SACRA

Project Number: 249060

SEVENTH FRAMEWORK PROGRAMME

THEME ICT-2009-1.1
The Network of the Future

ICT SACRA Green Radio and Energy Efficiency
Mobile VCE Workshop on Green Radio - 23 June 2011

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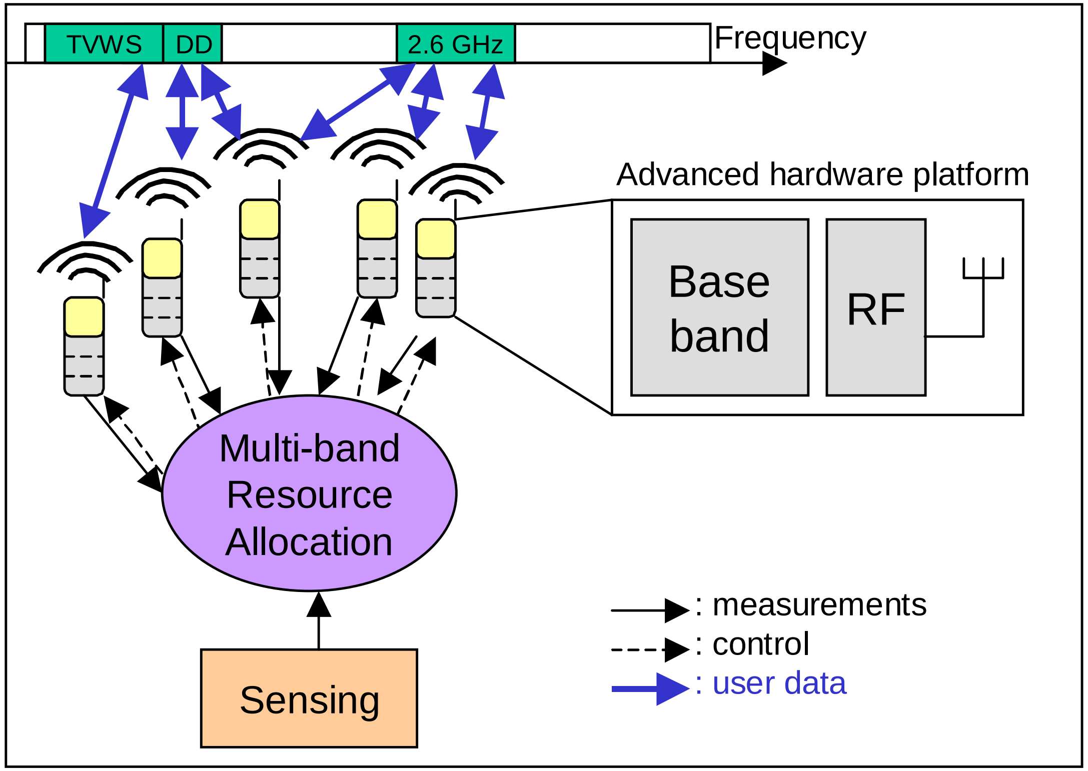
Outline

- SACRA Overview
- Part 1: Green Radio aspects in the scope of the SACRA Project
- Part 2: University of Athens work on Energy Efficiency

SACRA Overview

SACRA objective: study and demonstration of spectrum and energy-efficient communications through multi-band cognitive radio

