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The ACROPOLIS Network of Excellence: Overview and Update

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Prepared taking content from numerous joint works of ACROPOLIS members

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Outline

- ACROPOLIS overview
  - Members
  - Structure and purpose
  - Topics and workpackages
- Some examples of recent ACROPOLIS technical work
  - Along the lines of ACROPOLIS key technical interest groupings
- “Integration” and “Spreading of Excellence” efforts
  - Standardisation and regulation
  - Courses/tutorials
  - Preparation of events/publications
- Some Future Directions

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ACROPOLIS Overview

ACROPOLIS Members

Liaison agreements

Associate memberships

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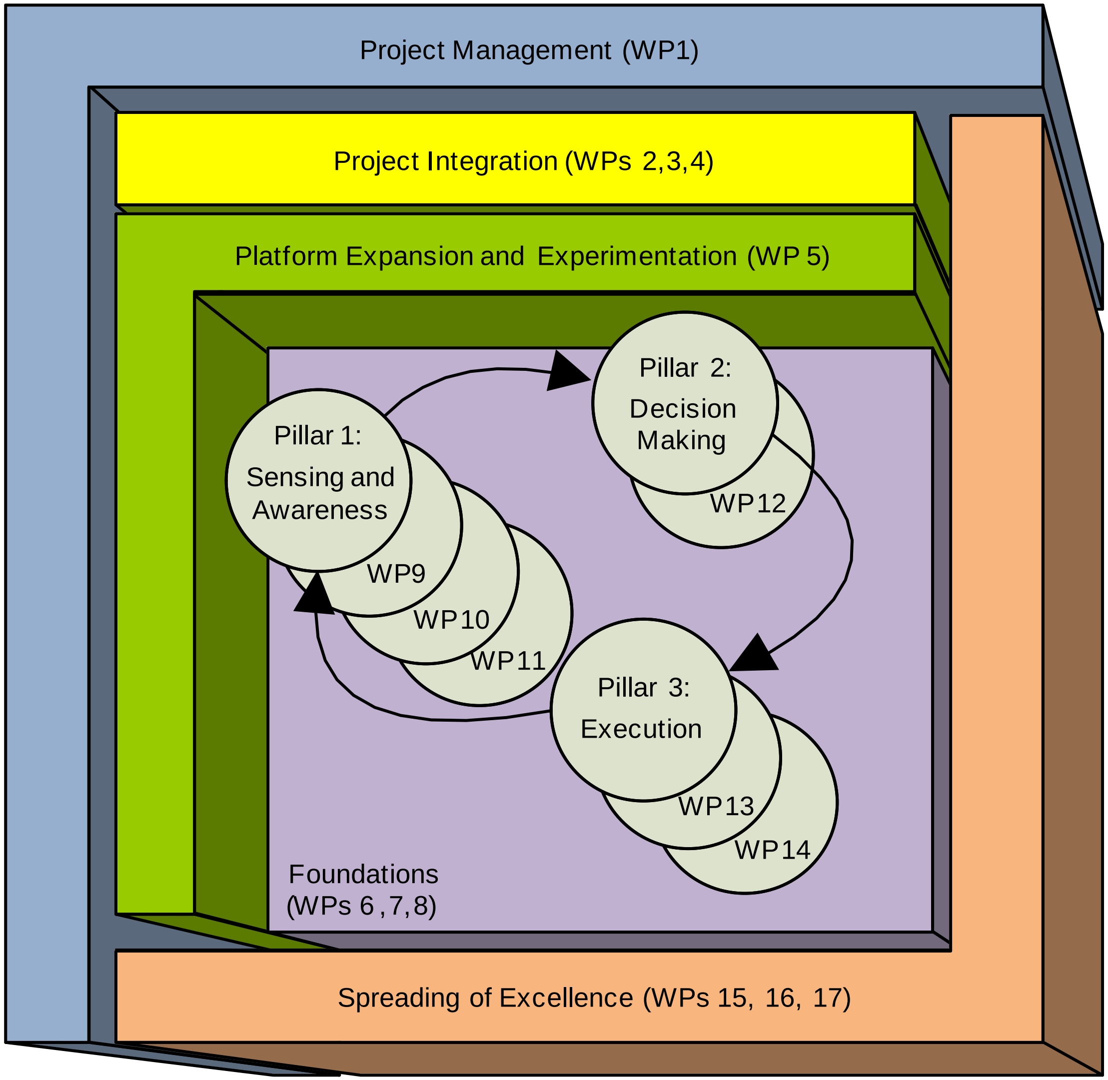
ACROPOLIS Structure and Purpose

- A "Network of Excellence" EU Research Project. Follows typical structure:
  - "Integration".
  - "Collaborative Research".
  - "Spreading of Excellence".
- Such a project aims to bring some of the best EU researchers on a particular topic together (in this case, spectrum coexistence technologies such as CR), in order to share ideas, "integrate" their research and make the whole more than the sum of its parts.
  - Analyses current situation and fills the gaps in terms of what is missing in the EU research repertoire.
  - Aims to maximise the impact of the research through contributions to standards, regulators and other long-term impacts.
- Also aims to promote the prospects for the technology in question, by educating future researchers in the area, and organising dissemination events, etc.

ACROPOLIS Topics

- ACROPOLIS aims to further progress in spectrum coexistence technologies such as CR, DSA, and self-organising networks, on axes mirroring the “cognition cycle” and foundations, such as:
  - Supporting fundamentals (e.g., SDR, game theory, optimisation, capacity analysis).
  - Awareness and learning (e.g., spectrum sensing, database approaches, device and network awareness, machine learning).
  - Decision making and execution (decision making, CR PHY/MAC considerations, interference management, post-deployment validation, certification requirements).
  - Market prospects and long-term viability, including standardization and regulatory enhancement.
- More detail at www.ict-acropolis.eu, or email oliver.holland@kcl.ac.uk, hamid.aghvami@kcl.ac.uk

ACROPOLIS Workpackages



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Some Recent Examples of ACROPOLIS Technical Work

Supporting Fundamentals

SDR Design and Hardware Implementation Example

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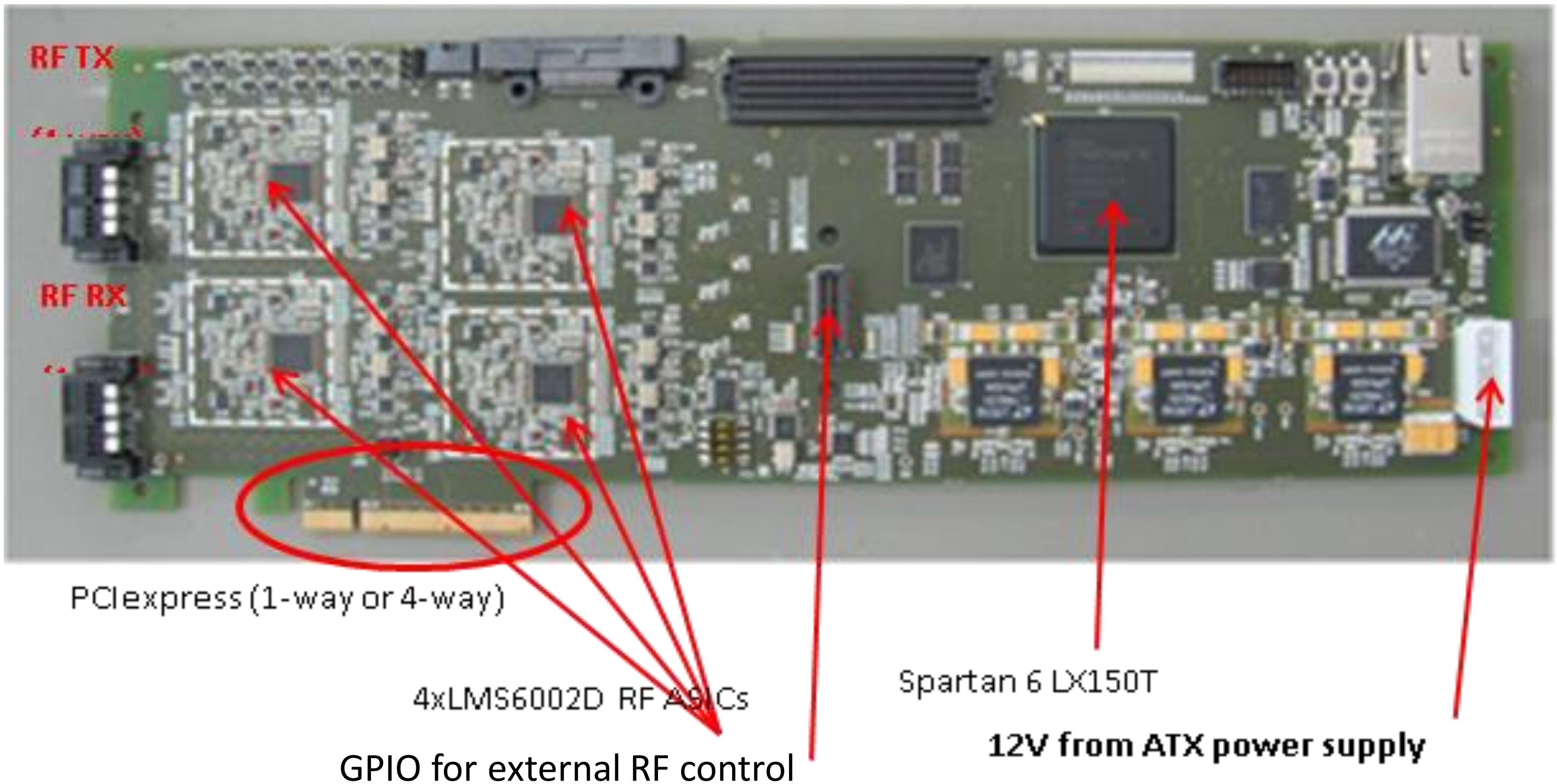
- Development of a new OpenAirInterface hardware, known as ExpressMIMO2, targeted specifically for experimentation in agile spectrum usage.
- Main objectives.
  - Low-cost for experimentation in networking and not only point-to-point PHY.
  - LTE-grade multi-channel RF (high quality components).
  - Real-time PC-based Linux SDR with minimal HW development (i.e. pure software radio).

