DSA with MAC cooperation

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Problem Description - Assumptions

- Focus: DSA for cognitive systems with subsystems sharing **license exempt spectrum**
  - Directly applicable to a case of different operators in unlicensed spectrum bands
- *L* pairs of users (transmitter & receiver), *M* spectrum areas with same width
- Only users from the same operator are synchronized
- Every user selects his transmission power level trying to maximize a **utility function**
  - Utility function selected such that the algorithm converges in a **maximum** in a finite number of steps
- Message exchange ("interference prices") between users is completely asynchronous

Overall Technical Approach

- **Step 1 - Problem partitioning:** each of the K transmitters determines the most appropriate contiguous set of the M areas according to its channel quality and its needs in bandwidth and QoS
- **Step 2 - Interference suppression:** for transmitters selecting the same area, a utility maximization algorithm determines the transmission power for each user
- PHY layer parameters are directly impacting the **final utility value for the network**
  - Reduced power for a given bandwidth in FBMC compared to OFDM [5] results in lower interference to other users
- Simulations **quantify the advantage** of FBMC over OFDM in terms of total network utility

Step 2 – Interference Suppression

- The problem of DSA in distributed networks that operate in license exempt spectrum bands is challenging
  - the interference that each user is causing to the rest of the users implies that the users' **utility functions are coupled**
- This means that in the general case the overall network utility is **not necessarily concave** in regard to the transmission power of each user

Step 2 – Interference Suppression

transmission power for i user on channel k

Link gain between R_i and T_i

SINR for *ith* user on channel *k*

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

Link gain between R_i and T_j

Ambient noise level

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

Interference price [2] for *ith* user on channel *k*

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

[2]J. Huang, R. A. Berry, M. L. Honig, "Spectrum Sharing with Distributed Interference Compensation" in the Proceedings of IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks,(DySPAN) 2005

Step 2 – Interference Suppression

- In each step, every user *i* sets p_i^k [2] to maximize:

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

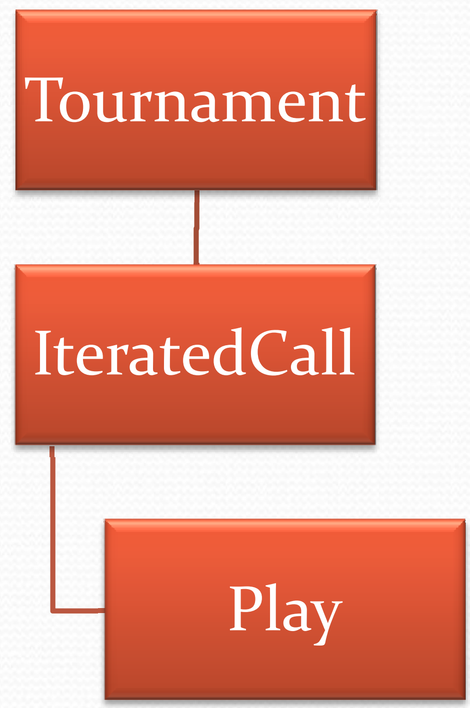
- Parameter *α* expresses uncertainties for the interference level
  - ⇒ outcome of a **fuzzy Reasoner** [4]
    - ⇒ Fuzzy Logic is efficient for dealing with uncertainties
    - ⇒ More effective than Boolean algebra in handling vague requirements
- After setting the new p_i each user also sets and broadcasts the new π_i
- Each user can update the transmission power and interference price in different times
- It can be proved theoretically that the algorithm converges in an optimum in a finite number of steps
- Total network utility is defined as the sum of the user utilities

Step 2 – Interference Suppression

- In order to execute the algorithm every user needs to know its own SINR and channel gain, as well as the channel gains and the interference prices announced by other users.
  - The SINR and the channel gain between a user pair can be calculated at the receiver and forwarded back to the transmitter.
  - The channel gains between users can be calculated if receivers periodically broadcast a message
- Since every user announces a single interference price, the delay that is introduced by the algorithm scales **linearly with the number of users**.

