GAME THEORY FOR POWER ALLOCATION IN COGNITIVE RADIO

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AGENDA

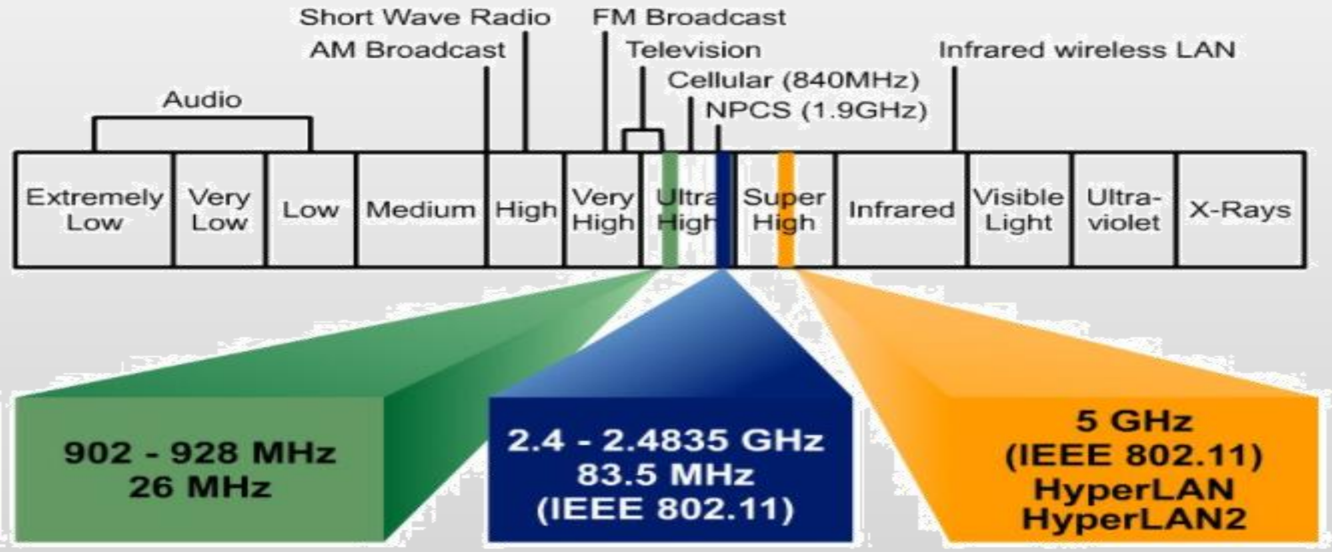
- WhyCognitive Radio (CR)?!!
- Power Allocation Competition in CR.
- Normalized Nash Equilibrium (NNE).
- Quasi-Nash Equilibrium (QNE).
- Reinforcement Learning (RL).
- Q-Learning (QL).
- Discussion

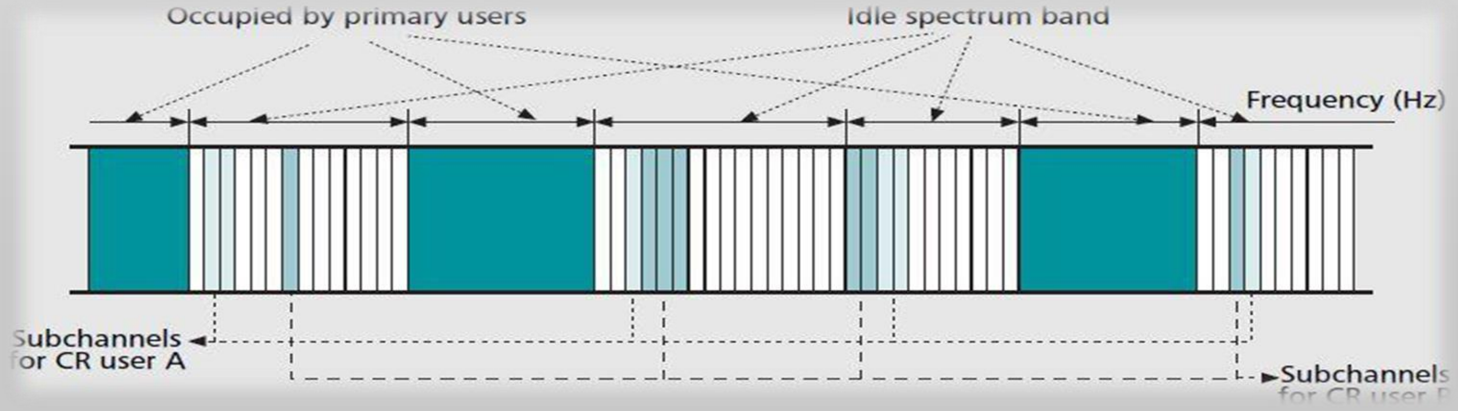
WHY COGNITIVE RADIO ?!!