ExpressMIMO2



- RF + PCI Express baseband interface
- Four 20 MHz RF chipsets (0.35 – 3.8 GHz), extension for power/switching possible
- Fabrication run of 15 cards in January 2013
- Low cost (2800 euros)

ExpressMIMO2 RF Performance

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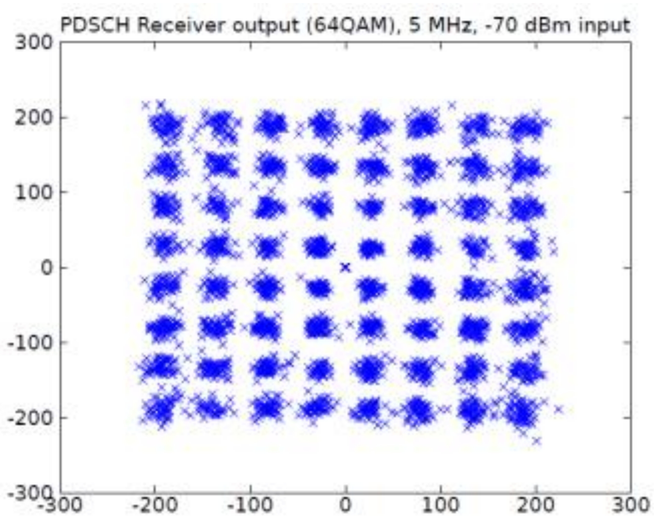
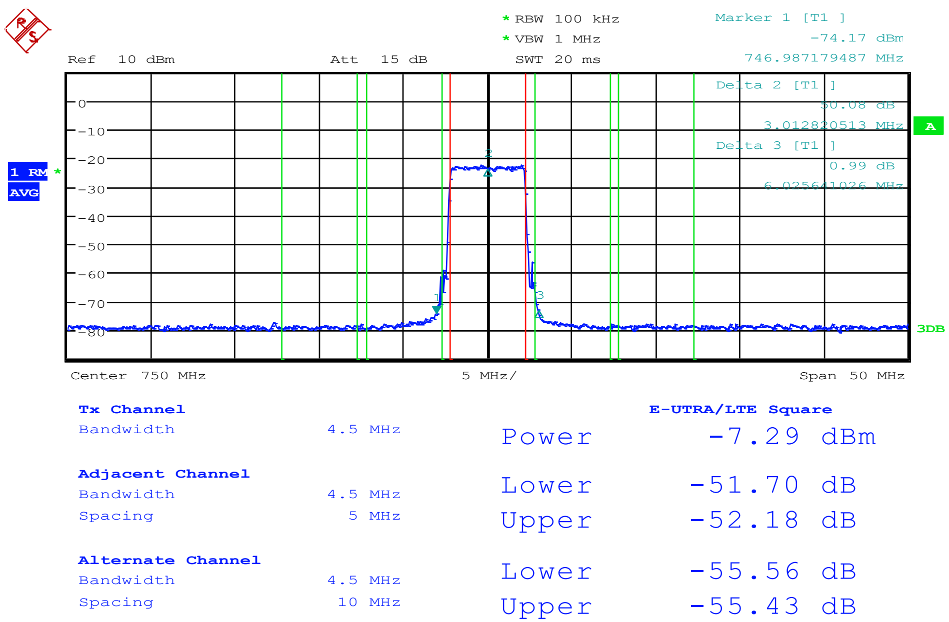


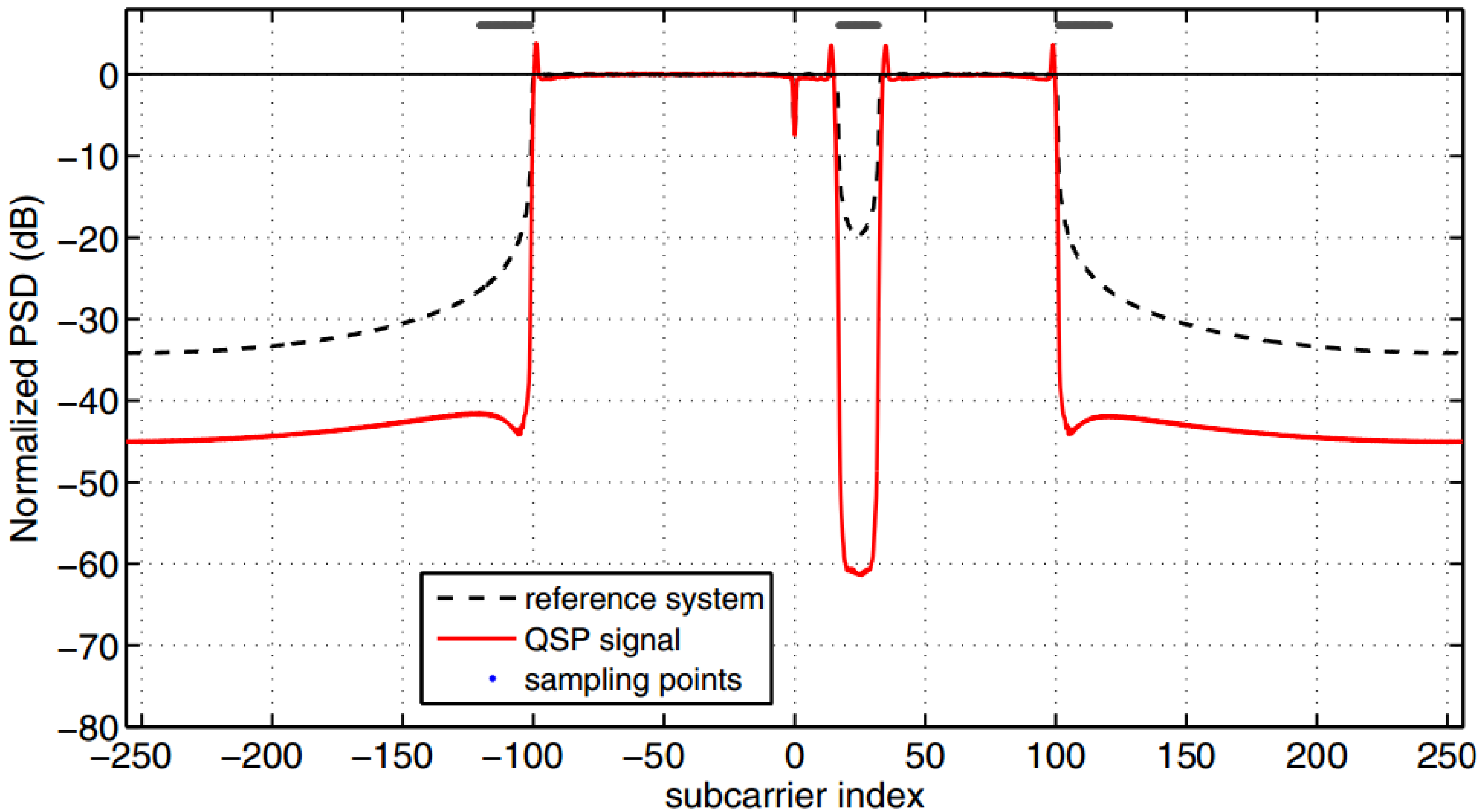
RX with LTE 5MHz 35dB SNR



TX with LTE 5MHz @ 750 MHz

Radio Interface Development for Spectrum Sharing and Cognitive Radio

- Out-of-band emissions reduction in for secondary NC-OFDM using flexible Quasi-Systematic Precoding (QSP).



