Energy Efficiency and Fairness in Cognitive Radio Networks: a Game Theoretic Algorithm

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Outline

- Introduction
- Resource allocation methods:
  - ✓ Simulated annealing
  - ✓ Iterative Water-Filling
- Game theoretic model
- Simulation results
- Conclusions

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Created on 1 June 2011 by the merger of SELEX Communications with Elsag Datamat, an operation also involving SELEX Service Management and Seicos, SELEX Elsag is the Finmeccanica Group company specialised in the design and development of hi-tech systems, products, solutions and services for the following business areas:

Military BU - SELEX Elsag

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Integrated communication solutions for strategic and tactical, naval and satellite applications

Land Electronic Warfare

Electronic Warfare solutions for the Electronic Attack, Support and Protection components, integrated with communication systems based on the "Connect and Protect" paradigm to guarantee the connectivity of friendly forces and protect them from the threat posed by improvised explosive devices (IEDs)

Digital Legionary

Modular soldier digitalisation systems that improve operating flexibility and effectiveness, as well as delivering superior mobility and survival capacity

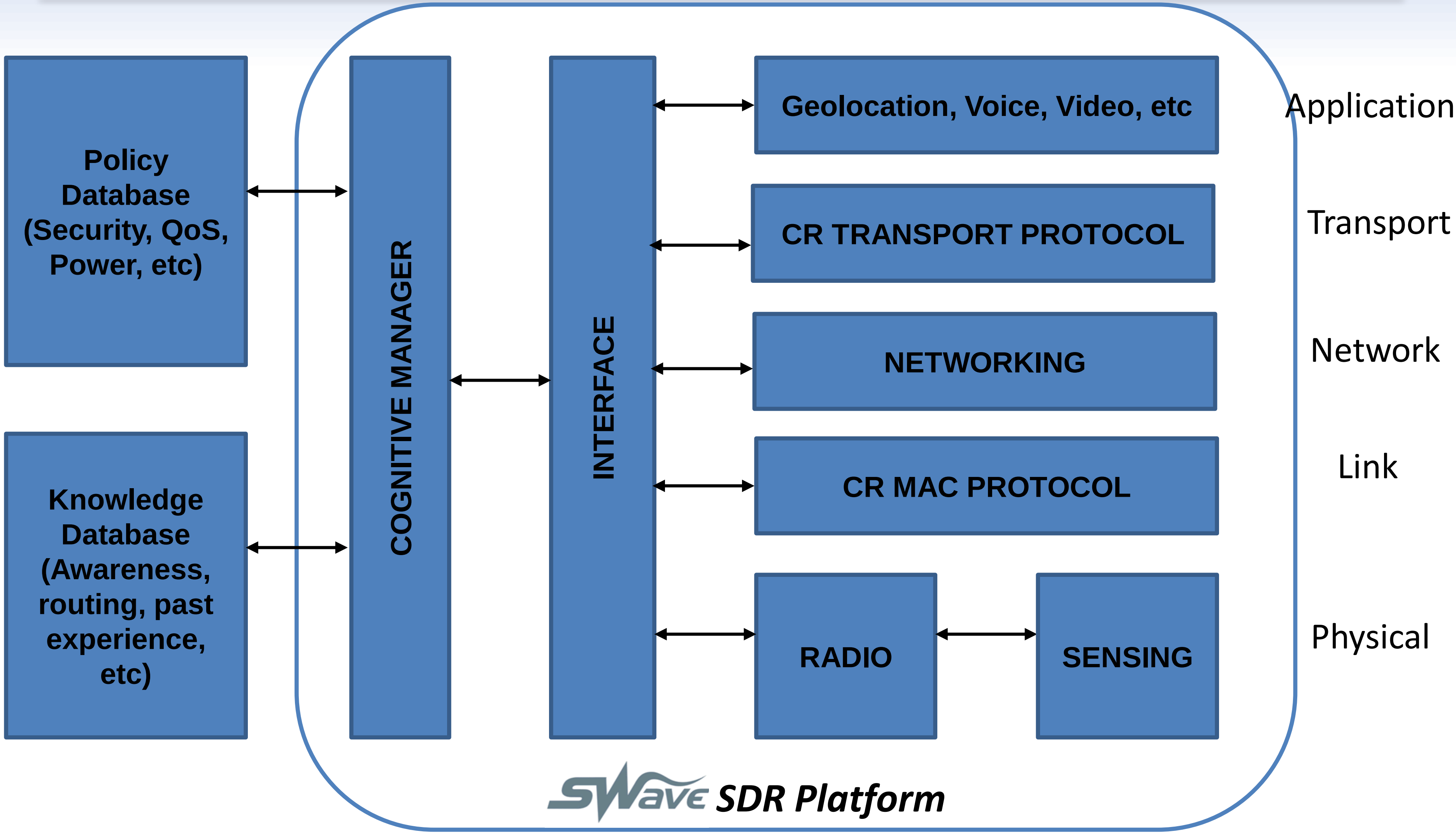
Network Enabled Capabilities

New generation communication systems for sea and land platforms, with advanced networking capabilities to allow coalition forces to achieve information superiority in the NEC framework

