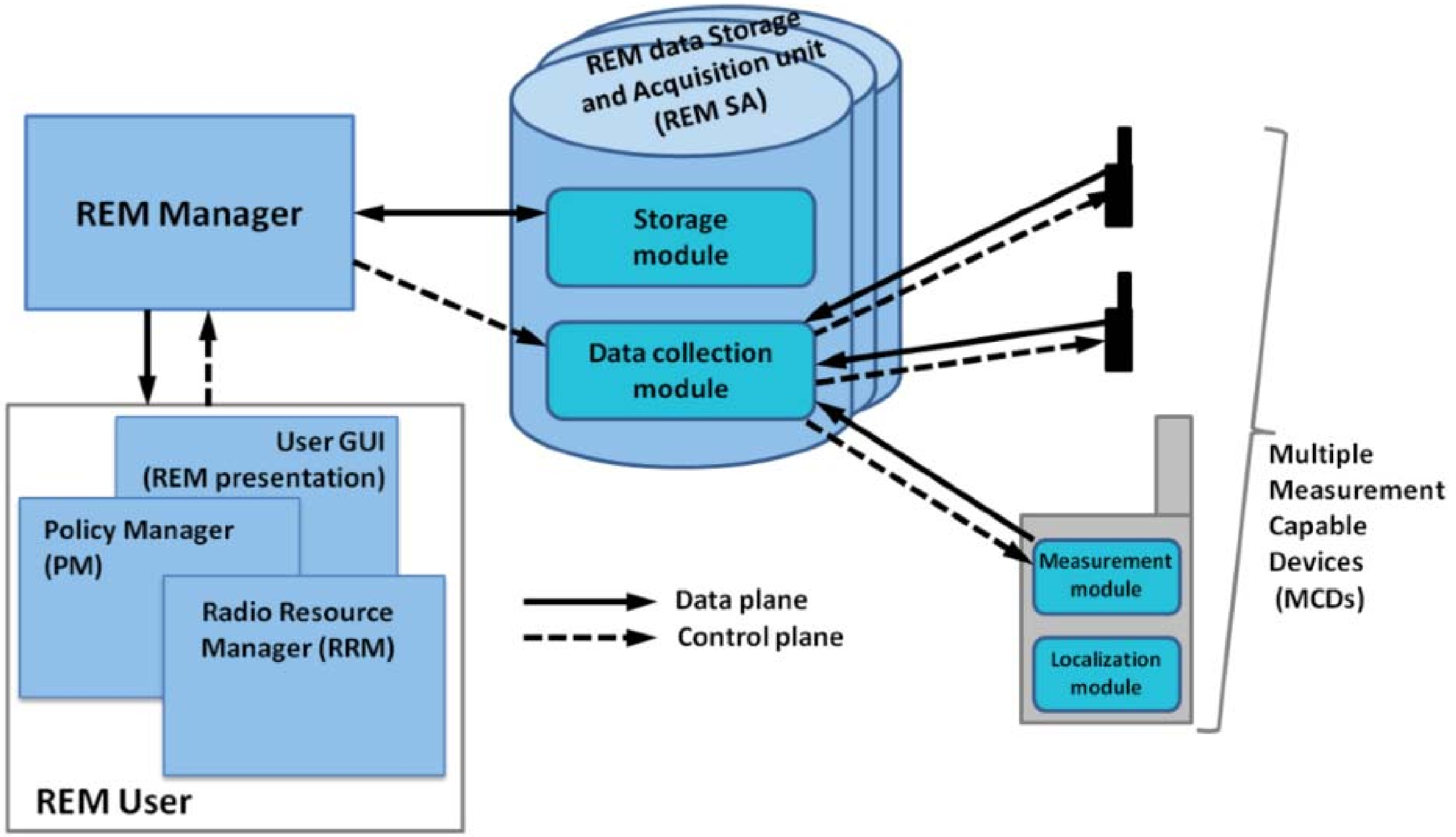
Radio Environmental Maps providing basis for system optimization