Multi-Antenna Transmission for Overlay Cognitive Radio with Explicit Message Learning Phase

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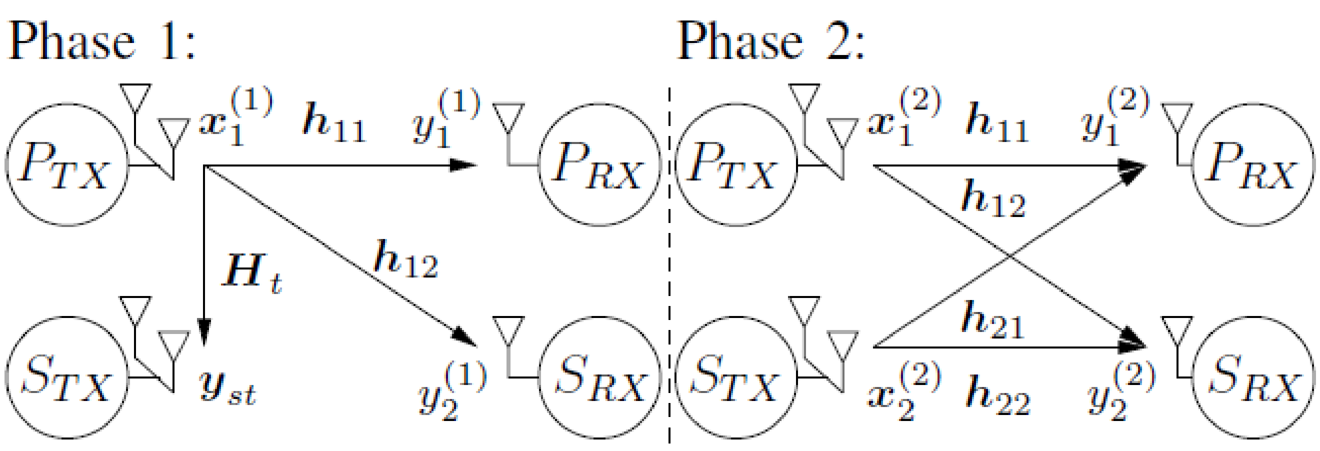
- New CR channel with message learning. Considers rate loss due to message learning. Combines DF relaying with conventional CR channel.
  - Introduces model for this channel and coding strategy using techniques for cooperative communication and classical cognitive radio channel.
  - Optimizes the system to maximize the rate of communication for the secondary users under a primary-user rate constraint and find efficient algorithms to compute the optimal system parameters.
  - Compares this strategy to an underlay cognitive radio strategy to assess their relative merits and the cost of acquiring the primary message.



Multi-Antenna Transmission for Overlay Cognitive Radio with Explicit Message Learning Phase

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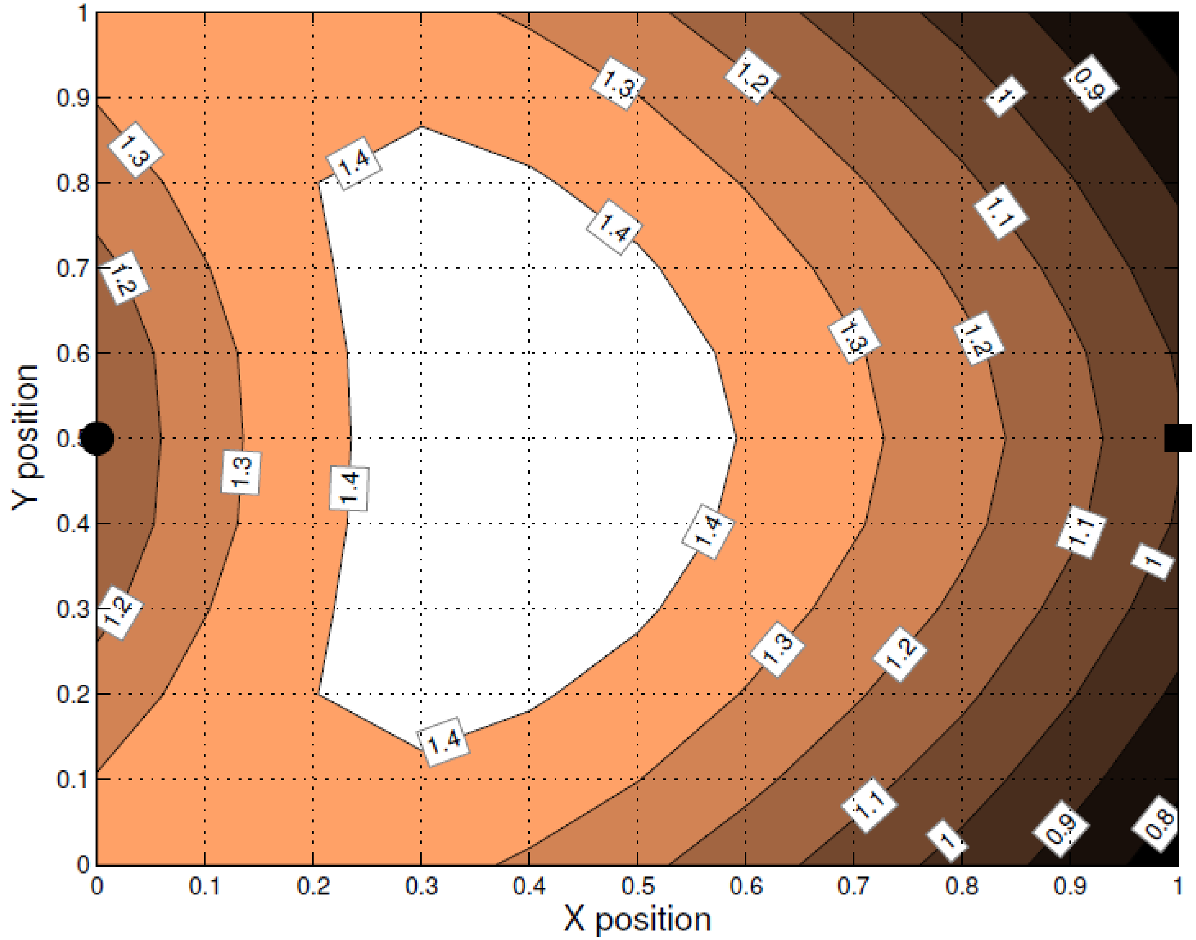
- Advantage of the overlay strategy over the underlay strategy measured by the ratio of average rates.



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Some Recent Examples of ACROPOLIS Technical Work

Awareness and Learning

Spectrum Measurements in London

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- Further analysis of extensive spectrum measurement campaign in London, July 2011.
- Measurements covered a wide range of spectrum bands below 3GHz in frequency.
- Measurement locations included a busy shopping area (Oxford Street), a touristic/night-life area (around Covent Garden/Trafalgar Square), a residential area, a suburban area, the Wimbledon men's final, Heathrow Airport, a central business district area, partial coverage of a terminus train station in the rush hour, and the roof of King's College London in central London for a prolonged duration of over two weeks.
- This reported work concentrates on some analysis of stationary measurements on roof of King's College London.
- Reported analysis has particularly concentrated on aspects such as duty cycle and associated variation, that may be used to assess potential for dynamic spectrum access. Other work has looked at aspects such as spatial correlation to assist dynamic spectrum access.

Spectrum Measurements in London

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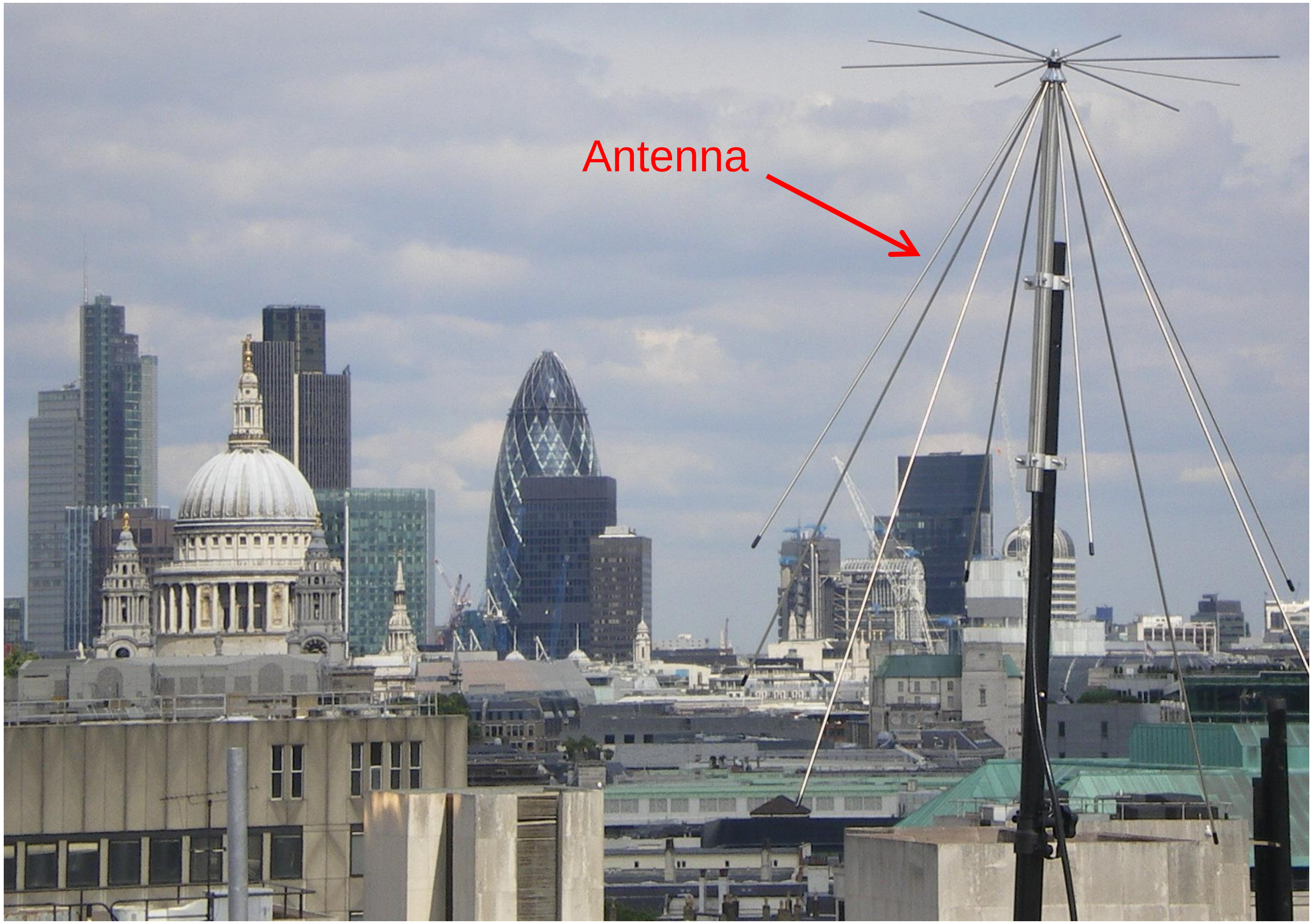