Tactical communications

Programmable or software-defined radio and satellite systems, with multi-role and multi-mission capabilities, for the digitalisation of modern armed forces in both interforce and coalition scenarios

Possible update of SDR Platforms to COGNITIVE architectures



SELEX Elsag SDR SWave Platforms and Waveform

SWave HANDHELD

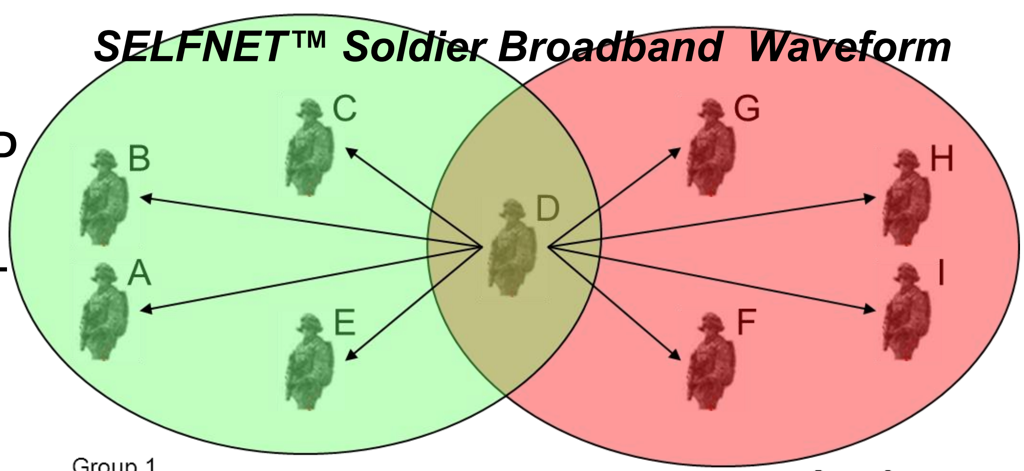
SWave Vehicular Mono-Channel

SELFNET™ Soldier Broadband Waveform

WIDEBAND

QoS

MANET



MULTIHOP

VOICE/DATA SERVICES

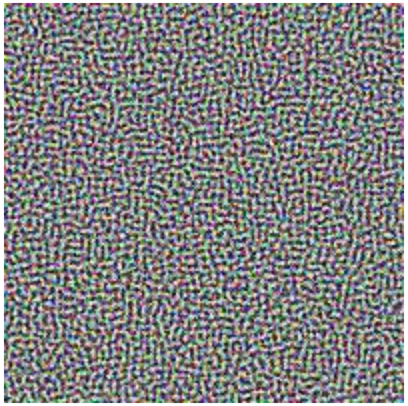
Resource Allocation (RA) Methods

- Distributed (Non-Cooperative) based on Game Theory
  - Potential games
    - Common (shared) utility function
  - Super-modular games (w pricing)
    - Individual (private) utility function
- Centralized (Non-Cooperative) based on Heuristics Methods
  - Simulated annealing
  - Tabu search
  - Genetic algorithms
- Centralized (Non-Cooperative)
  - Water Filling
  - Game Theory

Simulated Annealing

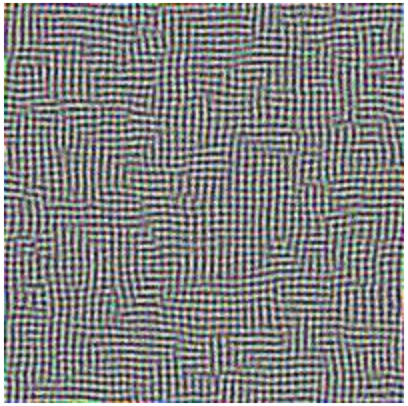
Main features:
- Stochastic heuristic method
- Escaping local optima
- High flexibility
- At each step solution may be worst than previous solution
- Optimal solution is guaranted for infinite decision time

Fast Cooling



Temperature is a control parameter that decreases at each step. When temperature is low, the probability of accepatence of a solution is small.