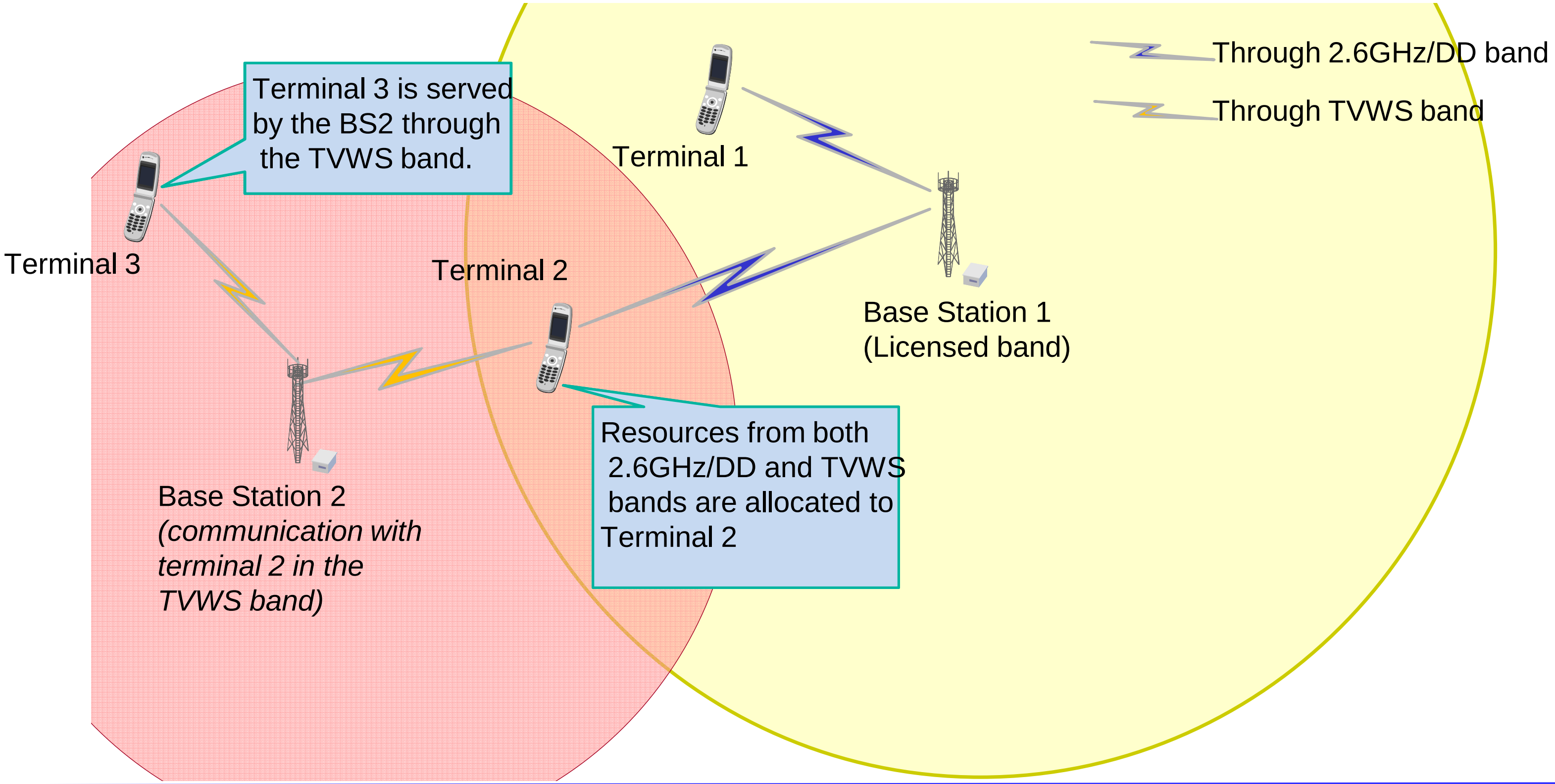


SACRA features for a more dynamic behaviour of the operating networks:

- capability to use **jointly and simultaneously two different frequency bands,**
- capability to perform **an opportunistic use of the spectrum** in the TV white spaces (until 470 MHz).

SACRA Use Cases

➤ Main SACRA use cases: intra/inter-cell spectrum aggregation, cognitive relaying and cognitive femto-cell



SACRA Use Cases

- They derive benefit from the multi-band capability of SACRA terminals:
  - To sense in one band (when required) while communicating in the other band,
  - To aggregate the data blocks from two frequency bands,
  - To communicate over multiple antennas when only one frequency band is in use.
- Expected gains in terms of:
  - Throughput and/or coverage depending on the use case ;
  - Energy efficiency thanks to the monitoring of the spectrum to select the most efficient parameters (band, power,…) to achieve the expected QoS.