Spectrum Measurements in London

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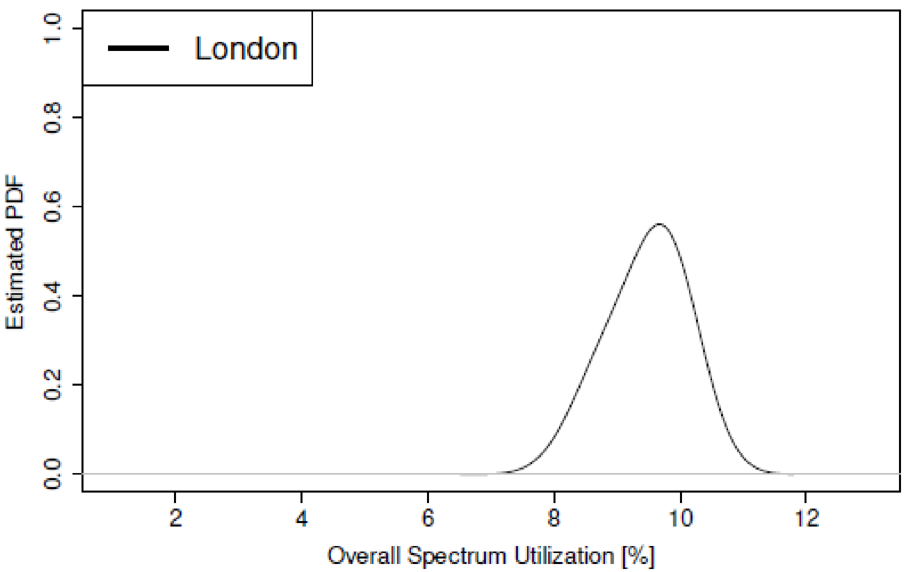
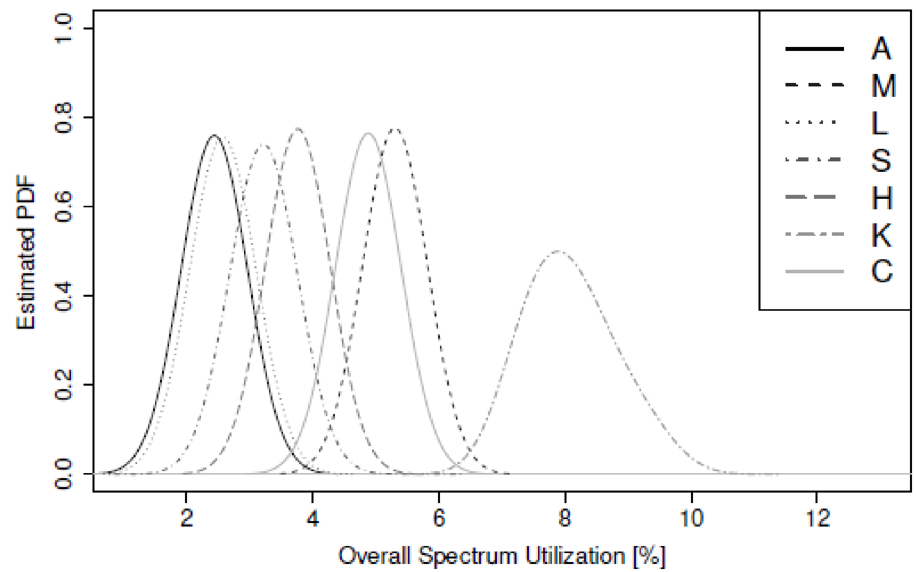
- Spectrum Utilization for 300 MHz to 3 GHz spectrum compared against the findings of the rest seven European cities measurement sites. The 7 European Cities are: Aachen (A), Maastricht (M), Skopje (S), Leuven (L), Hannover (H), Krefeld (Kr) and Constance (C).



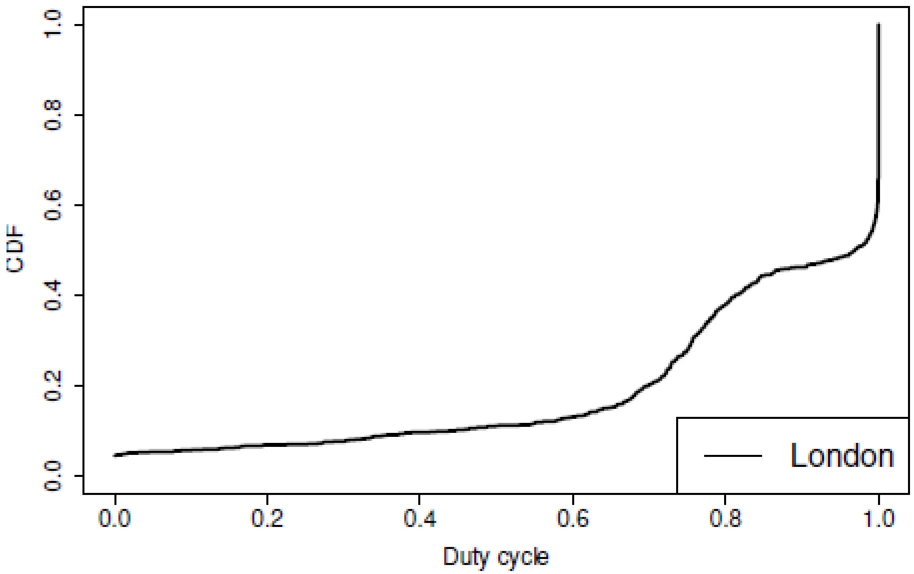
(a) London, Thursday 28.07.



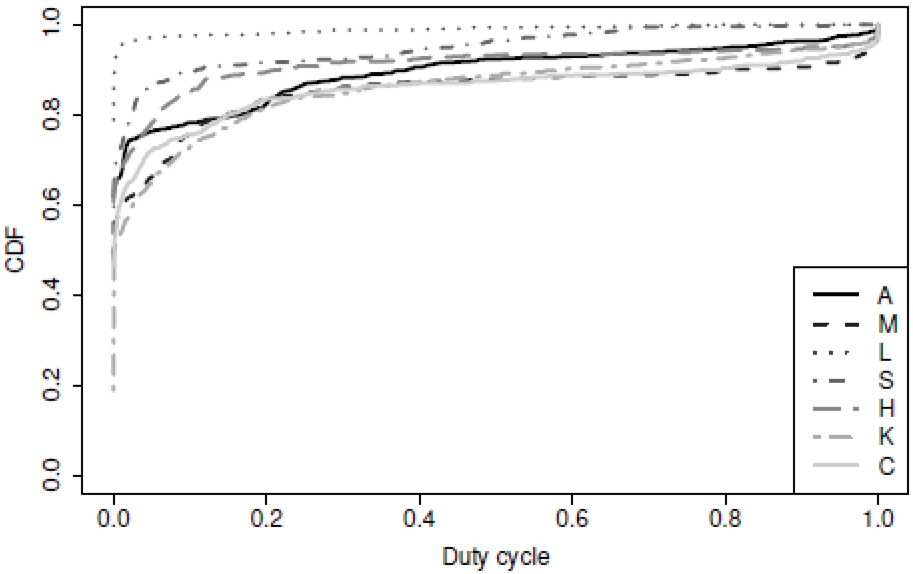
(b) 7 European Cities, Thursday 13.10.

Spectrum Measurements in London

- CDF plots of the Duty Cycle for the GSM 1800 band compared against the findings of the rest seven European cities measurement sites. The 7 European Cities are: Aachen (A), Maastricht (M), Skopje (S), Leuven (L), Hannover (H), Krefeld (Kr) and Constance (C).