Slow Cooling



In a power allocation scenario:
- Complexity depends on users' number
- Algorithm is not oriented to energy efficiency

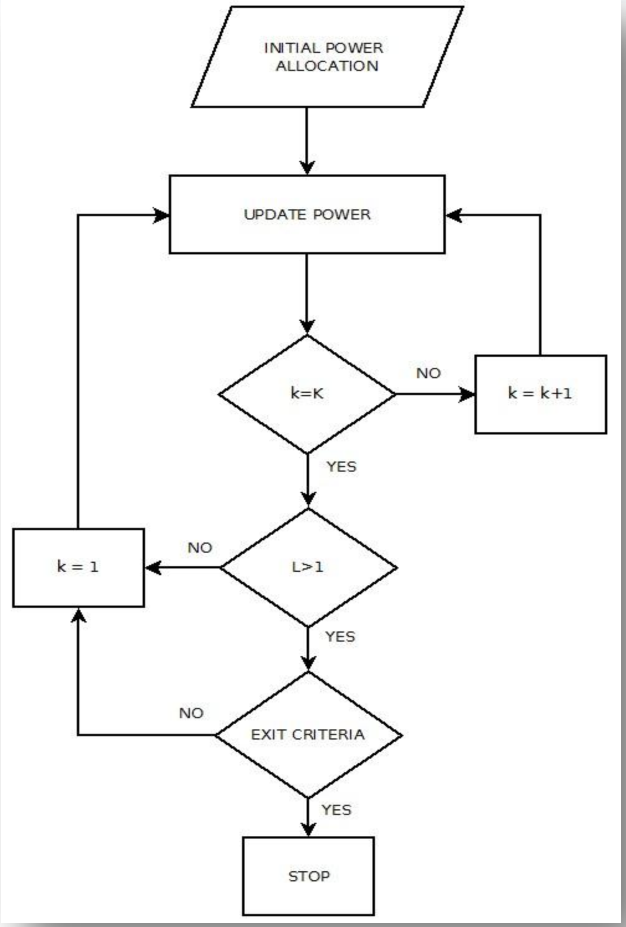
Iterative Water Filling

Main features:

- Halfway between modern heuristics and Game Theory
- High flexibility
- Quasi-Optimal solution

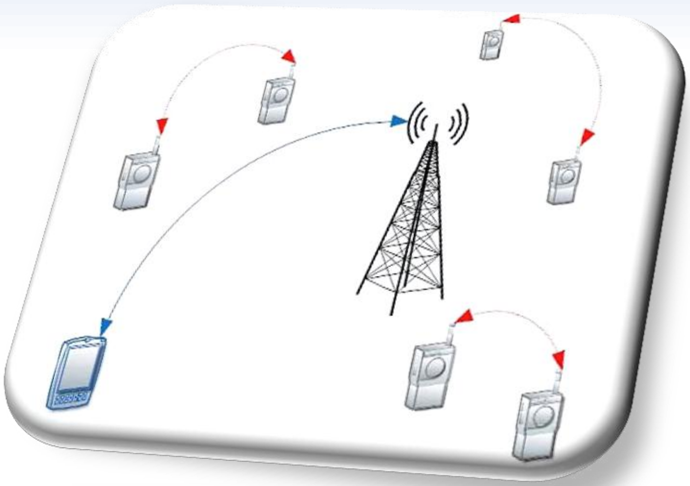
In a power allocation scenario:

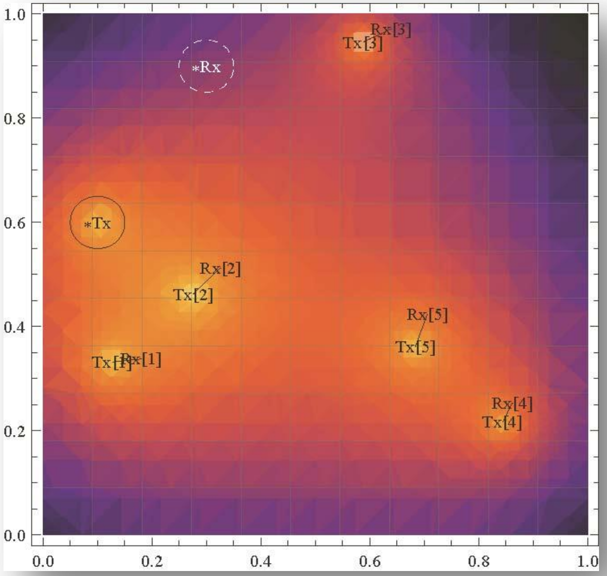
- excellent performance only in weak interference environments
- in strong interference environments only the user with best conditions channel should be active.
- Algorithm is not oriented to energy efficiency