MATLAB Simulator Structure

- “Tournament” sets the initial values for the Transmission Power and Interference Price for every user pair
- “IteratedCall” calls “Play” in order to generate the new values of Power and Interference Price for each user pair in a complete round of execution
- “Play” implements the update of Power and Interference Price for one user in a round



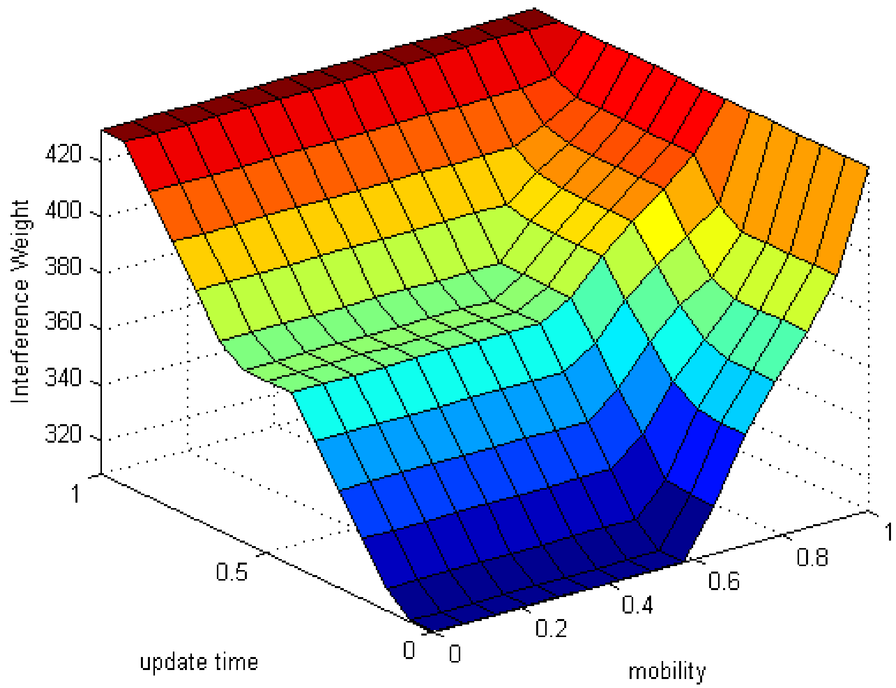
Dealing with uncertainties (1/2)

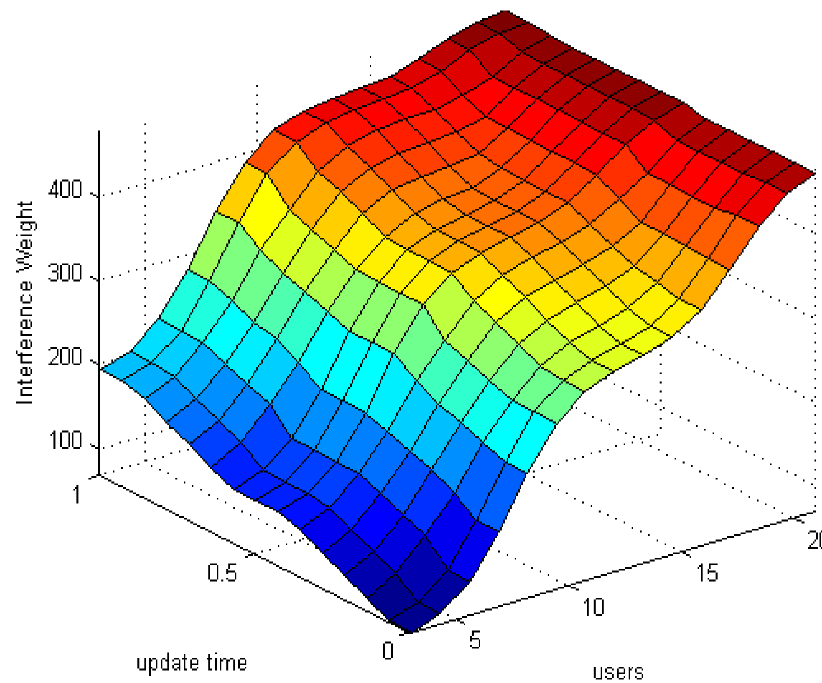
- Uncertainties are taken into account (i.e. due to high mobility, time interval between last update of the interference price)
  - Handled by a **Fuzzy Logic Reasoner**
  - The output of the fuzzy logic reasoner defines the coefficient α in the mathematical formula:

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

  - If uncertainty is significant the coefficient is larger, increasing the impact of the subtracted interference term
- The total number of users also effects the coefficient α, because in such cases the **counter-motive** for setting maximum transmission power should be increased