(a) London, Thursday 28.07., GSM 1800



(b) 7 European Cities, Thursday 13.10., GSM 1800

Spectrum Measurements in London

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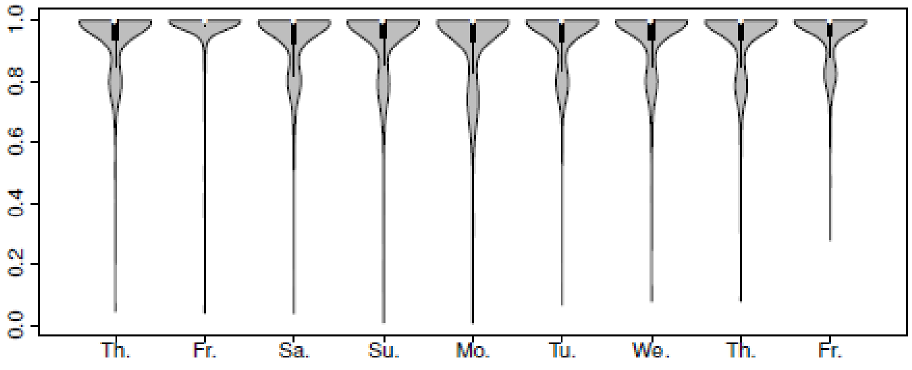
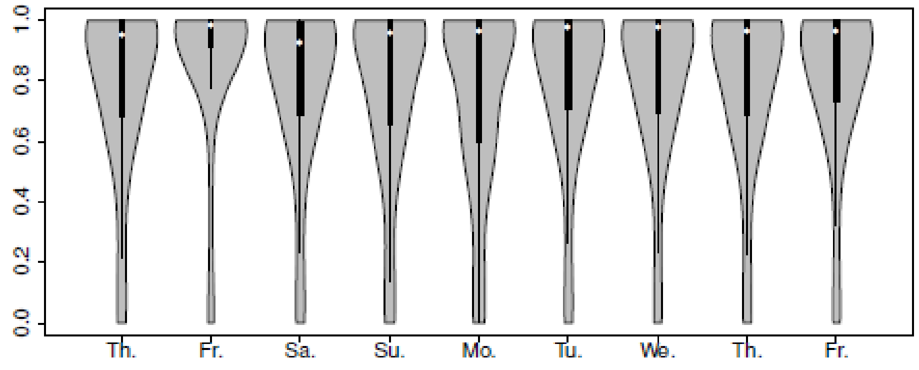
- Violin plots of the duty cycle for the GSM bands each day.

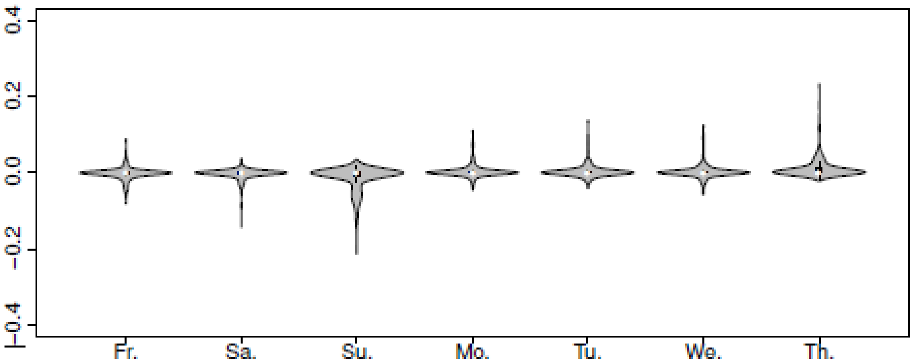


(a) GSM 900

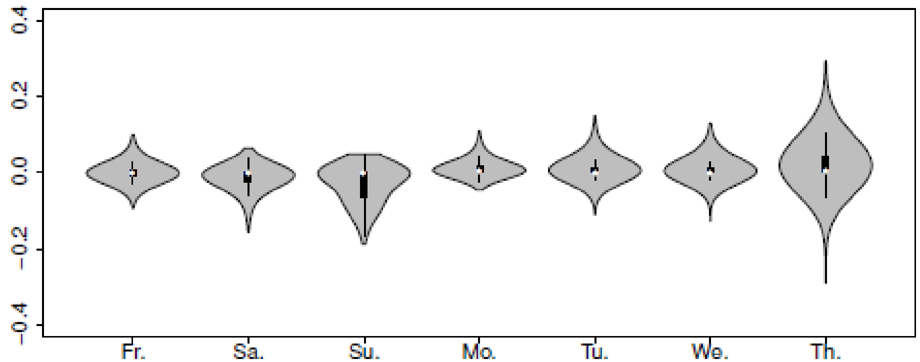


(b) GSM 1800

- Variation in the duty cycle from the mean each day.



(a) GSM 900



(b) GSM 1800

Radio Environment Mapping and Awareness

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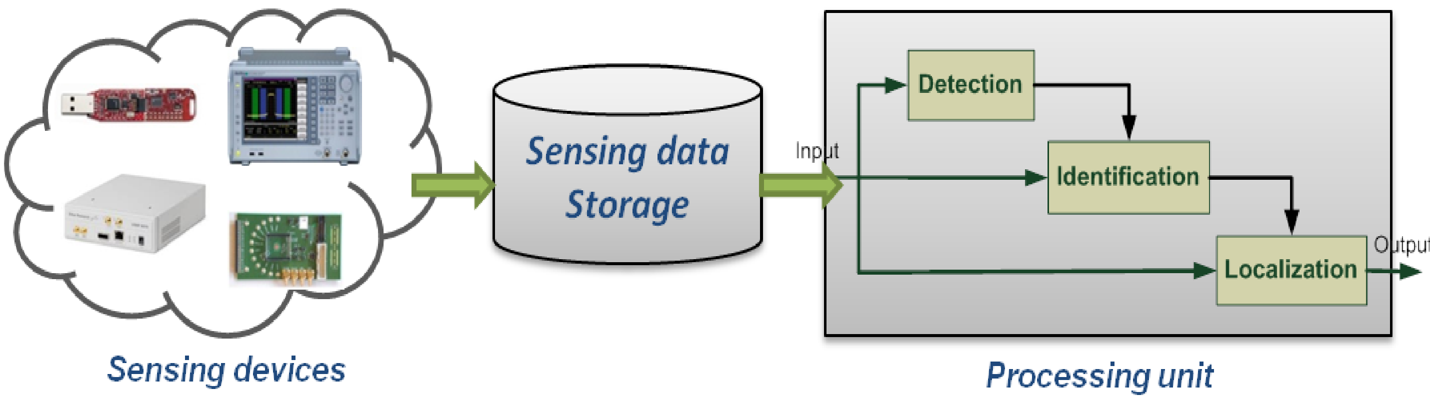
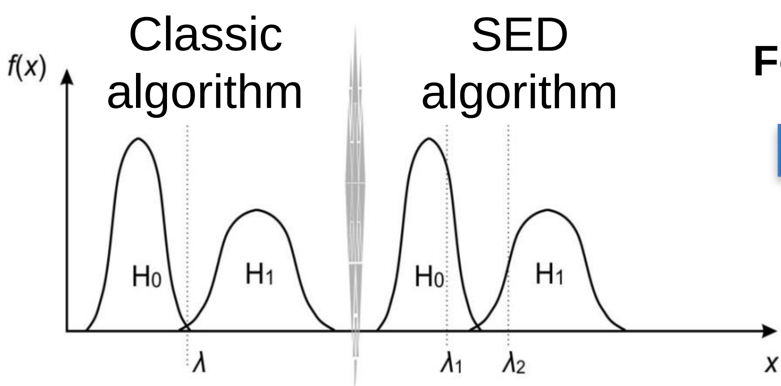
- Working on integrated architecture aiming to unify the following techniques supporting dynamic spectrum access, and explore the synergies amongst them.
  - *Source detection* determines the *existence* of a source (or sources) above and beyond the radio background and, as such, alerts the system to proceed with further processing.
  - *Source identification* looks for *unique features* in the detected source(s) and classifies them accordingly.
  - *Source localization*, which seems to *position* the source(s) in space and determine exactly their radiating profile.

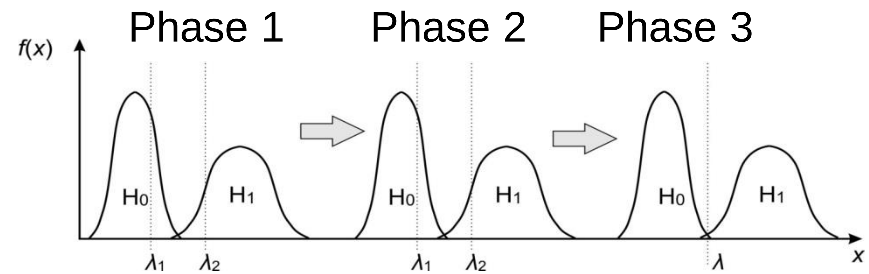


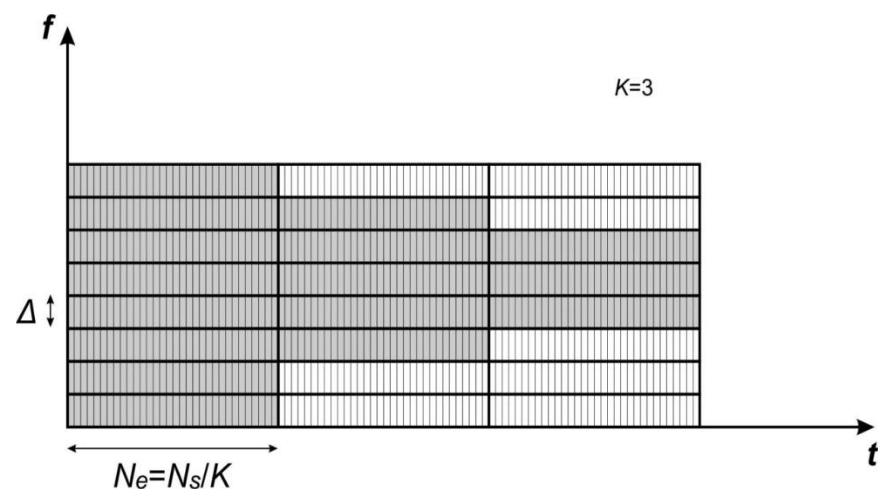
Combination of these elements in a synergistic way in a database and processing unit.