The scenario

- 1 primary system
- N secondary users (completely independent positions)
- 1 radio resource.
- Discrete-time model
- No "direct" cooperation among primary and secondary users → “Interference Cap”





<u>REMARK</u>

Proposed scheme can be extended to include:

- more than one primary user
- M available radio resources (i.e. different channels or subcarriers of the same multi-carrier channel)

Fair energy efficient distributed RA based on GT

The Game

- <u>Players</u>: N users (completely independent positions)
- <u>Strategies</u>: transmission power levels
- <u>Utility function</u>:

$$u_i\big(p(t), p(t-1)\big) = W\frac{R_i f(\gamma_i)}{p_i(t)} - \Omega_i\big(p(t), p(t-1)\big) \cdot p_i$$

Where:

- p is the complete set of strategies of all secondary users,
- W is the ratio between the number of information bits per packet and the number of bits per packet,
- R_i is the transmission rate of the *i*th user in bits/sec,
- $f(\gamma_i)$ is the is the efficiency function, that represents a stochastic modelling of the number of bits that are successfully received for each unit of energy drained from the battery for the transmission.
- $\Omega_i(p)$ is the pricing function that generates pricing values basing on the interference generated by network users.

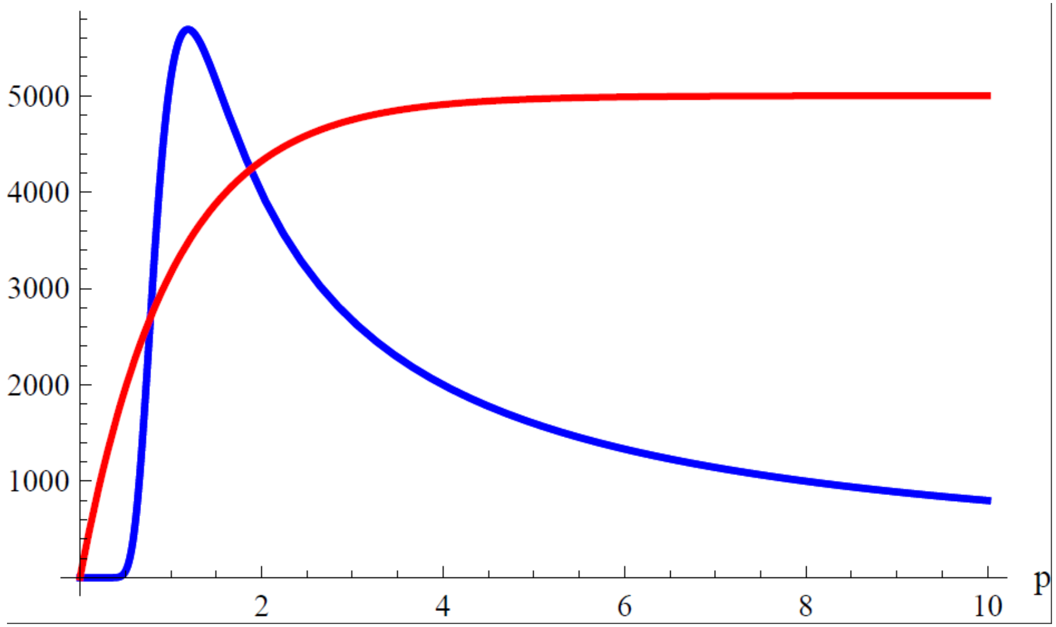
Pricing function

The pricing function is defined as follows:

$$\Omega_i = \beta - \delta exp\left(-\mu \frac{p_i(t-1)\sum_{i=1,k\neq i}^{N} g_{k,i}}{I_i^r(p_{-i}(t-1),P)}\right)$$

where:

- $\beta > 1$ is the maximum pricing value,
- $\delta > 1$ is the price weight of the generated interference,
- $\mu > 1$ is the sensitivity of the users to interference.