PROJECT WORKFLOW

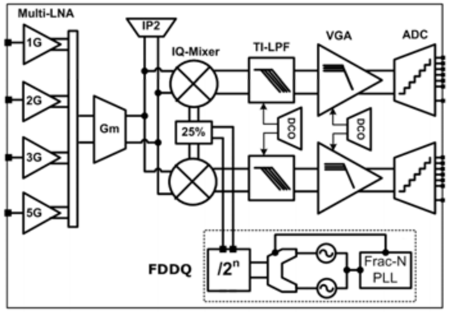


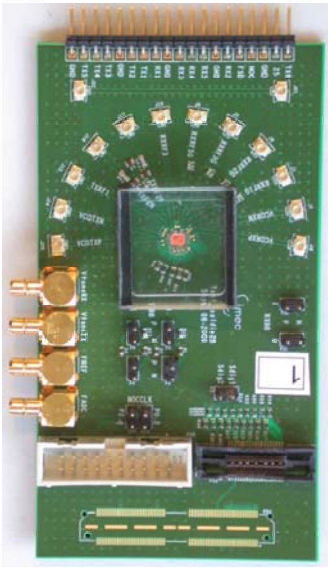
FUNCTIONAL ARCHITECTURE FOR REMS



NOVEL SENSING SOLUTIONS

- Fully reconfigurable and implemented in 40nm CMOS technology
  - Receiver RF operating frequency is programmable from 100 MHz to 6 GHz
  - Channel bandwidth is programmable between 1 and 40 MHz
- Fast switching between different RF frequencies and channel bandwidths
- Low noise figure: 2.4 to 4 dB below 3 GHz, together with low power consumption
- Well suited for low power flexible sensing





PROTOTYPING WORK

processed data queries/replies **(C# socket communication)**

REM Manager

Dynamic REM processing

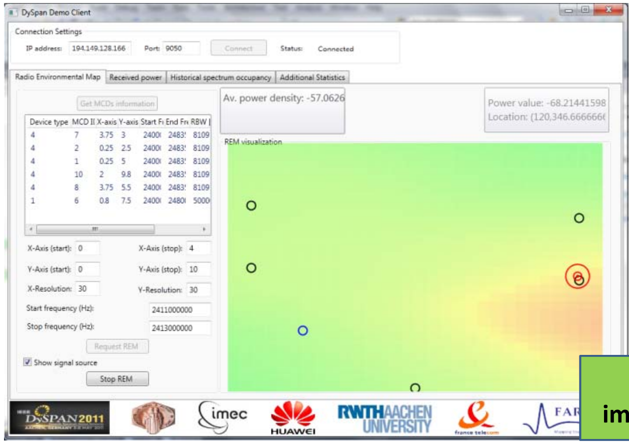
- **inverse distance weighting** (IDW) spatial interpolation (modified Shepard's method) [1]
- **transmitter localization** algorithm[2]

Historical data processing

- **duty cycle** calculation
- **density functions** calculation

C# implementation

Rich REM C# GUI



C# implementation

read/write REM storage **(C# based DB access)**

REM Storage and Acquisition

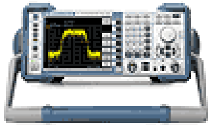
Microsoft SQL Server 2008 Database

C# based database handler (registering MCDs and storing data)

Heterogeneous measurement capable devices

Universal Software Radio Peripheral 2 (USRP2)

IMEC's SCAlable raDIO (SCALDIO)

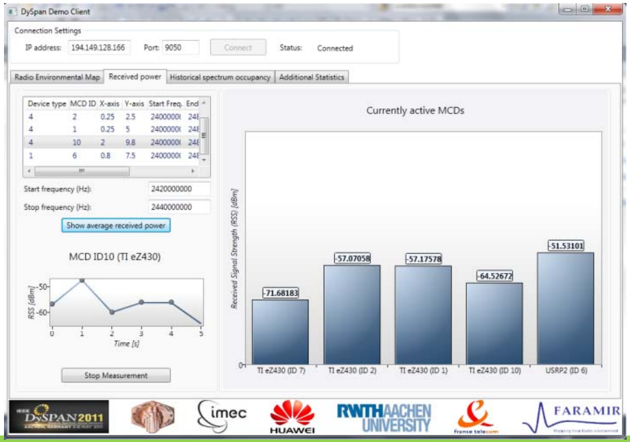


R&S FSL6 Spectrum Analyzer

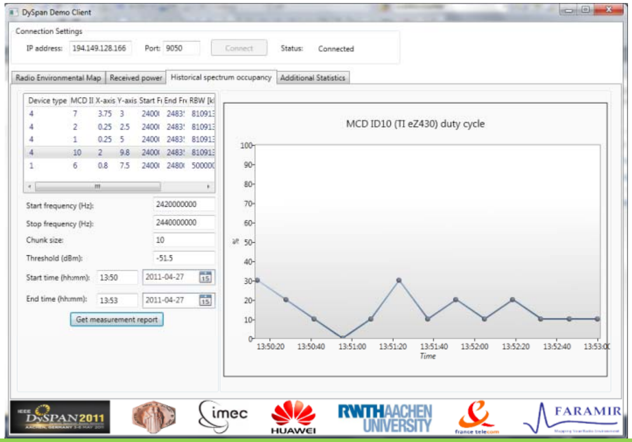
TI eZ430 RF2500 spectrum sensors

Unified MCD–REM SA interface (C/C# socket communication)