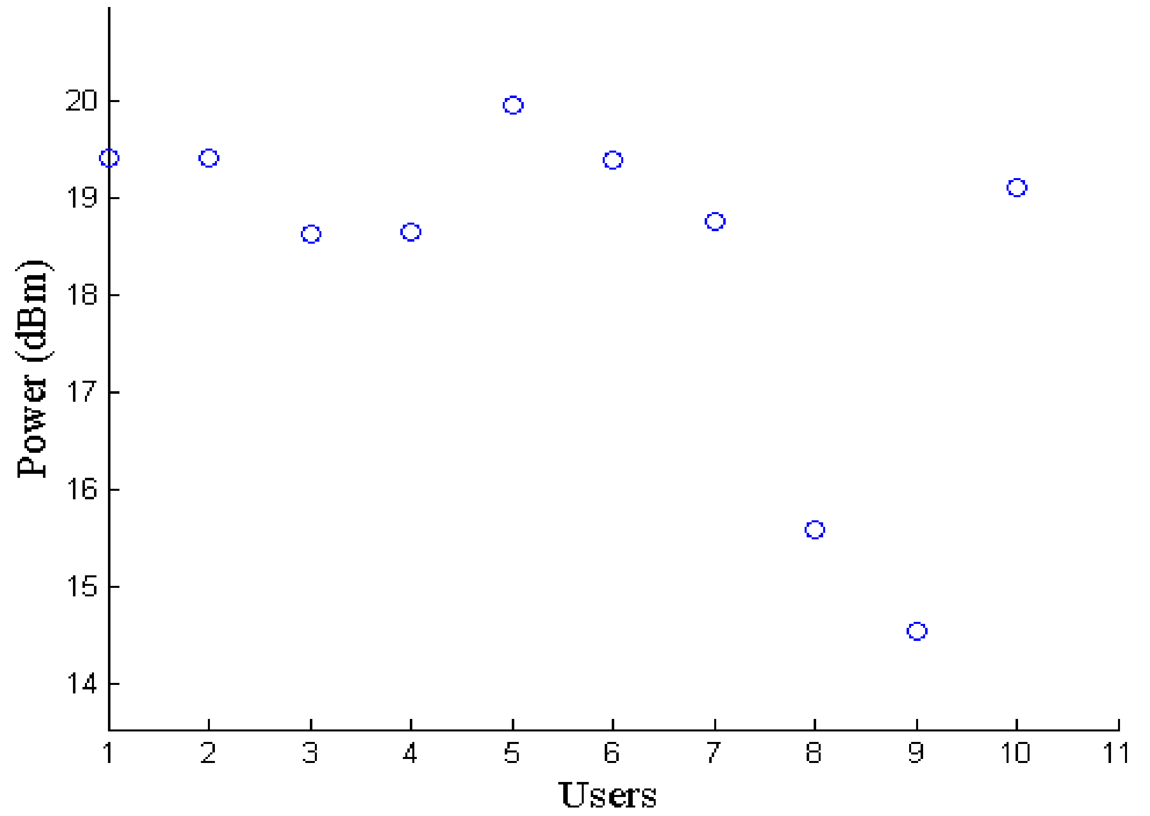
Dealing with uncertainties (2/2)