Part I - Green Radio Aspects in the SACRA Project

- SACRA aims to develop new “Green" Techniques for the global efficiency of wireless systems in the following 3 directions:
  - Minimization of electronic components’ number which further leads to the minimization of the ICT environmental impact
  - Energy optimization for wireless communication terminals by optimizing architecture design and algorithms implementation
  - Minimization of the generated interference in the environment by selecting the adequate band which will guarantee the shortest transmission distance and the minimum power while preserving the Quality of Service

Energy Efficiency in the SACRA Project

- Energy efficiency is a global indicator considered by SACRA
- SACRA targets:
  - Less total energy spent at the whole system scale for a given Quality of Service
  - Less energy spent locally on an element (e.g. a terminal) for a given Quality of Service, so as to increase the battery life
- Energy efficiency is used in several SACRA Work Packages related to implementation and radio resource management

Energy efficiency at the System Scale

- Energy savings shall target:
  - First, base stations because they account for a large amount of the total energy
  - Next, RF and analog parts of User Equipments (UE) on TX path because they represent (or will in the future) a significant portion of the energy consumed by a UE
  - Next, RF and analog parts of UE on RX path
  - Last, the whole UE digital data processing (baseband and application processor) because it is (or will be) a small portion of the whole energy consumed by a UE

Energy Savings at the System Scale

- Energy savings shall rely on:
  - System level optimizations (sensing, cognition, RRM, …) that reduce the BS power and maybe also the UE power
  - Power transfers from RF to BB in UE
    - Exchange energy inefficiencies if the RF against digital signal processing in the baseband
      - Digital Pre-Distortion (DPD)
      - Peak to Average Power Ratio reduction (PAPR reduction)
    - Might be not that efficient at a given point in time but… Moore’s Law
  - Optimizations of the digital part of the UE

Energy-aware Sensing optimizations

- From the sensing point of view Energy Efficiency optimization depends on the final goal:
  - local optimization **or**
  - global optimization.
- For a given set of requirements (e.g., Detection Probability, False Alarm Probability), Energy Efficiency optimization is done through:
  - Local Energy Consumption Minimization
    - Can be done through cooperative sensing – Cooperative sensing is increasing the global energy consumption, but it can be used to decrease local energy consumption.
    - Can be done by using less complex sensing algorithms
  - Global Energy Consumption Minimization
    - By choosing the lowest energy consuming cooperative sensing algorithm
    - Can be done by using less complex sensing algorithms

Complexity of the Sensing Algorithm

- The complexity of the Sensing Algorithms is increasing the energy consumption
- The acquisition time and the sampling time have also an impact on total Computation Load (CL)
- CL is given by total number of instructions (multiplications and additions)
- Reducing the local complexity can be done by:
  - Tuning parameters of a specific sensing algorithm, e.g.:
    - **Welch Method:** For a given set of requirements, number of segments used by the periodogram plays an important role in the energy consumption.
    - **Energy Detector :** with/without complex noise estimation.
    - **Cyclostationary Detector:** Data Base assisted/not assisted (the cyclostationary features are known/not known)
  - Choosing between different algorithms the one that meets the requirements and has the smallest complexity.