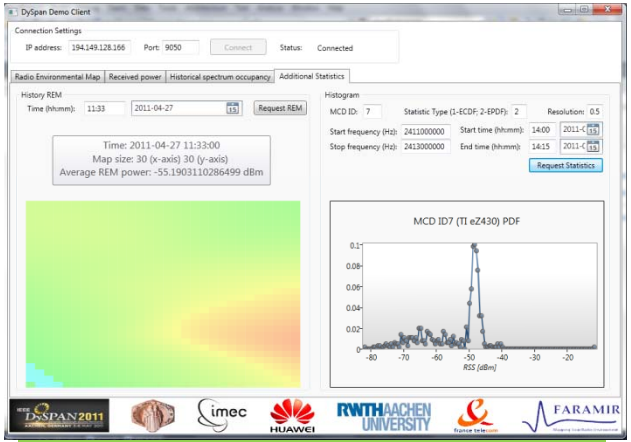
ENABLING REAL-TIME REM CONSTRUCTION



Received power variations



Historical spectrum occupancy

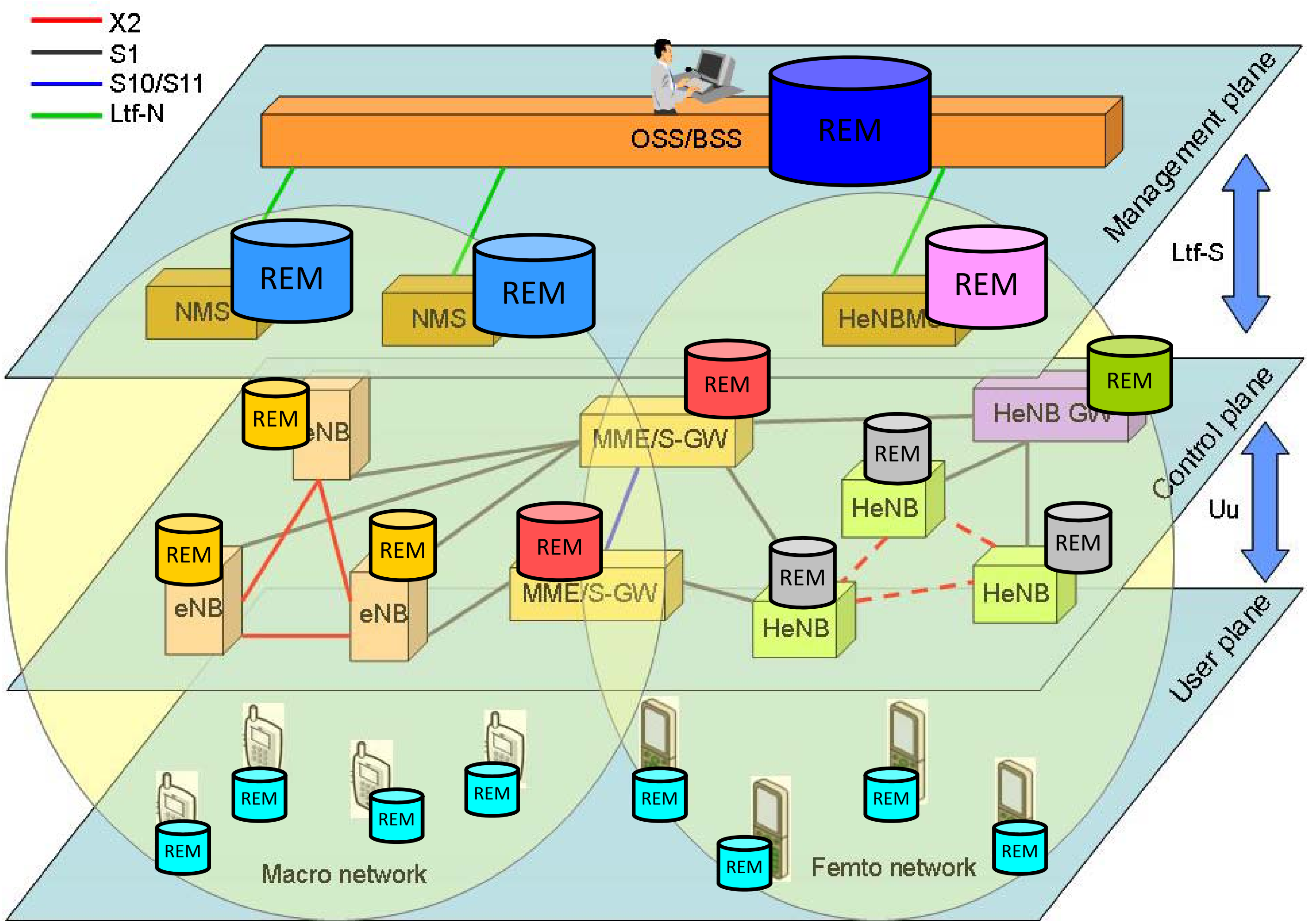


Statistical analysis

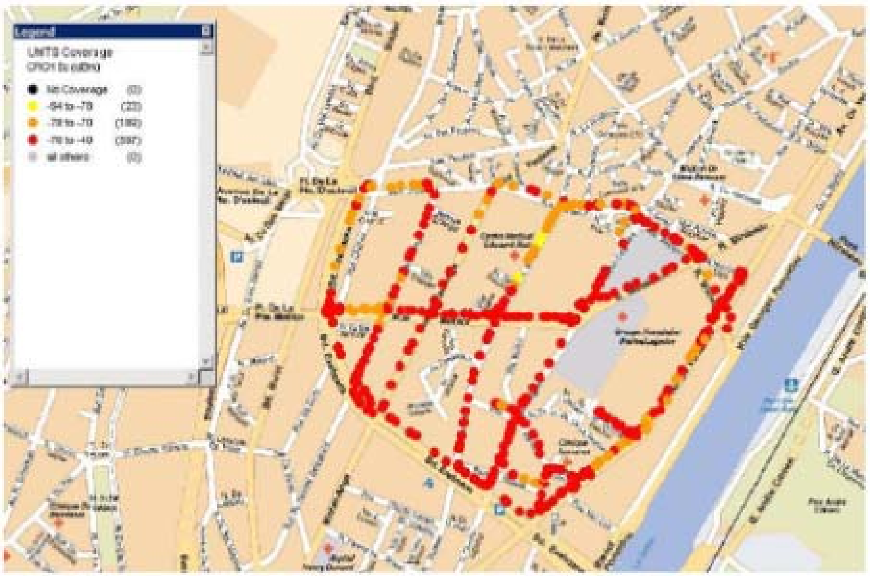
APPLICATIONS IN CELLULAR SYSTEMS

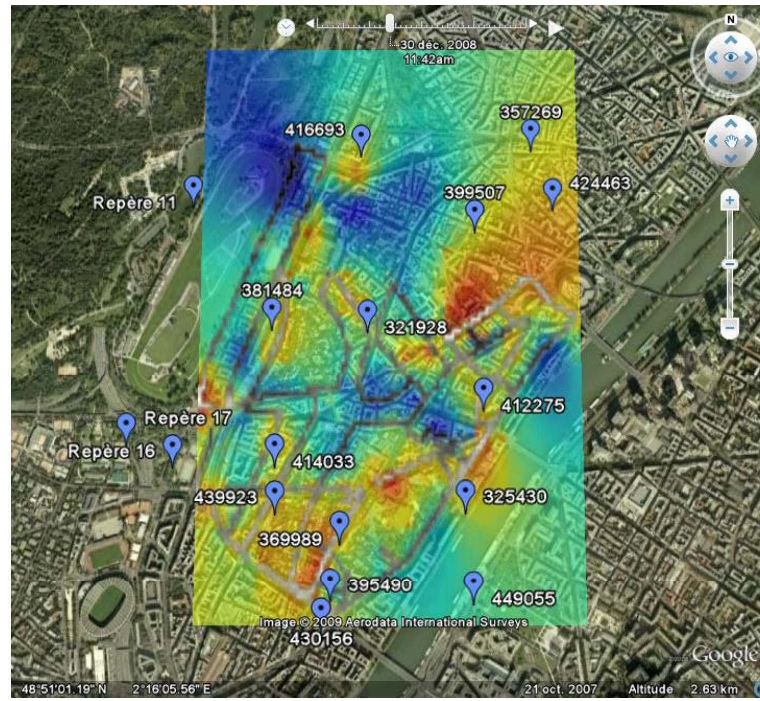
- Exploring several applications of these techniques directly to cellular networks with our industrial partners
- Examples of key scenarios considered
  - Automatic neighbor relation
  - Minimization of drive tests
  - Femtocell radio resource management
  - Introduction of new technologies through refarming
- Both empirical work and simulations (using actual planning tools of the operators) used for the work
- Prototyping with actual LTE hardware (including TVWS operation and applications)