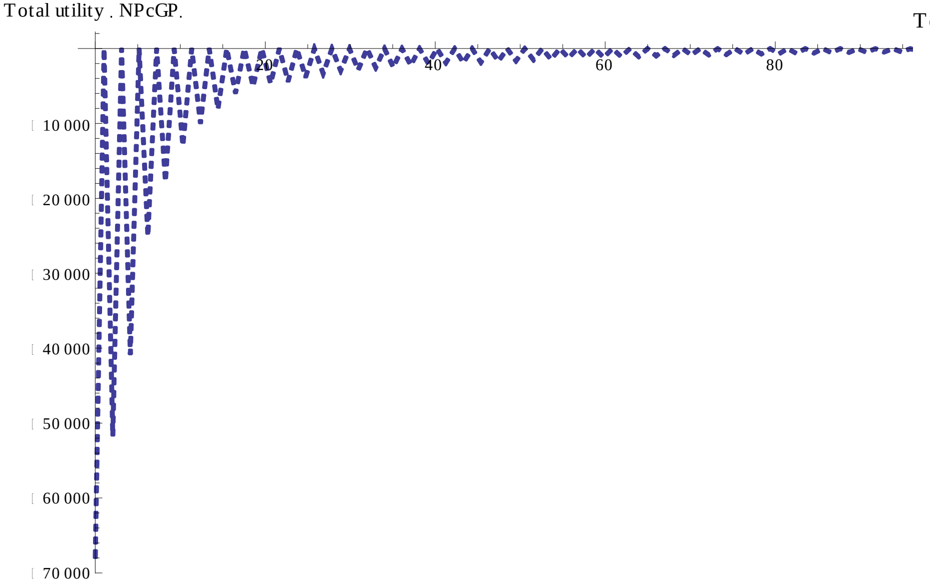


Pricing function in red;
Utility function in blue.

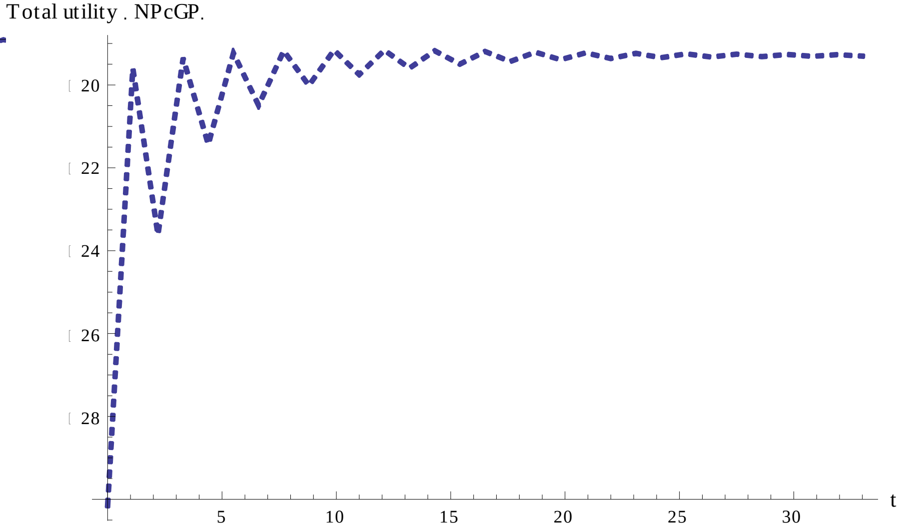
Speed of Convergence

Thanks to the pricing parameters (β,δ,μ), simulations are easily tunable in terms of:

- Time for convergence
- Sensibility of users to interference



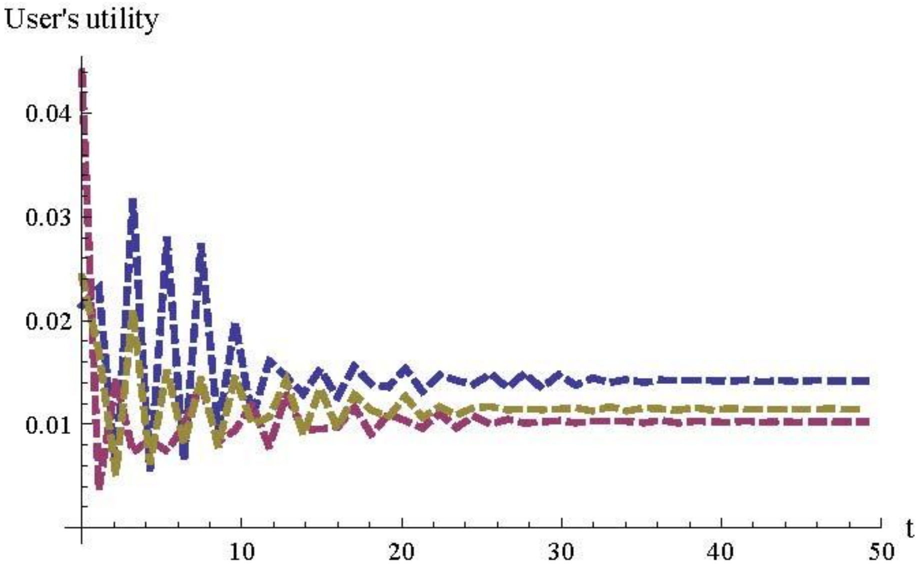
Utility convergence for $\delta = 10^{-4}$