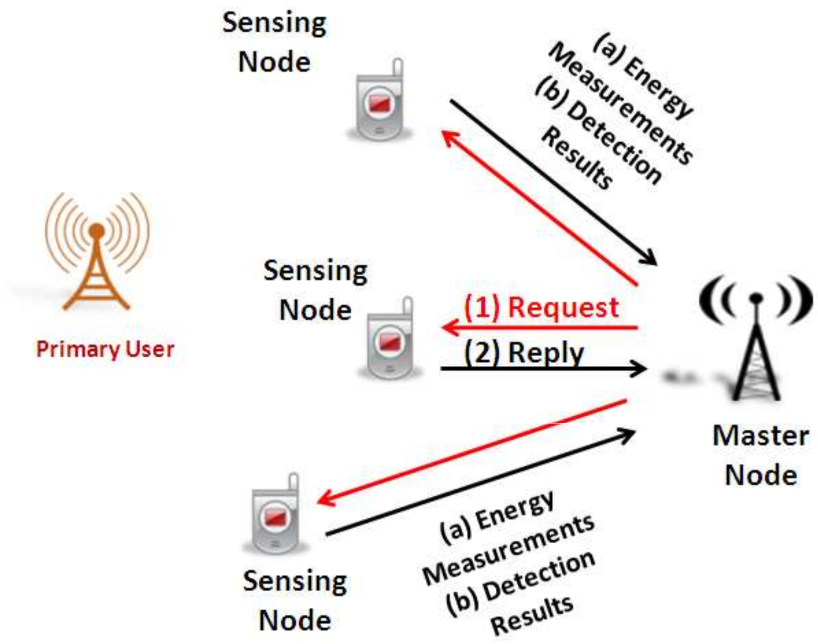
Sensing algorithms comparison

Method	Real multiplications	Real additions
ED	2N+4	2N+1
CD (Generalized Likelihood Ratio Test)	$(8K+4K\log_2 N+8)N+KL$	$(6K+6K\log_2 N+4)+7KL-3K$
Welch	$2N\log_2(N/M)+4N+(N/M)+1$	$3N\log_2(N/M)+3N+L_s-(N/M)-1$
Welch with Noise Estimation	$2N\log_2(N/M)+4N+(N/M)+2$	$3N\log_2(N/M)+3N+L_s+((B-1)(L_n-1))-(N/M)-1$
Etc..		

- N is the number of samples
- K is the number of cyclic frequencies
- For GLRT, L is the window length used
- M is the number of segments used by Welch Periodogram
- Ls is the length of the frequency domain region where signal + noise is estimated
- Ln is the length of the frequency domain region where noise is being estimated
- B is the number of sub-bands where noise is being estimated

Cooperative Sensing

- SACRA is studying how the cooperation is improving detection performances.
- A large number of acquired samples increases the local single-node energy consumption.
- For a given set of requirements, compared to a node involved in the cooperative sensing, a non-cooperative sensing node consumes more energy to reach the same performance.
- However, cooperative sensing means also reporting: while for single node sensing techniques the sensing information is locally used, for the cooperative sensing extra energy is consumed when acquisition results and/or measurements are transmitted to the master node.



Cooperative Sensing

(a) Soft-Information based
(b) Hard-Information based

Energy efficiency at the Local Level

- Energy savings shall target:
  - First, RF and analog parts of UE on TX path
  - Next, RF and analog parts of UE on RX path
  - Last, on the whole UE digital data processing
- In order to minimize the electronic components, SACRA will use a Software Designed Radio (SDR) approach to design a flexible and agile architecture for the RF including antennas, the Analogue to Digital conversion and the digital baseband processing.
- SACRA also propose Baseband/RF co-design techniques for the energy minimization in wireless communication terminals

General Modem Power Efficiency

- Remove critical components:
  - Remove external filters (insertion loss)
- Reuse HW structures
  - Sharing PAs /LNAs -> reduced band configurations(1 HB + 1 LB)
  - Sharing control units / single CPU controlling multiple lanes
- Relax WC scenarios
  - Avoid critical system scenarios based on sensing
- Tune TRX
  - Performance / linearity on demand based on detection / sensing
- DPD
  - Optimizing PA performance using digital pre - distortion

SACRA Modem Power Efficiency

- Energy efficient implementation:
  - Integration of two RX / TX lanes (common control and lower number of components)
  - Highly reconfigurable RX and TX architectures (single lane approach)
  - Minimum number of analog components (shift to digital domain)

- DPD is main modem contributor to power efficiency

Flexible baseband processor

- Capable of handling all RX/TX, plus sensing
- Much more efficient power optimizations than with separate, dedicated processors
- Each processing unit operates at the best power node (voltage/frequency) for a given instantaneous load
- Better utilization of internal memories
- Less useless data transfers between units
- Plus all classical power saving techniques
  - Clock gating, low leakage, …

Part II- Energy-Aware Cooperative Decision Making

- Study of mechanisms for cooperative decision making based on:
  - Sensed radio conditions by opportunistic and autonomous nodes
  - Opportunistic nodes situated awareness and self-monitoring that will be adaptive from the (energy) cost and efficient standpoint
  - Formulation of policies motivating, rewarding and controlling synergistic behavior from a network perspective
  - Conform to the energy constrains and to the so-called *Green Radio necessity*
  - Multi-objectiveness, flexibility and computational efficiency