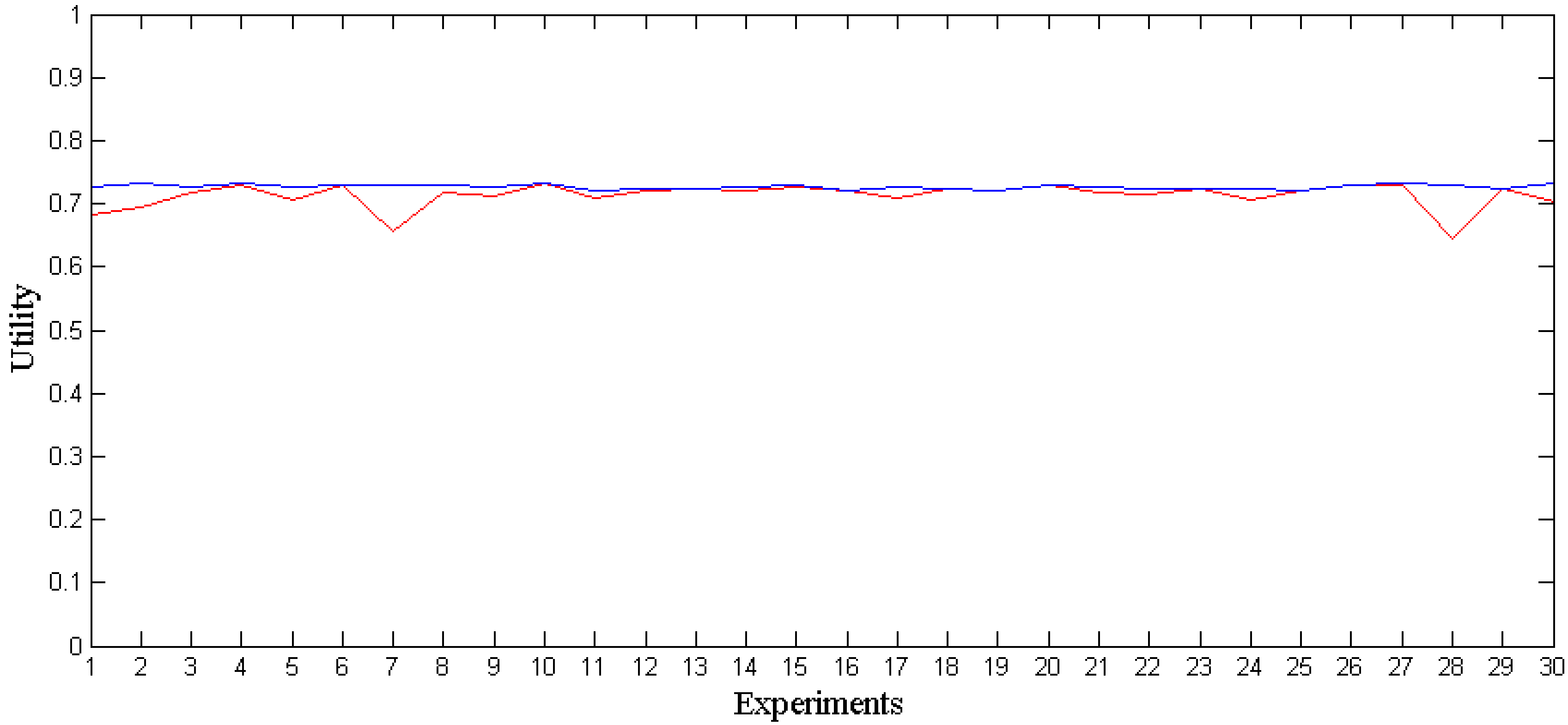
- Left: The coefficient α (crisp value after defuzzification) as a function of user mobility and the update time interval for interference price
- Right: The coefficient α (crisp value after defuzzification) as a function of the number of users and the update time interval for interference price