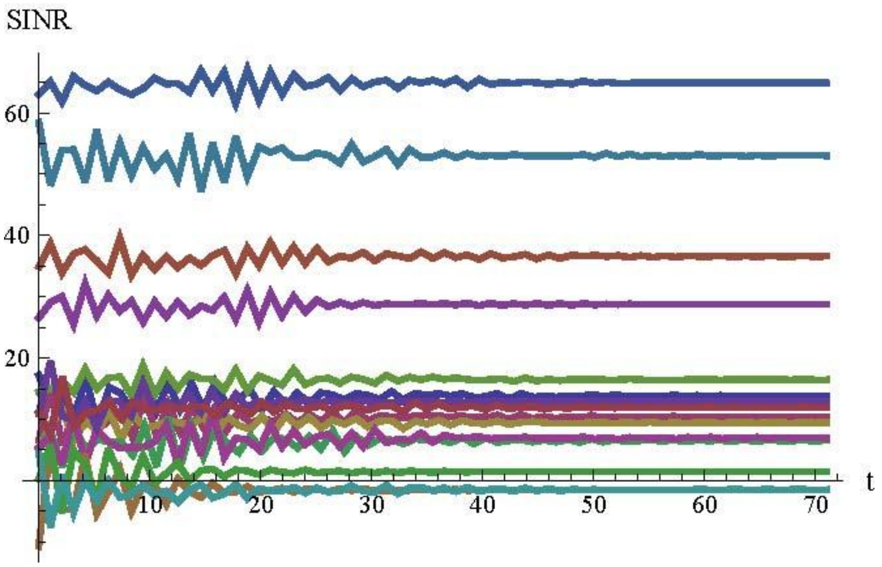
Utility convergence for $\delta = 9 \cdot 10^{-3}$

Simulation Results

- Convergence of the proposed system is quasi-independent from the number of users in the networks.



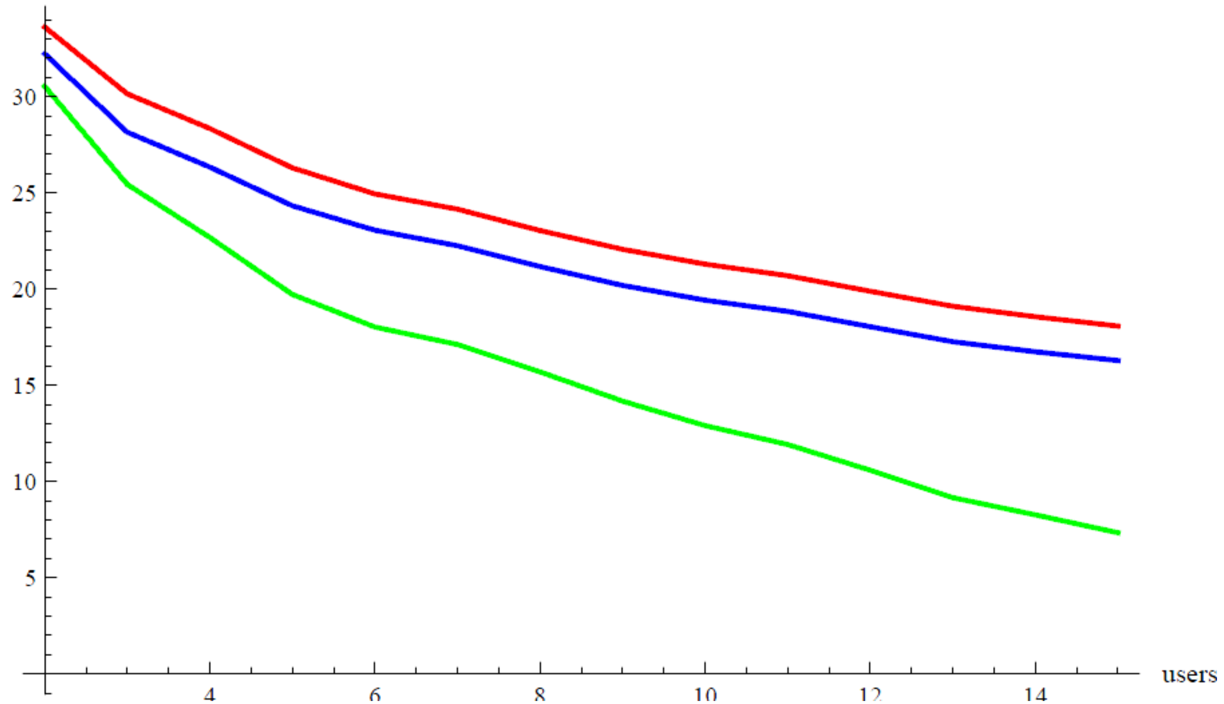
Convergence of the utility for a 10 users cognitive network.