Detection Example: Sequential Energy Detection

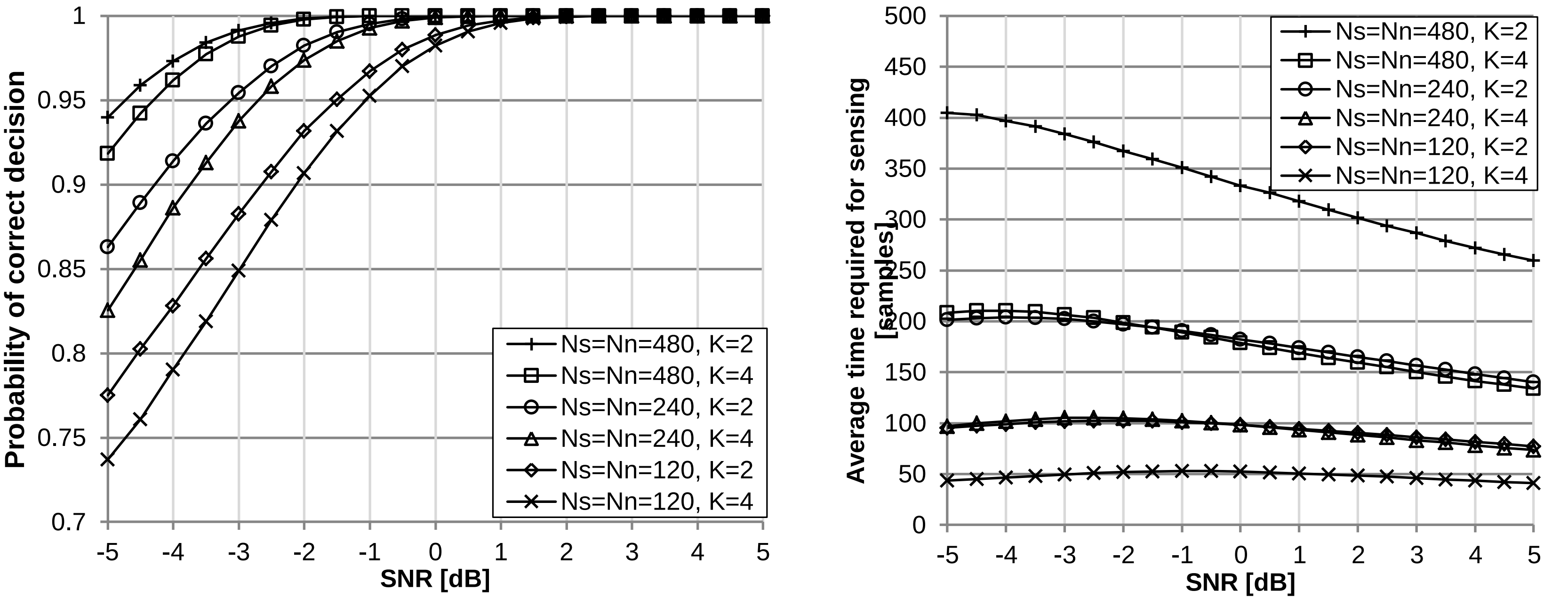


For K=3 stages





Detection Example: Sequential Energy Detection



Some exemplary results for the selected cases of the number of times that the sequential process is iterated, K=2 or K=4, where Ns and Nn represents the maximum number of signal and noise samples collected before making decision

Identification Example: Signal Classification Artificial Neural Network

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- Aim is to distinguish between DVB-T, W-CDMA and (OFDM-based) 802.11
- Could (futuristically) be applied, for example, in determining whether signal in TV band is a secondary or primary hence whether it is OK to transmit.
- The confusion matrix below shows a good performance of a simple yet efficient MLP neural network with an overall correct classification of over 90%.
- Similarity of IEEE 802.11a and DVBT standards where misclassification rate is higher than in the cases of differentiation between a WCDMA based UMTS network and the other two.

All Confusion Matrix after Cross Validation

Output Class \ Target Class	1	2	3	
1	**221.13** 30.13%	**0** 0.0%	**27.87** 3.8%	88.81% 11.19%
2	**3.51** 0.48%	**237.57** 32.37%	**7.92** 1.08%	95.41% 4.59%
3	**31.32** 4.27%	**0.47** 0.06%	**204.21** 27.82%	86.53% 13.47%
	86.39% 13.62%	99.8% 0.02%	85.09% 14.91%	**90.31%** **9.69%**

Class 1: DVB-T
Class 2: W-CDMA
Class 3: (OFDM-based) 802.11

Localisation Example – Gaussian Mixture Model

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- Step 1: choose a direct approach (search on full 2-D plane instead of on a grid) for a range of possible number of sources.
- Step 2: estimate the correct number of sources via either the Akaike Information Criterion or the Minimum Description Length criterion
- Step 3: invoke a *novel approximation* for the measured signal strength at each sensor, which leads to the Gaussian Mixture Model (GMM)
  - GMM will be parameterized by the positions and tx powers of the sources ***(θ)***
- Step 4: employ the iterative Expectation-Maximization (EM) algorithm for estimating this $\boldsymbol{\theta}$ which defines the GMM

Fact: complexity of proposed solution *grows linearly with the number of sources*

Localisation Example – Gaussian Mixture Model

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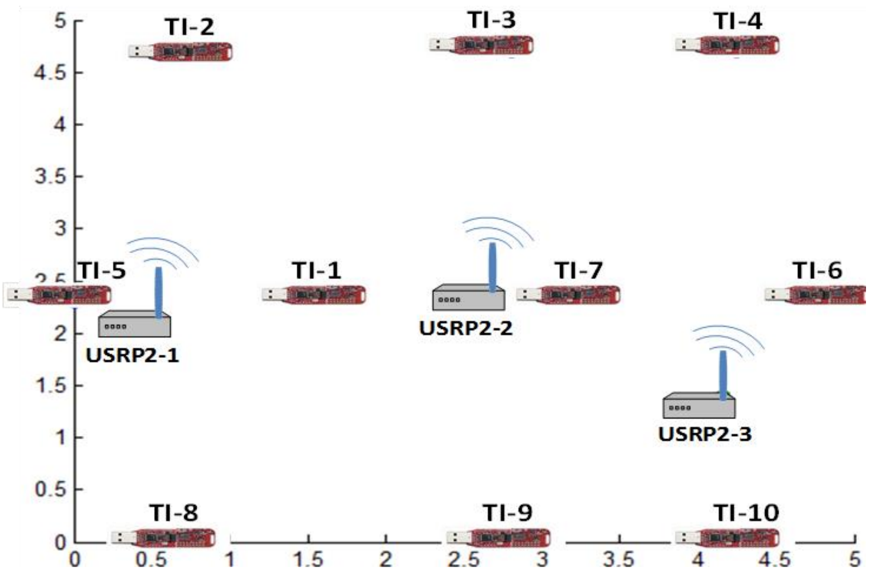
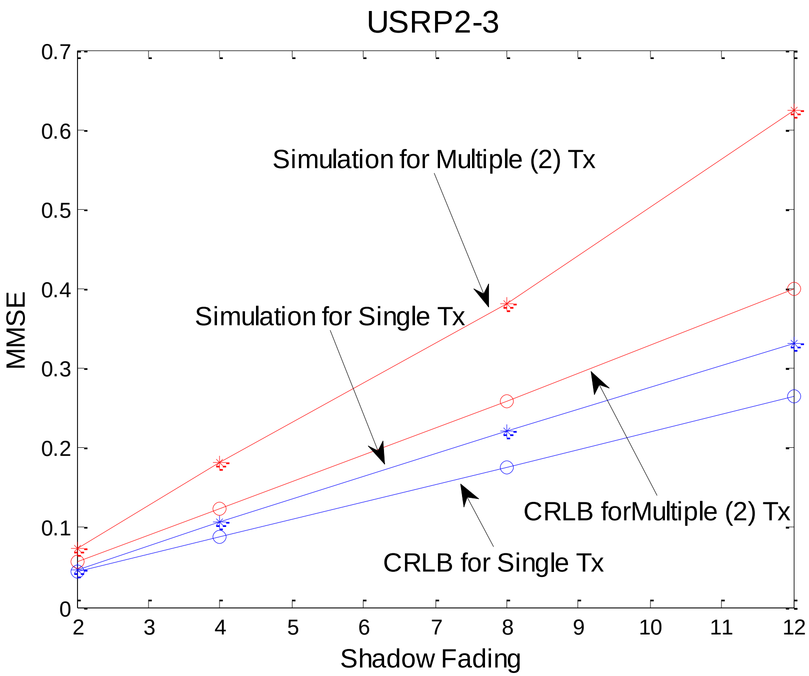
- Topology: ten sensors, regular grid in a 25m^2 area of a classroom
- Measurements on 3 USRP transmitters, 2.4 GHz ISM band, various on-off combos
- Propagation parameters derived via Least-Squares fit, one transmitter on at a time
- Active sources are USRP2-1 and USRP2-3.
- Shadow fading variance σ^2=(2,4,8,12); path-loss exponent = 2; *Tx* power = -10dBm
- Topology and localisation results, in terms of MMSE vs. Cramer-Rao Lower Bound (CRLB)