- There exists an apparent spectrum scarcity for new wireless applications and services.

- The spectrum is not totally occupied .

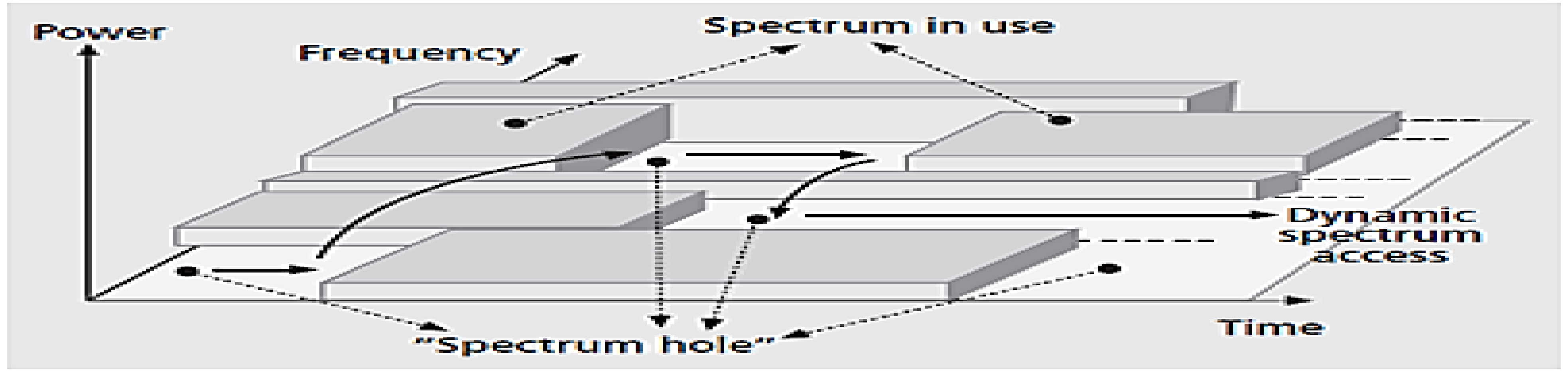
- The key enabling technology of dynamicn spectrum access techniques is Cognitive Radio Technology (CR).