Example transmission power levels



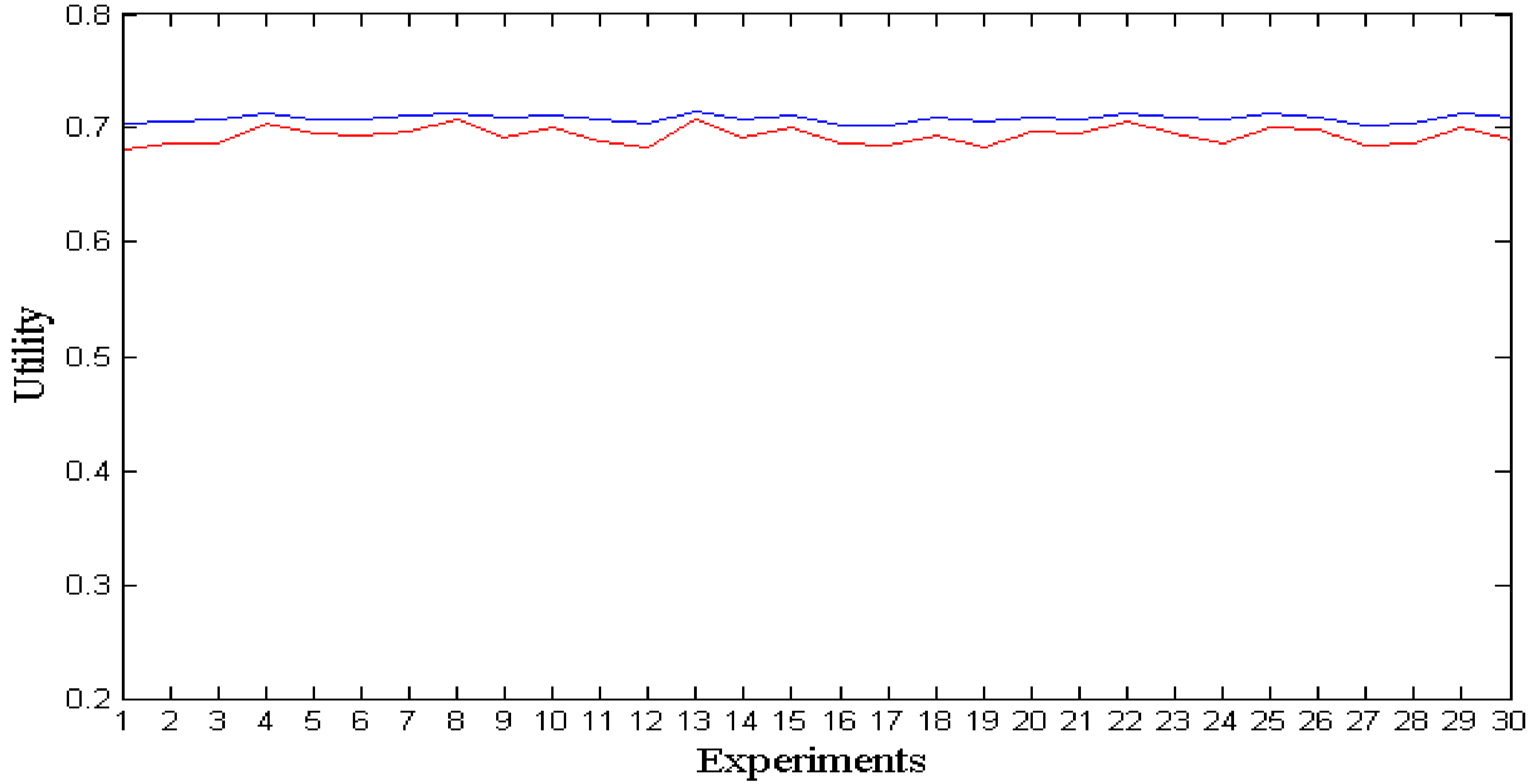
- Transmission level for a number of 10 user pairs with random distances
- The algorithm prevents the users for selecting always the maximum valid power level and maximizes total network utility

Improvements over the always max power case



Improvement in total utility for the proposed algorithm in 30 random experiments compared to the case that all users transmit with maximum power

Improvements over OFDM



Improvement in total utility for the proposed algorithm in FBMC over OFDM (due to reduced interference, caused from the fact that the same bandwidth is achieved with reduced transmission power [5])

Work in Progress and Next Steps

- Focus on making the system more "realistic" than existing works that use distributed utility functions
  - Scalability
  - Complexity
- Refine and optimize the rules of the fuzzy reasoner
- Fairness: if the final transmit power for one user is not sufficient for the desirable QoS the user searches for another spectrum area using again the algorithm of [1]
  - A "**priority**" **coefficient** can be included in the user's utility function in order to favor him

References

[1] D. Xenakis, D. Tsolkas, S.Xergias, N. Passas, and L. Merakos : "A Dynamic Subchannel Allocation Algorithm for IEEE 802.16e Networks", published in the IEEE International Symposium on Wireless Pervasive Computing (ISWPC) 2008, Santorini, Greece, May 2008.

[2]J. Huang, R. A. Berry, M. L. Honig, "Spectrum Sharing with Distributed Interference Compensation" in the Proceedings of IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks,(DySPAN) 2005

[3] Tao Jin, Chunxiao Chigan, and Zhi Tian, "Game-theoretic Distributed Spectrum Sharing for Wireless Cognitive Networks with Heterogeneous QoS", The International Journal of Computer and Telecommunications Networking

[4] A. Merentitis, E. Patouni, N. Alonistioti, M. Doubrava, "To Reconfigure or Not to Reconfigure: Cognitive Mechanisms for Mobile Devices Decision Making" in the Proceedings of the 68th IEEE Vehicular Technology conference (VTC), 21 – 24 September 2008, Calgary, Canada

[5] D. S. Waldhauser, L. G. Baltar, J. A. Nossek, "Filter Bank Based Multicarier systems" Techniken, Algorithmen und Konzepte für zukünftige COFDM Systeme (TakeOFDM)


THANK YOU!