Situation-Aware Cooperative Power Control Algorithm

- **Idea:** Allow secondary nodes from different operators to cooperatively set their power levels
- **Main Scope:**
  - Optimize consumption of unlicensed UEs' (limited) power resources
  - Securing a lower bound of QoS for the UEs
  - Mitigate network interference
- **Key Points - Requirements:**
  - Distributed: distributed interference compensation
  - Cooperative decision making: message exchange schemes between nodes
  - Situation-aware: considers uncertainties through Fuzzy Logic
  - Applicable to real systems: converge within finite number of iterations
  - Supports multiple SU networks operating in TVWS
- **Cooperativeness:**
  - Nodes exchange "interference prices": marginal loss in utility if a node increases its transmission power level
- **Situation-Awareness:**
  - Uncertainties of the interference level may arise during message exchange (e.g. due to high mobility) or because of large delays in the update time of "interference prices"
  - Fuzzy Logic is introduced in order to consider uncertainties and compensate for the underestimation of interference

Situation-Aware Cooperative Power Control Algorithm

- A secondary node sets its power level by considering:
  - SINR requirements
  - The negative impact in utility for other users caused from the increased interference that will come as side effect of the increase in power of that particular node
  - This serves as counter-motive that discourages nodes from setting consistently their transmission power to the maximum allowable level.

Transmission power for *i* user on channel k

Link gain between R_i and T_i

SINR for *ith* user on channel *k*

$$\gamma_i\left(p_i^k\right) = \frac{p_i^k \cdot h_{ii}}{n_0 + \sum_{j \neq i} p_j^k \cdot h_{ji}}$$

Ambient noise level

Link gain between R_i and T_j

Logarithmic utility function for *ith* user on channel *k*

$$u_i\left(\gamma_i\left(p_i^k\right)\right) = \log\left(\frac{p_i^k \cdot h_{ii}}{n_0 + \sum_{j \neq i} p_j^k \cdot h_{ji}}\right)$$

Interference price for *ith* user on channel *k*

$$\pi_i^k = \frac{\partial u_i\left(\gamma_i\left(p_i^k\right)\right)}{\partial\left(\sum_{j \neq i} p_j^k \cdot h_{ji}\right)}$$

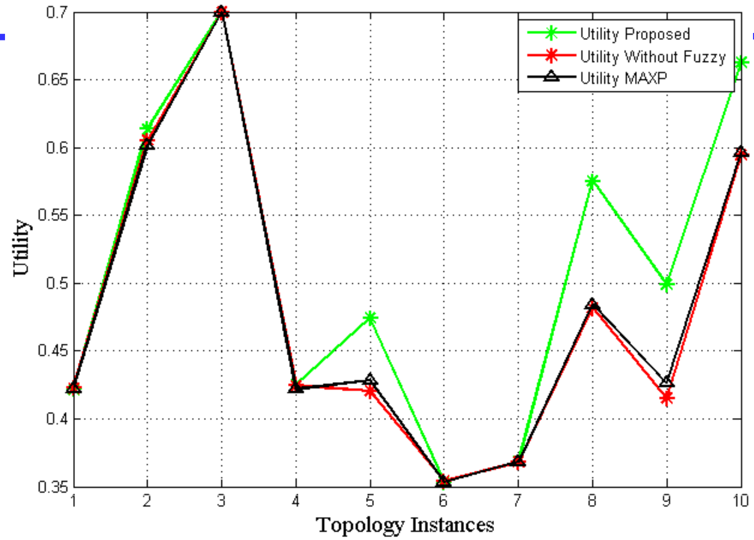
Situation-Aware Cooperative Power Control Algorithm

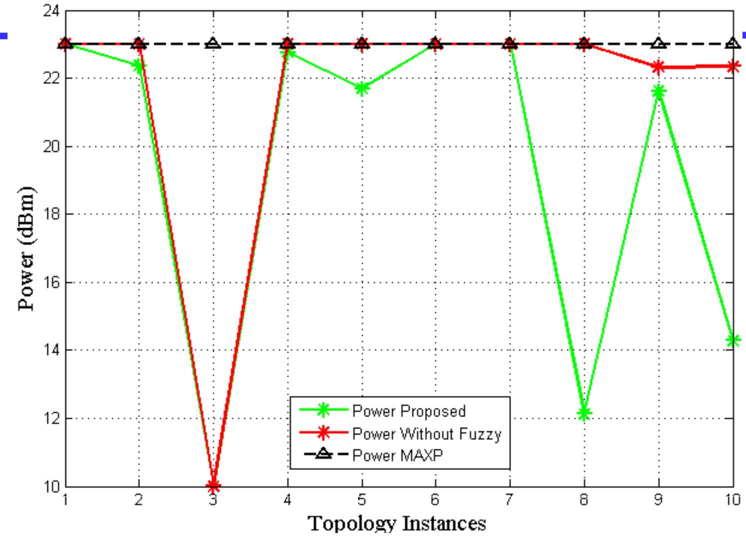
- In each step, every node sets its power p_i^k in order to maximize the Utility Function:

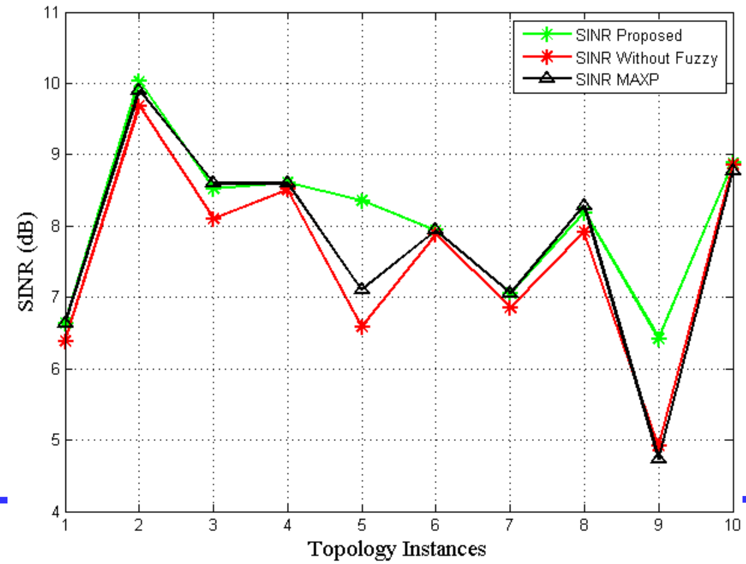
$$u_i\left(\gamma_i\left(p_i^k\right)\right) - a \cdot p_i^k \sum_{j \neq i} \pi_j^k \cdot h_{ji}$$

- Coefficient α :
  - Expresses uncertainties for the interference level
  - Acts as a weight that is multiplied with the subtracted interference term
  - Constitutes the outcome of a Fuzzy Logic Reasoner
- Fuzzy Logic Decision Making:
  - Is highly efficient for dealing with uncertainties
  - Can handle vague requirements more efficiently than Boolean algebra
  - Can be applied transparently in combination with other well known decision methods
  - Proper definition of the membership functions and linguistic rules can be used to reduce signaling overhead by avoiding the ping-pong effect
- After setting the new p_i^k each user sets and broadcasts the new interference price
- Each user can update the transmission power and interference price in different times
- It can be proved that the algorithm converges in an optimum in a finite number of steps

Simulation Results







- Simulations refer to a scenario with 10 LTE UEs acting as secondary users in an urban area
- Conclusions:
  - Utility is always higher compared to other methods
  - Significant power gains (i.e. Instance No.3, 8, 10)
  - Higher Average user SINR

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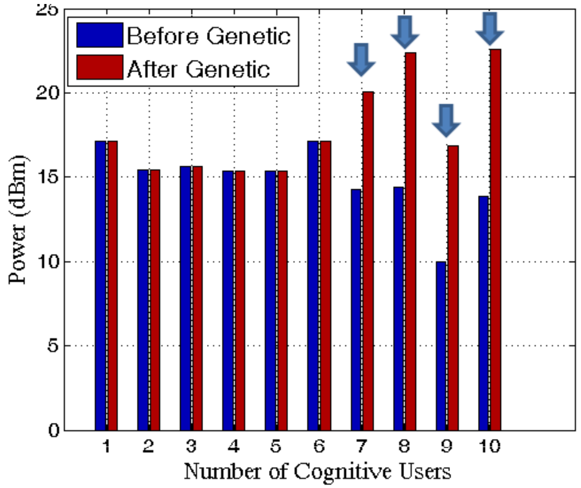
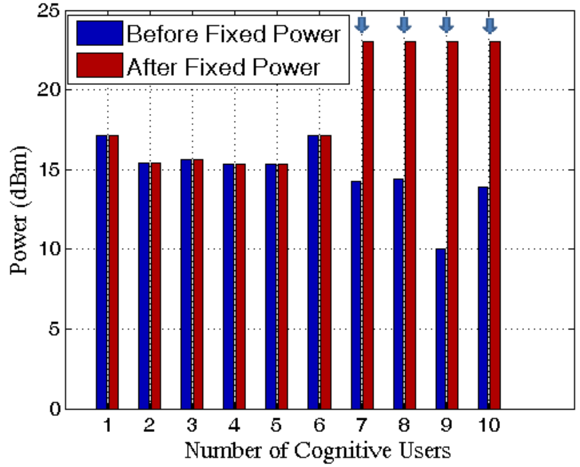
Paradigms of Rules and Policies