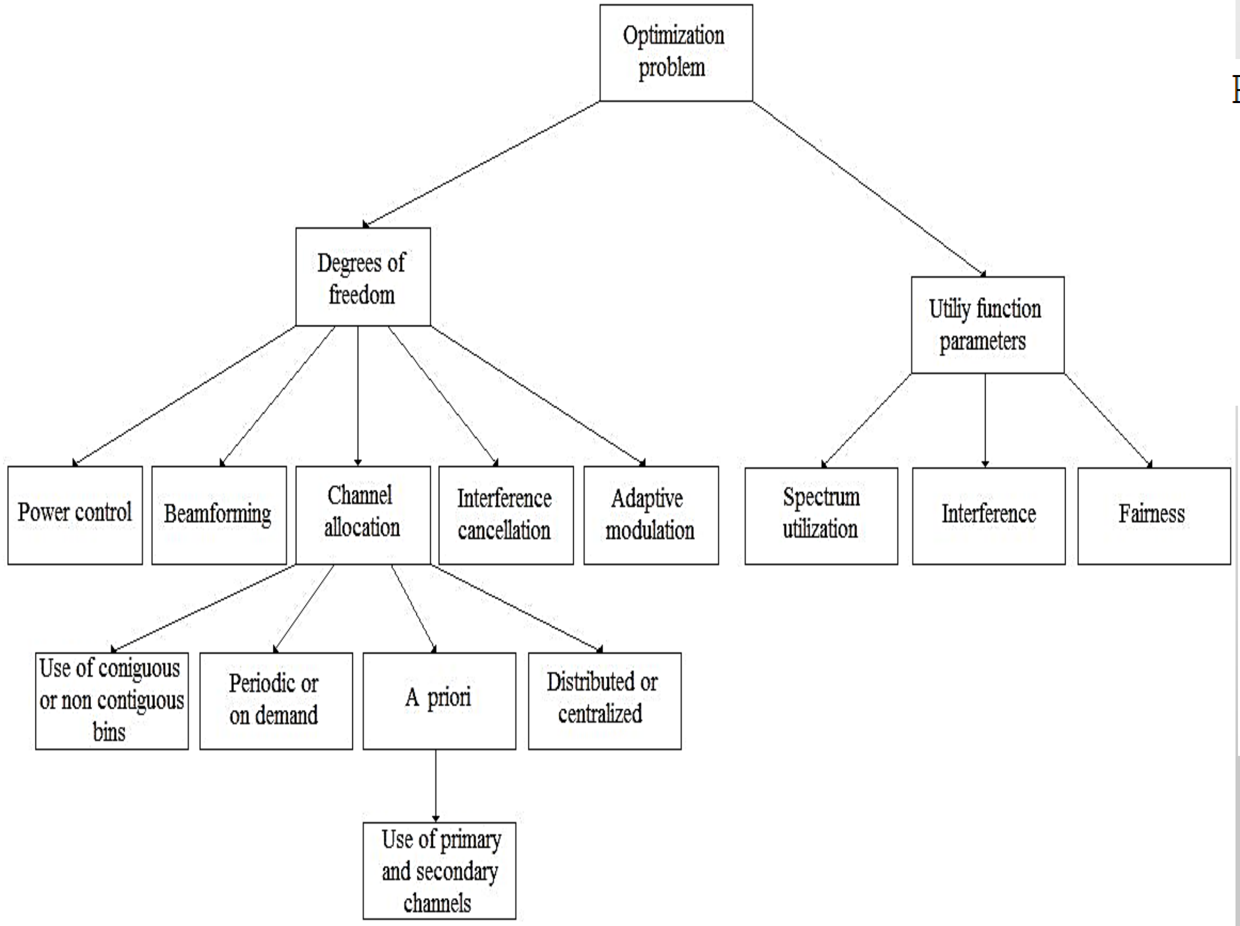
WHY COGNITIVE RADIO ?!!

- Cognitive radio can efficiently utilize the unused spectrum for secondary usage without interfering a primary licensed user.
- Cognitive Radio have two main characteristics:
  - **Cognitive Capability:** Identify the unused spectrum at a specific time or location (Spectrum Holes/ White Spaces).
  - **Re-configurability:** A CR can be programmed to transmit and receive on a variety of frequencies, and use different access technologies supported by its hardware design.