HIERARCHICAL MAPPING TO CELLULAR NETWORKS



EXAMPLE OF REM CONSTRUCTION

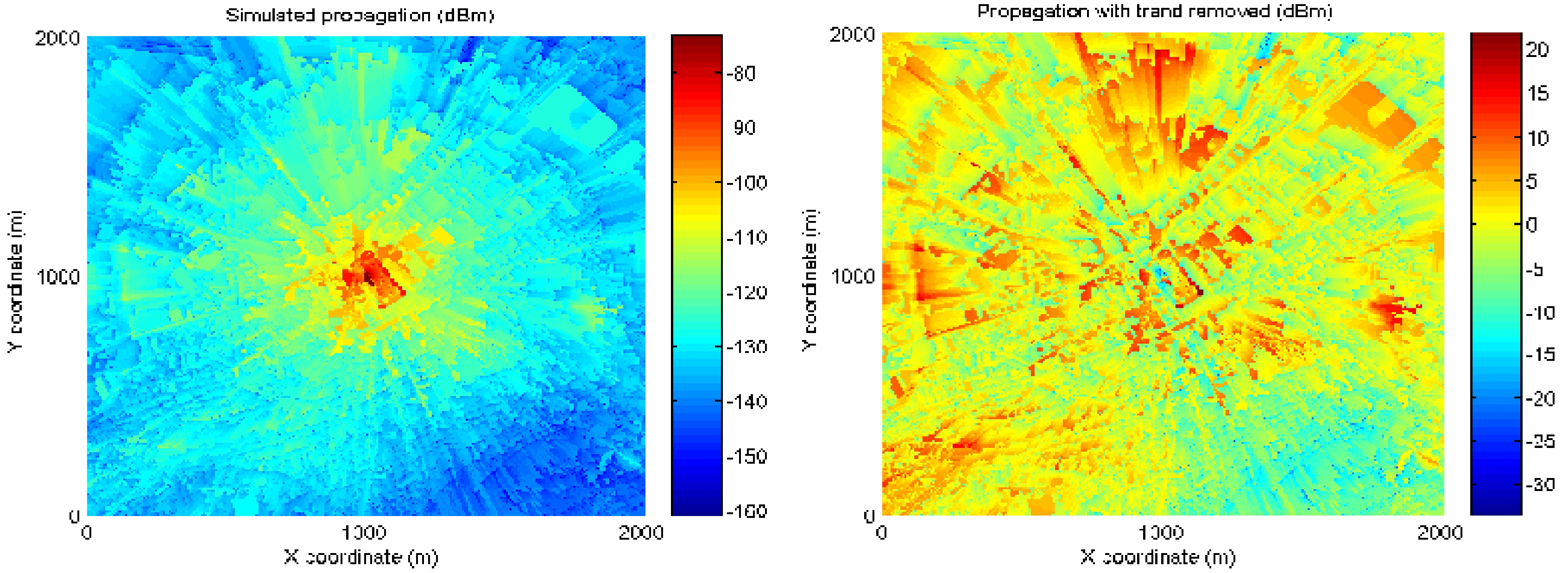




Figures courtesy of Dr. B. Sayrac, FT

CONSTRUCTING OUTDOOR REM

- System model
  - BS located in a urban area, on the rooftop of Orange Labs premises at Issy-les-Moulineaux (40 m height)



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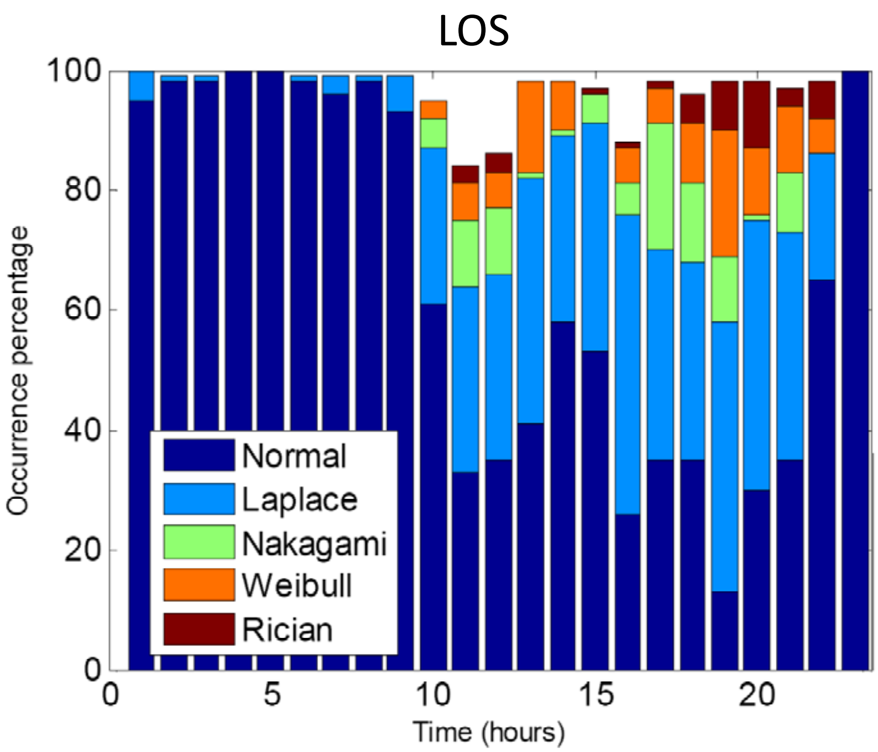
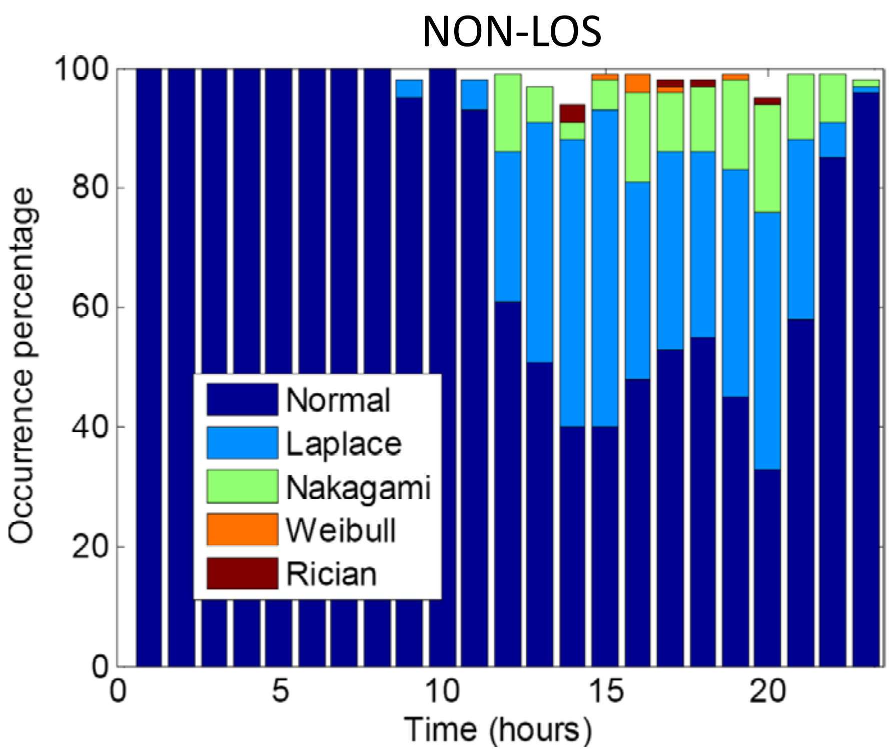
FEMTOCELL SCENARIO