- Outer loop sets policies/constraints/rules:
  - Reset the decision making objectives/priorities (of the inner loop)
  - Provide direct solution when inner loop fails to converge or converges slowly
- Fairness/Politeness Policy
  - Reward and orchestrate synergistic network behavior
  - Eliminate discriminated UEs that are constantly enforced with low transmission power over a long time period and achieve fair and efficient sharing of resources
  - Implementation based on Genetic Algorithms:
    - Sub-class of Evolutionary Algorithms → Generates optimized techniques to solve problems
    - Static power assignment (Pmax) is not efficient → May cause high interference among users
    - *Fast search* and *low complexity* due to small search space and quick convergence
- Convergence Time
  - Converge fast to a near-optimal value → restricting algorithm iterations → reduce latency → further save power resources
  - Near-optimal value: Subtle differences in overall Utility and Tx Power levels

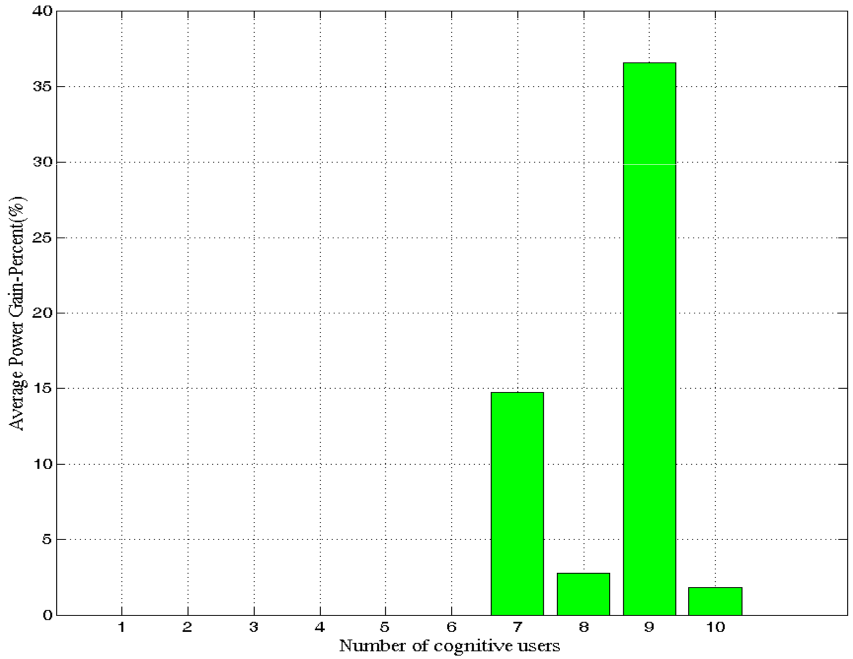
Fairness Policy

Genetic Algorithm vs. Static Power (MAX Power) assignment

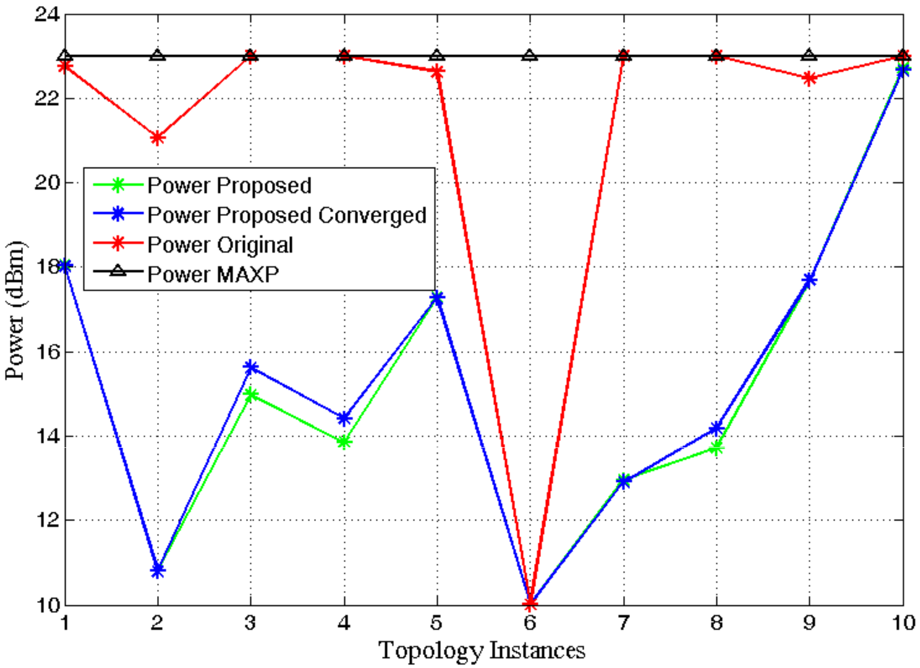


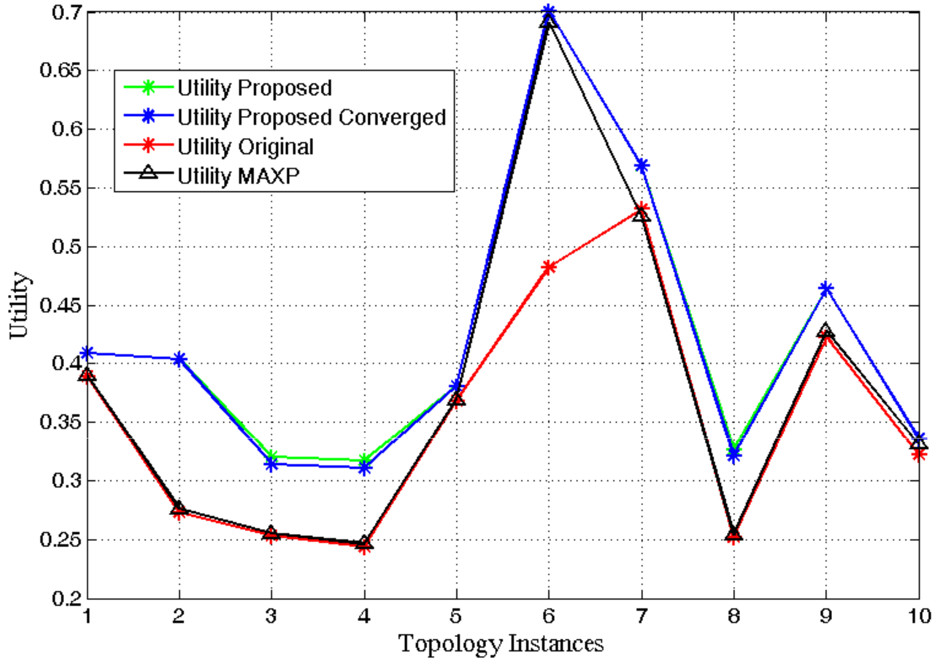


- Simulation Outcomes:
  - GA: Optimal (dynamic) computation of Tx power
  - Significant Power gains (up to 36%)



Convergence Policy





- Convergence Policy: MAX 5 iteration steps
- The proposed algorithm converges very fast in a near-optimum solution
  - Marginal difference in Utility
  - Marginal difference in Power (power efficiency still ensured)

6	3	13	12	7	2	9	11	5	10

Steps for convergence

Conclusion

- Presentation of Green Radio aspects, including Energy Efficiency studies, in the context of the ICT SACRA project
- More results, including proof-of-concept, are to come in the following of the project.

SACRA web site: http://www.ict-sacra.eu/

Acknowledgment

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement SACRA n° 249060.