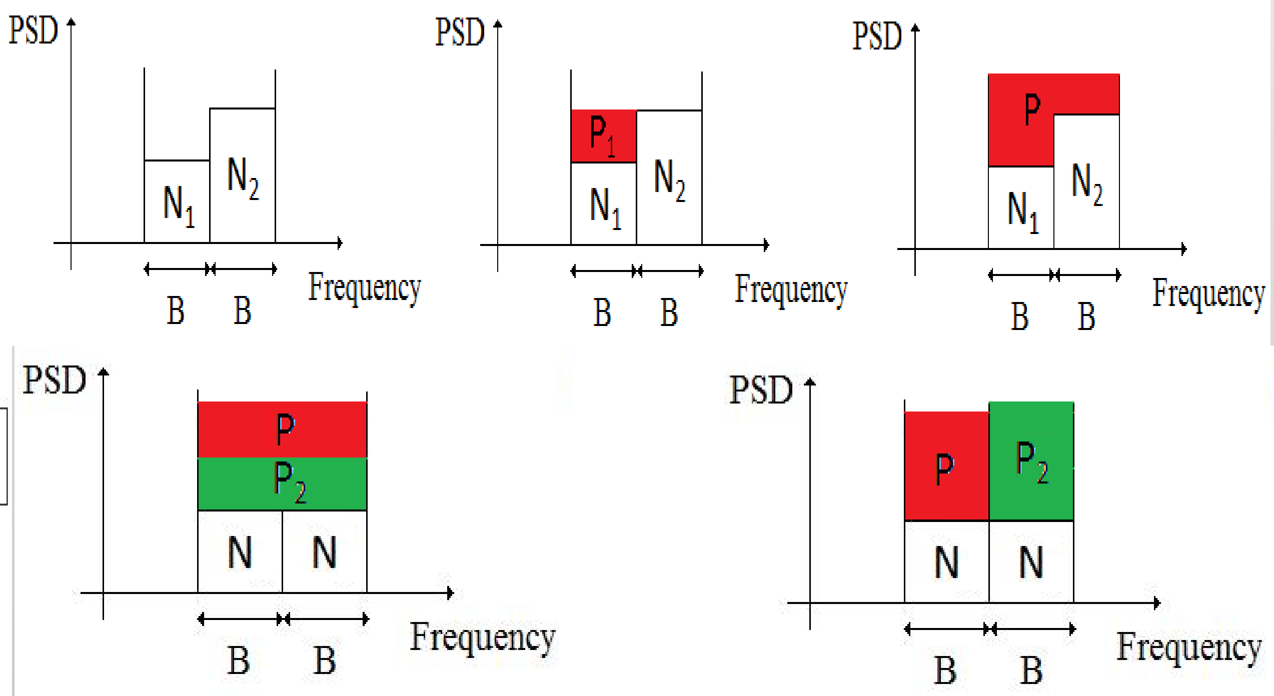


POWER ALLOCATION COMPETITION IN CR

- Parameters of the problem:



- Power Allocation simply.



NORMALIZED NASH EQUILIBRIUM (NNE)

- Is the Equilibrium Optimal?
  - **NO!**
- Normalized Equilibria

Given the coupling constraint $x \in X$ and positive numbers $r_i, i \in I$, Rosen (1965) called the strategy profile $x^* = (x_i)$ a *normalized equilibrium* provided it

$$\text{minimize} \quad \sum_{i \in I} r_i L_i(x_i, x^*_{-i}) \quad \text{subject to} \quad x \in X.$$