- Self-X femtocells can be significantly enhanced by REMs
  - REM can be constructed using geo-localized measurements performed by mobile terminals, neighboring femtocells and macro base stations
  - In FARAMIR, we hierarchical REM architecture
    - Different instances can sit in different elements (terminals, Home NodeB, HeNB Gateway, covering Macro BS, OMC)
- Femtocell scenario requires accurate indoor models and localization methods

LONG-TERM INDOOR PROPAGATION MODELS

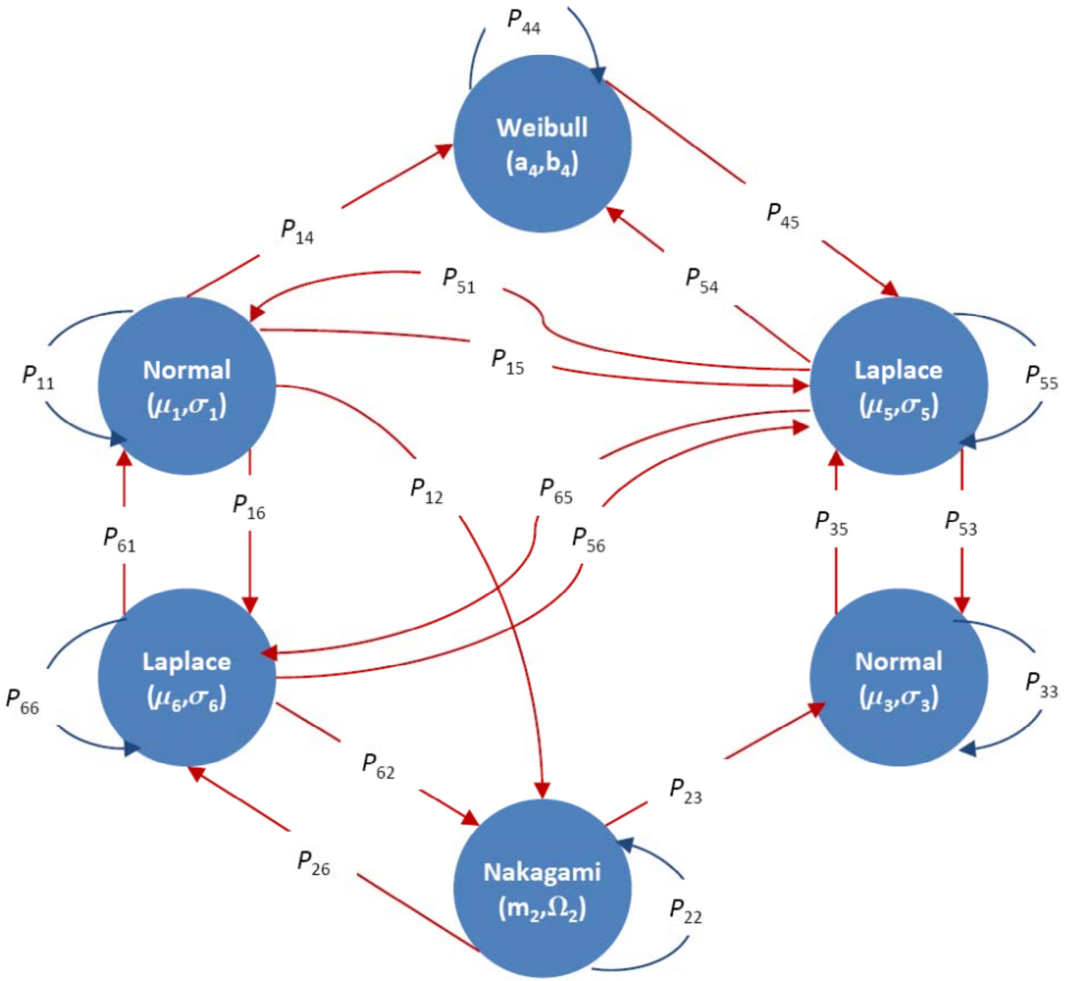
- A campaign of 109 hours including four full measurement days, LOS and NON-LOS scenarios