Convergence of the SINR values for a 25 users cognitive network.

Simulation Results – SINR values

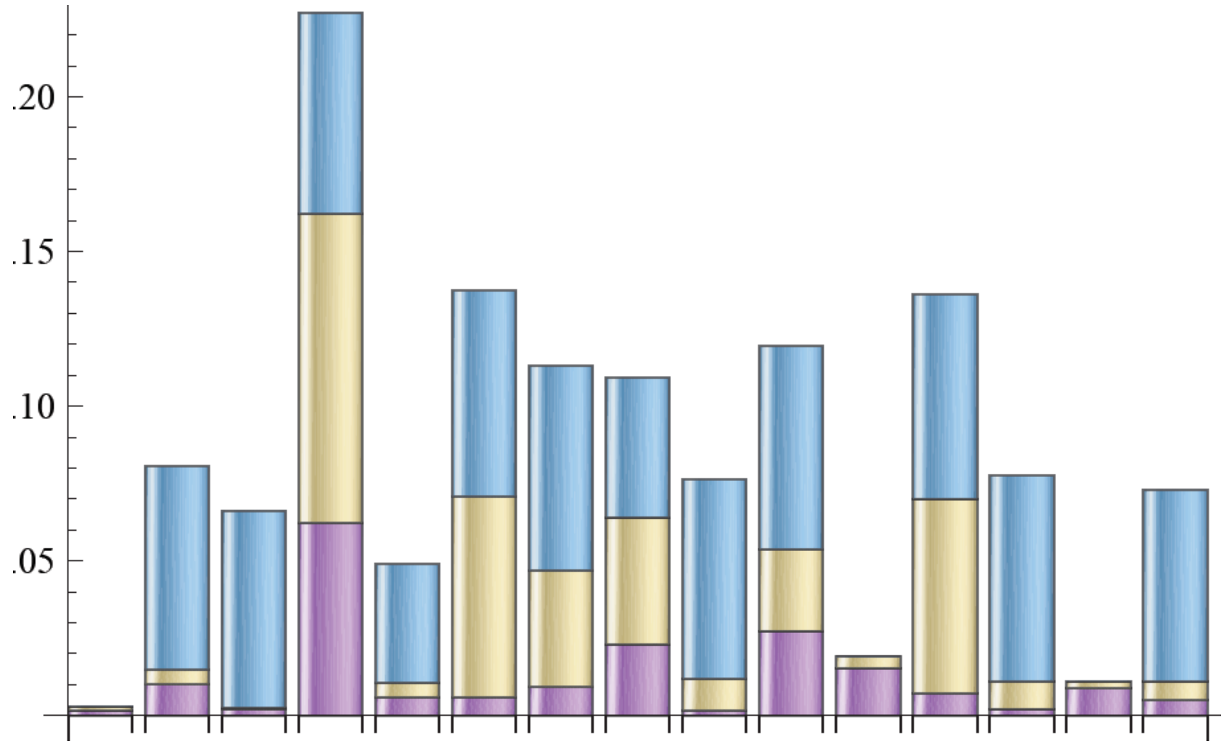
- Proposed game converges to similar SINR values obtained from Simulated Annealing, generally is better than Iterative Water-Filling.



Trends of SINR mean values for increasing number of secondary users in the network; SA in red, Game in blue, IWF in green.