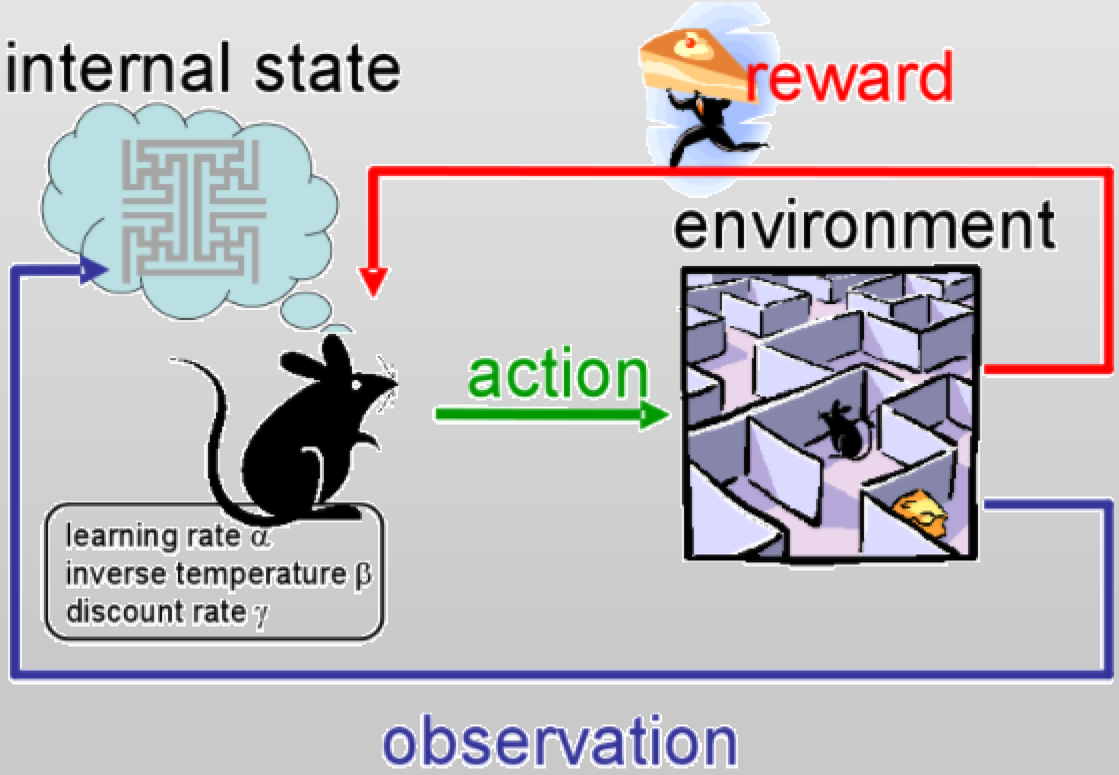
- The NNE may not be unique and the game does not necessarily admit a potential function.
- In [6], they identify a class of utility functions which admits unique NNEs and strictly concave potential functions even in presence of co-channel interference among secondary-BSs. Thus, algorithm DIST can be used to obtain the unique NNE.
- In [6], the authors show that in the setting with negligible interference among secondary-UTs, the NNE is always unique and the game admits a strictly concave potential function.

QUASI-NASH EQUILIBRIUM (QNE)

- NNE needs a specific relaxation on the game and the utility functions to be unique.
- Convex non-cooperative power allocation game (NNPG) based on the a new relaxed mathematical equilibria concept is proposed in [7].
- QNE ***Definition 1:*** A quasi-Nash equilibrium (QNE) of the game $\mathcal{G}(\mathbf{H}, \mathbf{G})$ is defined and formed by the solution tuple $(\mathbf{x}^{\star}, \boldsymbol{\alpha}^{\star}, \boldsymbol{\beta}^{\star})$ of the equivalent $VI(\mathbf{Q}, \boldsymbol{\Theta})$, which is obtained under the first-order optimality conditions of each player's problems, while retaining the convex constraints in the defined set $\mathbf{Q}$. A QNE is said to be trivial, if $\mathbf{P}_0^{\star}, \mathbf{P}_1^{\star} = 0$ for all $i = 1, ..., M$
- The QNE is by definition a tuple that satisfies the Karush-Kuhn-Tucker (KKT) conditions of all the players' optimization problems; the prefix *quasi* is intended to signify that a NE (if it exists) must be a QNE under a certain constraint qualification (CQ).