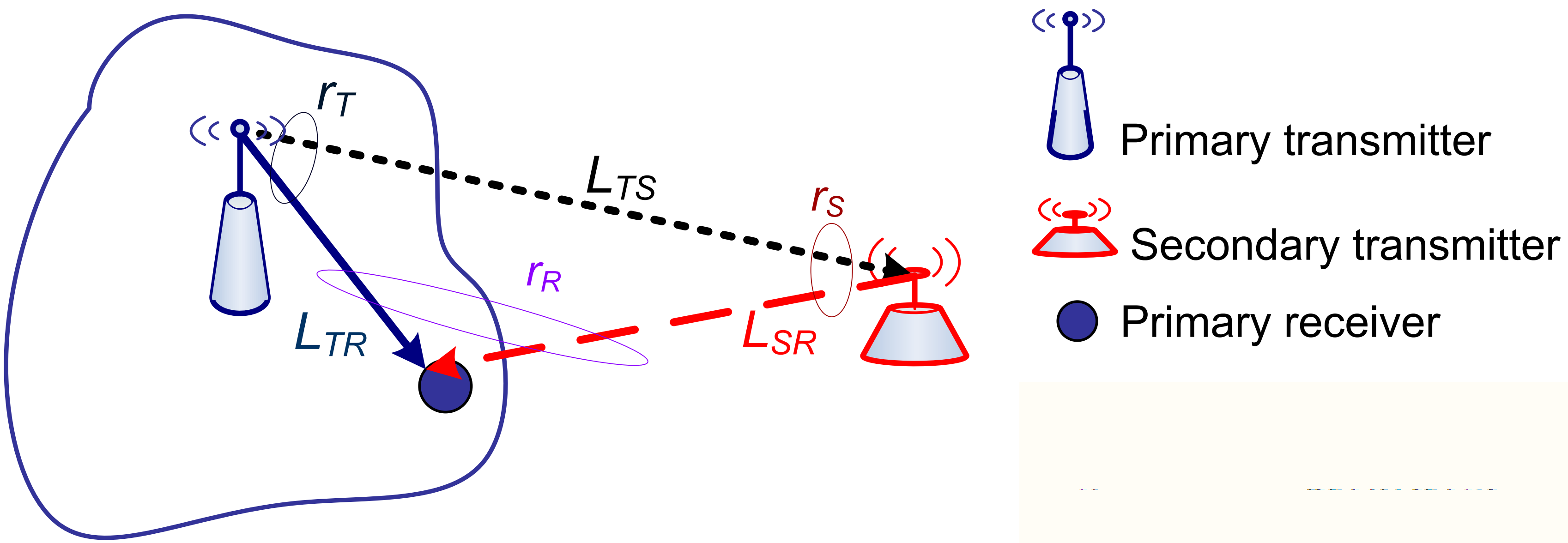


INDOOR PROPAGATION DYNAMIC MODEL

Need for dynamic propagation models for indoor scenarios



CORRELATION EFFECT



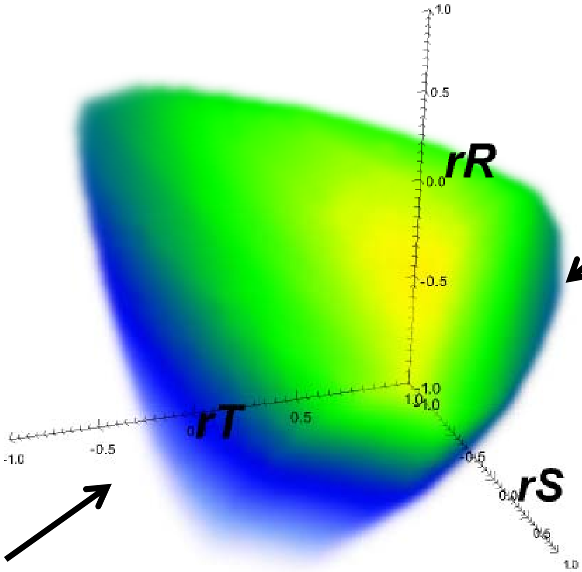
$L_{XY} = F_{XY}(d_{XY}) + \chi_{XY}$ (function F_{XY} and distribution of χ_{XY} are known)