Simulation Results – Energy Efficiency and Fairness

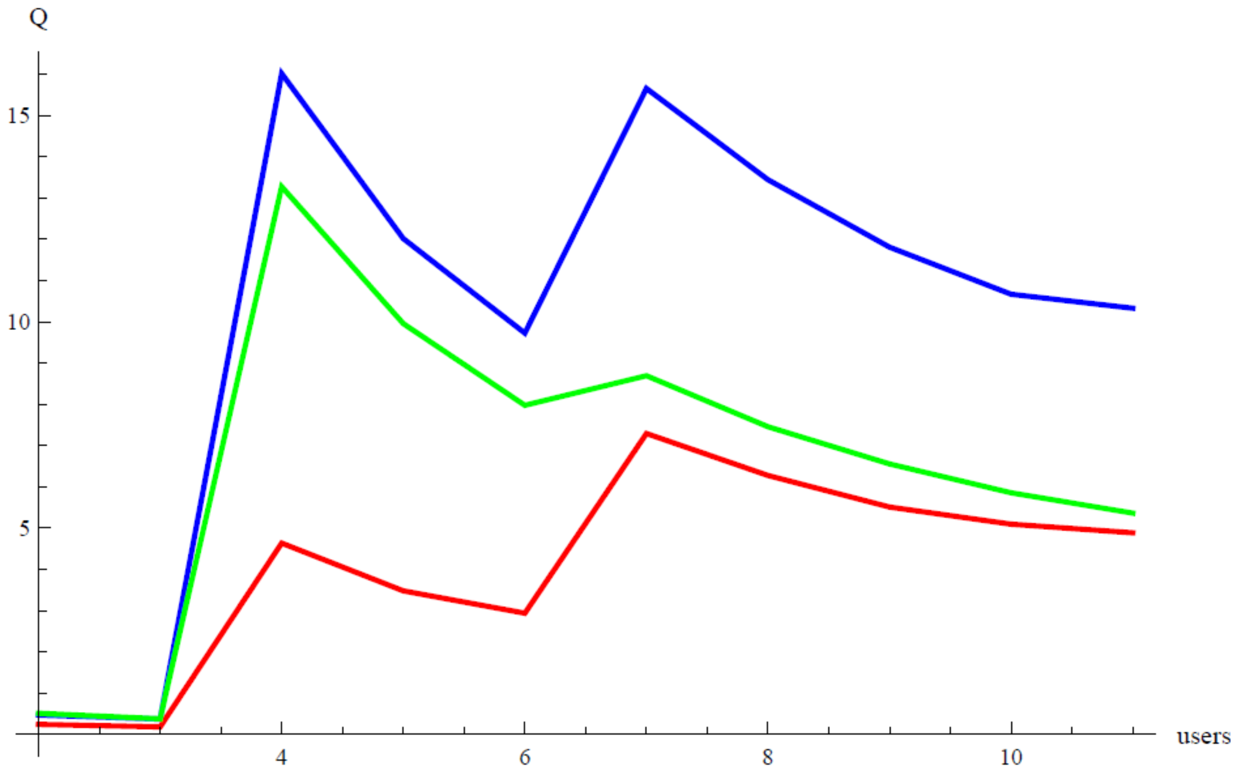
- Proposed game is much more energy efficient than Simulated Annealing and Iterative Water-Filling, also for a large number of considered users



Allocated power for a 15-user simulation;
Game in (purple), SA in (purple+yellow), IWF in (purple+yellow+blue).

Simulation Results – Functional Q

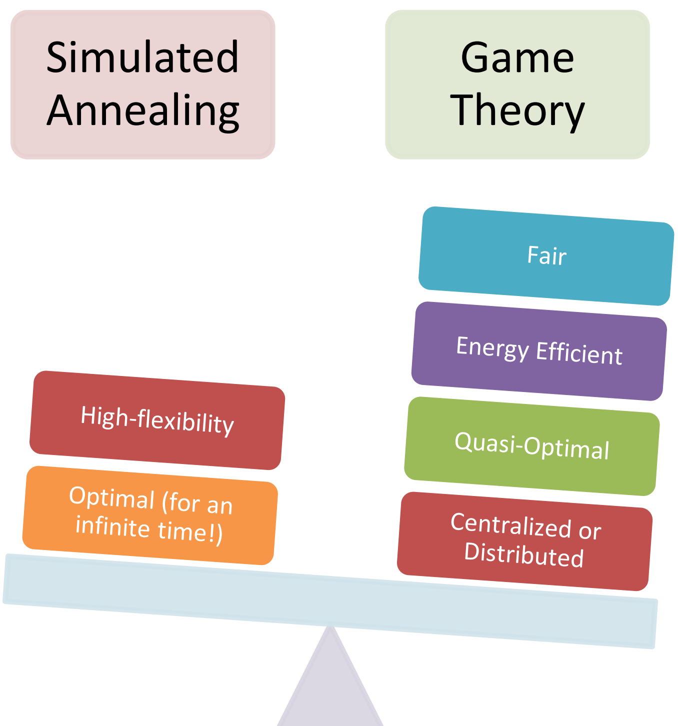
Functional Q: the mean value of the ratio between the SINR level received and allocated power of the transmitter, calculated for each user.



$$Q = Mean\left(\frac{SINR_i}{p_i}\right)$$

Trends of SINR mean values for increasing number of secondary users in the network; Game in blue, SA in green, IWF in red.

Conclusions



- Totally distributed (no central billing system)
- Throughput fairness among autonomous users
- Misbehavior avoidance
- Fast converging
- Easy tunable

Objective function:

- Total transmission rate maximization
- Total throughput maximization
- Total transmit power minimization

Let's play more!

Thanks for your attention!

Questions?