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Some Recent Examples of ACROPOLIS Technical Work

Decision Making and Execution

Decision Making Framework

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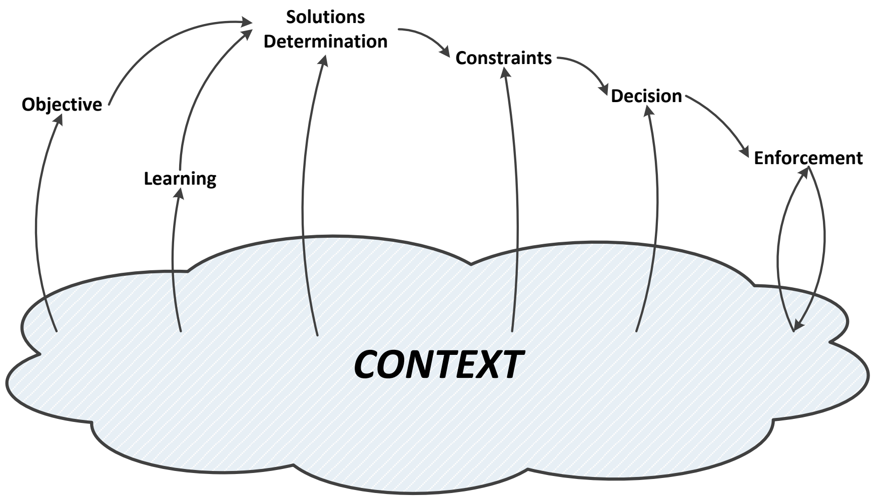
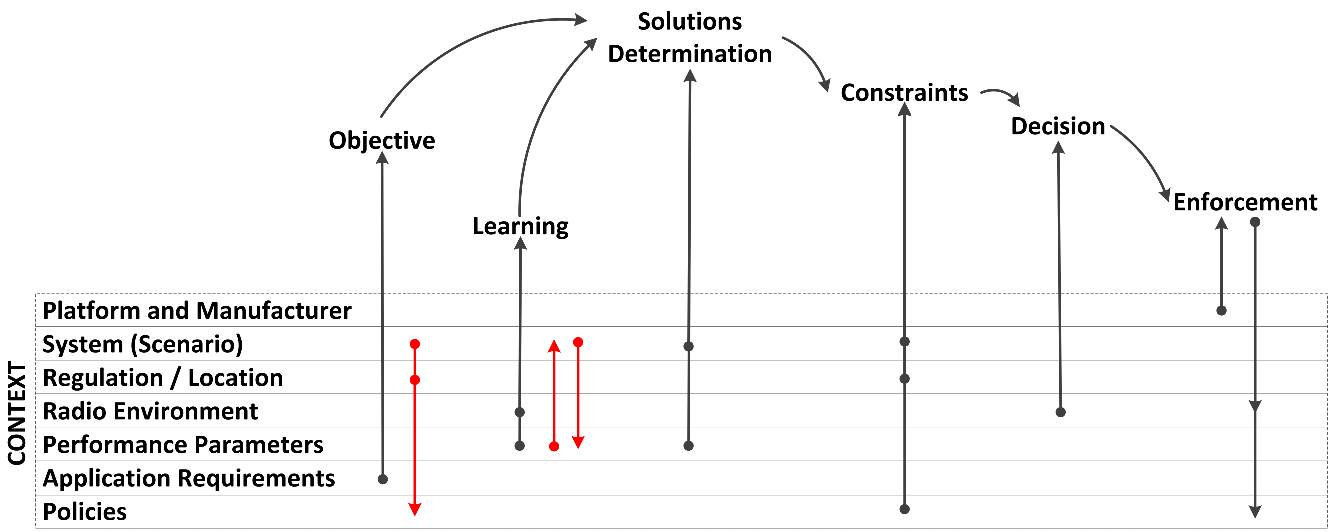
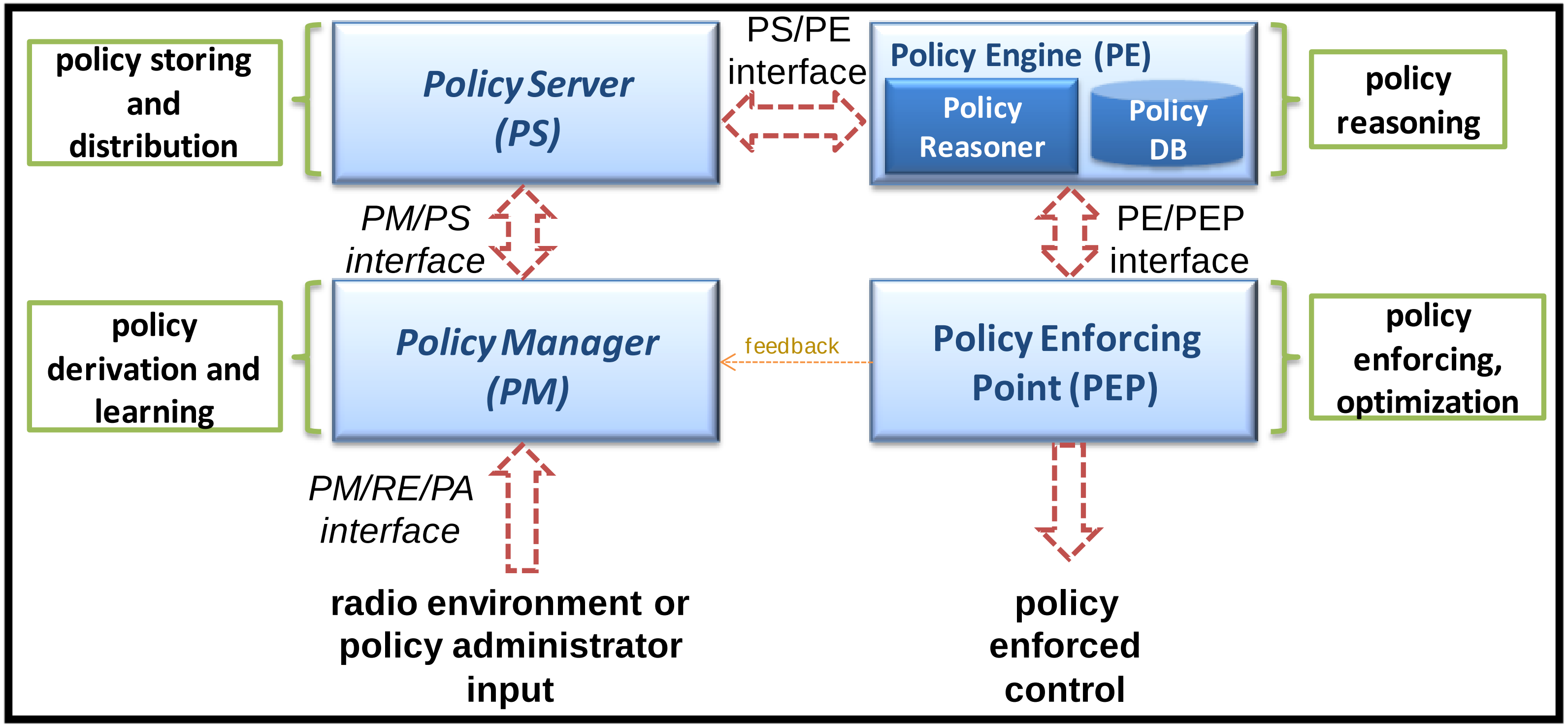
- A structured framework within which ACROPOLIS is assessing the context involved in different stages of the decision process
  - Aims to support information structuring and exchange within decision making processes
  - Further work in progress





Policy Derivation and Management

- Actively working on policy derivation and management processes
  - Architecture and functions as follows.