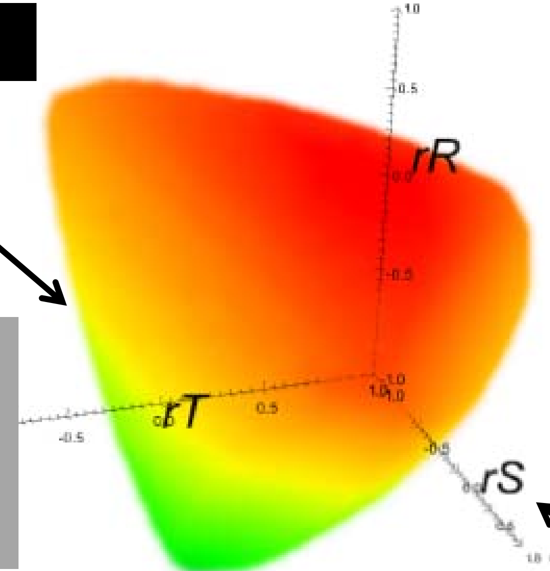
$$\mathrm{corr}(\chi_X, \chi_Y) = \frac{E\left[(X - E(X))(Y - E(Y))\right]}{\sigma_X \sigma_Y}$$

r_T, r_S and $r_R \in [-1,1]$ and the the correlation matrix is positive semi-definite

d_{TR} = 500 m, ε = 0.05

γ_r = -2.6 dB (QPSK, 1/8)





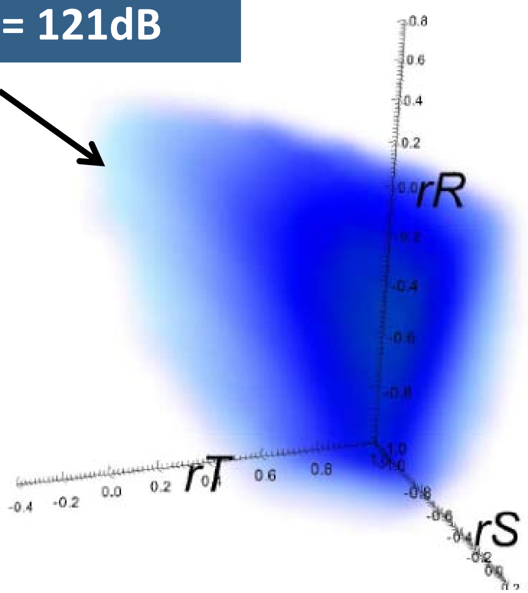
L_{TS} = 121dB

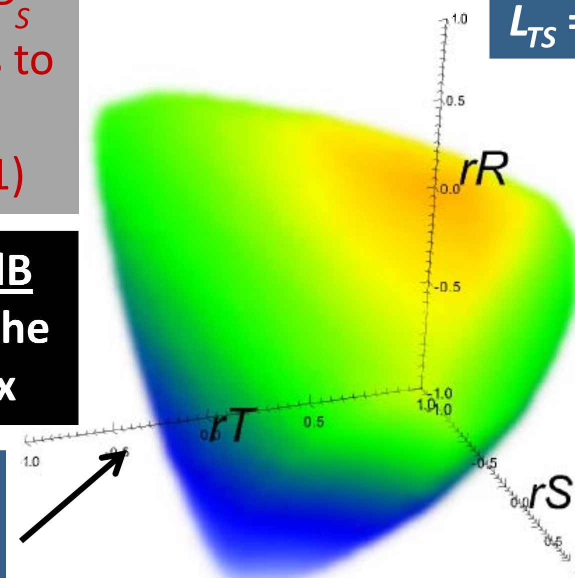
L_{TS} = 133 dB

P_S is an increasing funtion of r_T and r_R and decreasing function of r_S

The minimum of P_S corresponds always to the tuple ($r_T = -1, r_R = -1, r_S = 1$)

Range of P_S is 40 dB due to changes in the correlation matrix





γ_r = 10.9 dB (16QAM, 1/2)

NEED FOR TESTBEDS

- Cellular networks, especially with dense femtocell deployment
  - Difficult to simulate with all details
  - Measurements and performance metrics are difficult to obtain
  - Indoor propagation tools are available but there is a need for analytical models

- Building REMs requires detailed knowledge of operational measurements and system performance

SUMMARY AND CONCLUSIONS

- Radio Environmental Maps (REMs) and radio context information are clearly something that can have a big impact on future wireless networks
- In spectrum domain the proof of concept and a lot of measurements are ready, but we are also learning new problems
- Several lines of ongoing work for resource management and network diagnostics applications, with promising initial results
- A testbed providing detailed information about the radio environment is of high interest, especially in cellular networks and indoor environments

Q & A