REINFORCEMENT LEARNING (RL)

- Reinforcement learning is learning what to do [how to map situations to actions]so as to maximize a numerical reward signal.
- The learner is not told which actions to take, as in most forms of machine learning, but instead must discover which actions yield the most reward by trying them.
- https://www.youtube.com/watch?v=e3Jy2vShroE

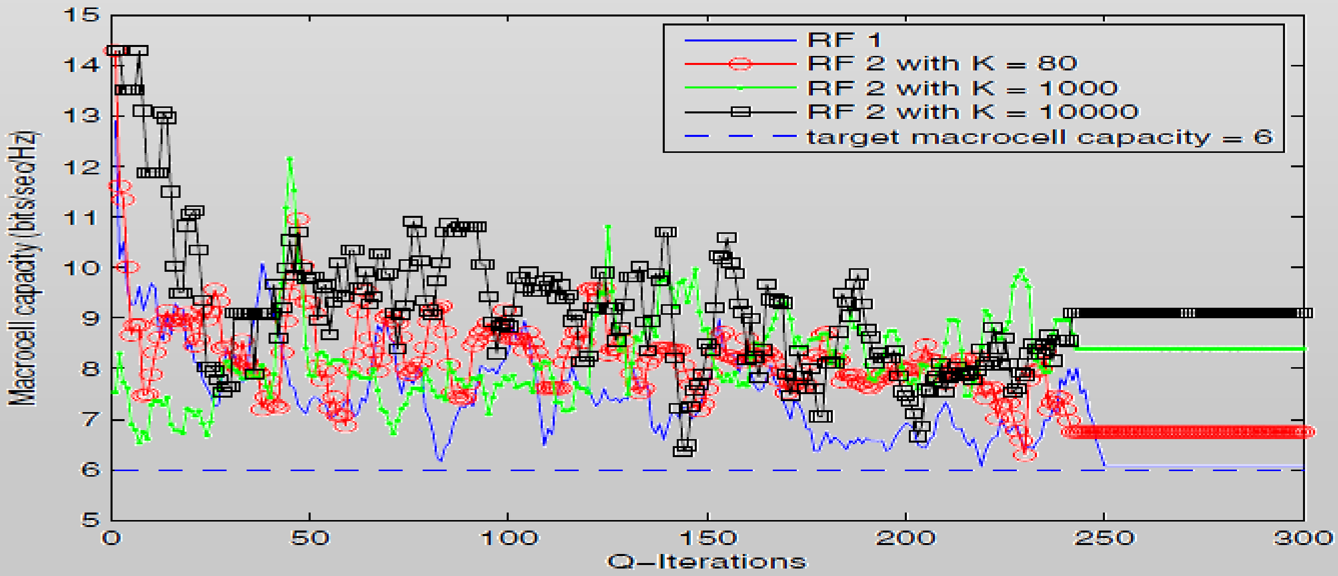


Q-LEARNING (QL)

- Q-learning (Watkins, 1989) is a form of model-free reinforcement learning.
- It can also be viewed as a method of asynchronous dynamic programming (DP).
- It provides agents with the capability of learning to act optimally in Markovian domains by experiencing the consequences of actions, without requiring them to build maps of the domains.
- https://www.youtube.com/watch?v=fHCm0gQRzC4
- Robot learn how to walk: https://www.youtube.com/watch?v=iNL5-0_T1D0

Q-LEARNING (QL)

- In [12], a distributed Q-learning algorithm based on the multi-agent systems theory called DPC-Q is presented to perform power allocation in cognitive femtocells network.
- The DPC-Q algorithm is applied in two different paradigms: independent and cooperative.
- Through simulations, they showed that the independent learning paradigm can be used to increase the aggregate femtocell capacity. However, due to the selfishness of the femtocells, fairness is reduced compared to the first scenario.



DISCUSSION

- The scarcity of the frequency spectrum become a sever problem, that implies using Cognitive Radio.
- Coordination between CR users are required, which introduce game theory concepts in the CR technology.
- **I am Motivated**


That's all Folks!
Any Question ?
THANK YOU!
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