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“Integration” and “Spreading of Excellence” Efforts

Standardisation, regulation, events, courses, tutorials, publications organisation

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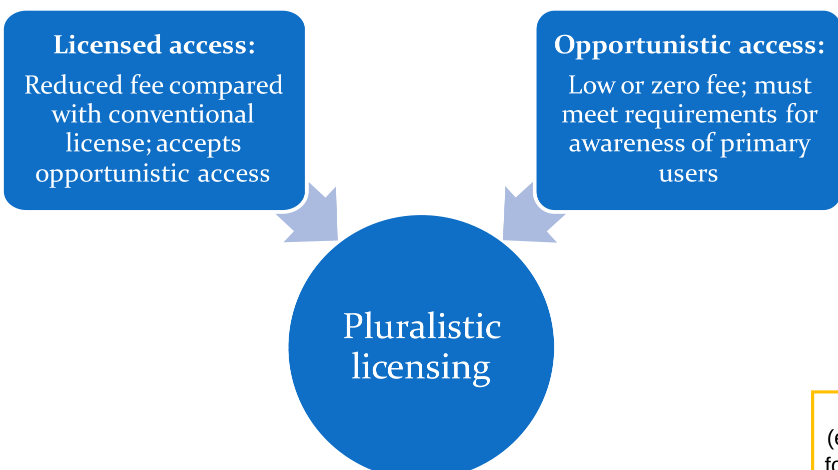
Standardisation and Regulation

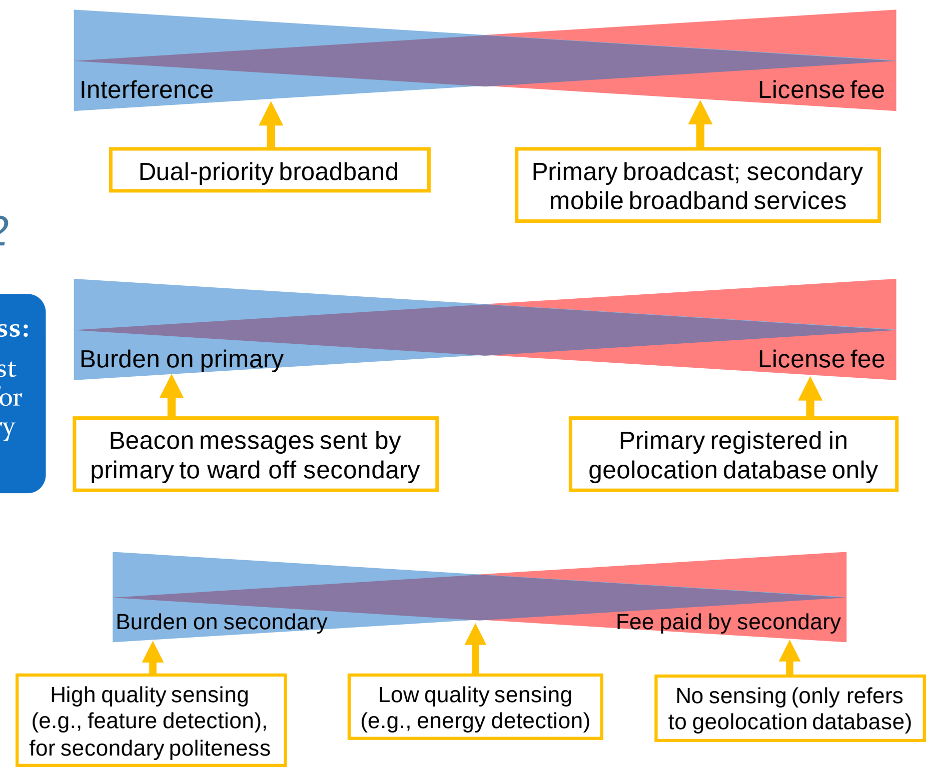
- Actively contributing to various standards.
  - IEEE 1900.1 – Terms and definitions.
  - IEEE 1900.6 – Use of 1900.6 to facilitate formation of opportunistic cognitive radio links for energy saving, capacity improvement and other purposes.
  - IEEE 1900.7 – General requirements, use cases, radio interface definition.
  - Ongoing impacts on IEEE DySPAN-SC (IEEE 1900) groups and ETSI-RRS through ACROPOLIS members leaderships therein.
- Continuing discussion with (proposals to) Ofcom on a variety of subjects.
  - Managing of secondary-secondary coexistence.
  - “Dedicated Cognitive Radio Band” and “Pluralistic Licensing”.
  - Aggregated interference.
  - 3D space/frequency path loss map.
- Further work on the “Pluralistic Licensing” and “ISM-Advanced” concepts (also within the scope of COST-TERRA).

Regulation: Pluralistic Licensing (with COST-TERRA)

- "…the award of licenses under the assumption that opportunistic secondary spectrum access will be allowed, and that interference may be caused to the primary with parameters and rules that are known to the primary at the point of obtaining the license…"

O. Holland, L. De Nardis, K. Nolan, A. Medeisis, P. Anker, L. Minervini, F. Velez, M. Matinmikko, J. Sydor, "Pluralistic Licensing," IEEE DySPAN 2012, Bellevue, WA, USA, October 2012





Workshops, Special Issues, Tutorials, PhD Courses Organisation, etc.

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- Has been very active in organising workshops and special sessions
  - IEEE PIMRC 2011; IEEE CAMAD 2011; EUSIPCO 2011; WSA 2012; CROWNCOM 2012; WInnComm-Europe 2012 (Annual Workshop and Industry Panel); IEEE ISWCS 2012; ICT 2013; IEEE ISWCS 2013; IEEE PIMRC 2013
- ACROPOLIS-supported journal special issues
  - Journal of Green Communications; Hindawi Journal of Electrical and Computer Engineering; IEEE Wireless Communications Magazine; Transactions on Emerging Telecommunications Technologies
- Organised several tutorials at IEEE DySPAN 2011 and other prominent events
- Organised ~15 PhD-level courses covering a range of topics in spectrum sharing/coexistence
- Held five summer/winter schools on spectrum coexistence technologies thus far

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Some Future Directions

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Focal Topics

- Intensive work on high energy “focal topics”, recently defined within the project.
  - Neighbor and network discovery
  - Source detection, identification and localization
  - Interference management and mitigation
  - The ACROPOLIS Decision Making Framework
  - Experimentation and hardware validation
- Will be the basis for intensive outputs as the project approaches its culmination.

Architectural Framework

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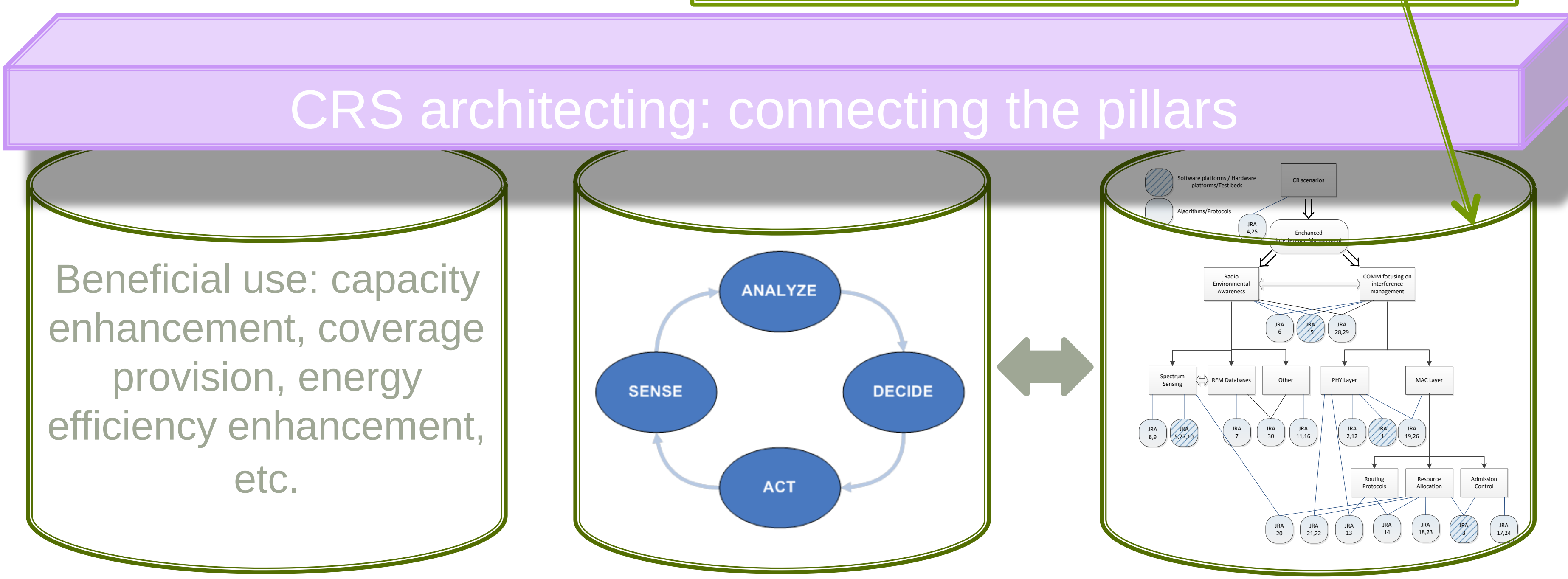
- Development of common component-based architectural framework using ACROPOLIS developed elements based on the cognition cycle and associated appropriate components and interactions therein.
- Different instantiations and selected modular components based on the beneficial use case.

ACROPOLIS Classified Research Activities



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That's all folks!

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Acknowledgement

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