Beamforming and Binary Power Based Resource Allocation Strategies for Cognitive Radio Networks

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A. Hayar
EURÉCOM Institute, Mobile Communications Department
Sophia Antipolis, France

outline

- Introduction
- Cognitive radio Spectrum Pooling Based on Binary Power Allocation
- Cognitive radio Spectrum Pooling Based Beamforming
- Performance Analysis
- Conclusion

Motivations

- In some locations and/or at some times of the day, 70 percent of the allocated spectrum may be sitting idle.
- The FCC has recently recommended that significantly greater spectral efficiency could be realized by deploying wireless devices that can coexist with the licensed users.

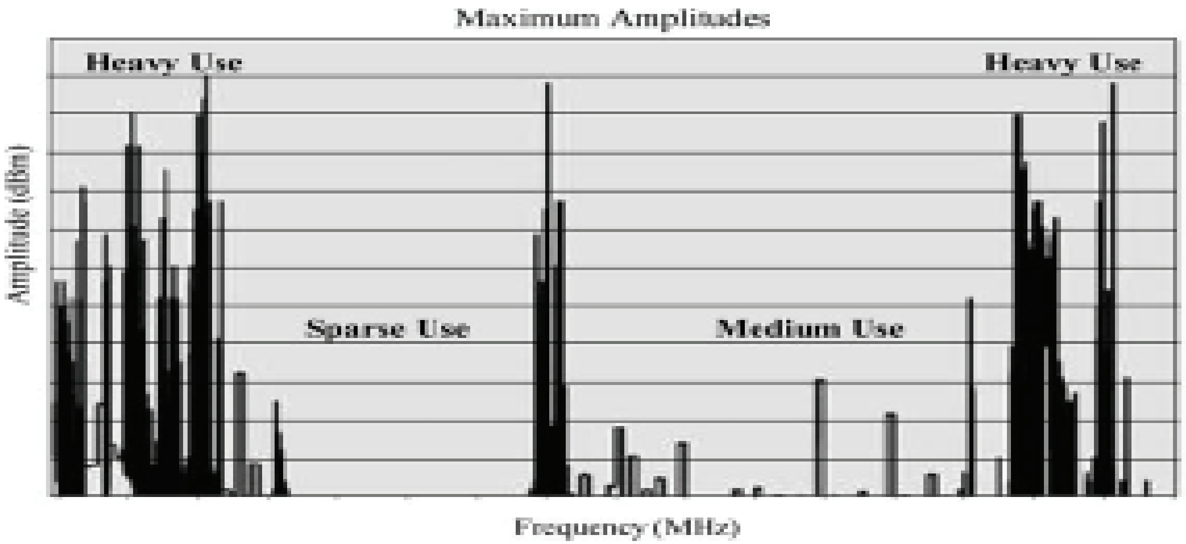
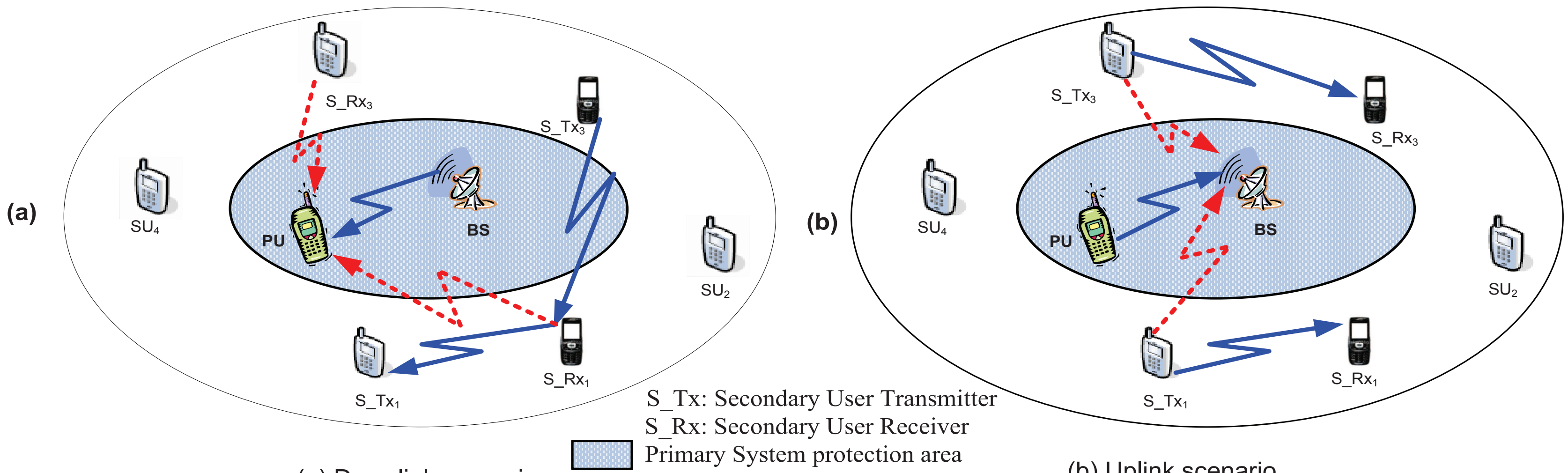


Figure 3: Spectrum occupation in frequency.

Cognitive Radio Overview

- A new class of radios was defined by the term *cognitive radio*
- Several definitions (and variations) of Cognitive Radio exist:
  1. Mitola: "*Cognitive radio signifies a radio that employs model based reasoning to achieve a specified level of competence in radio related domains*".
  2. FCC: "*A cognitive radio (CR) is a radio that can change its transmitter parameters based on interaction with the environment in which it operates*".
- Such devices must be able to:
  1. sense the spectral environment over a wide bandwidth,
  2. detect the presence/absence of legacy users (primary users),
  3. adapt the parameters of their communication scheme only if the communication does not interfere with primary users

Cognitive Radio Scenario (1)



(a) Downlink scenario (b) Uplink scenario

Figure 15: The Cognitive Radio Network with one primary user (PU) and $M = 4$ secondary users (SU) attempting to communicate with their respective pairs in an ad-hoc manner during an primary system transmission, subject to mutual interference.

Cognitive Radio Scenario (2)

- Consider a CRN that consists of a primary user, a base station, and M pairs of secondary users randomly distributed over the system. The channel gains are i.i.d random variable,

- Our goal is to maximize the total SU throughput under interference, noise impairments and constraints while **preserving the QoS of the primary system**.

Cognitive Radio Scenario (1)

- Thus, a cognitive transmitter can adapt its transmit power p to fulfill the following two basic goals:
  1. *Self-goal*: Trying to transmit as much information for itself as possible,
  2. *Moral-goal*: Maintaining the primary users' outage probability unaffected.

Binary Power Allocation: System model (1)

- The expression of the PU instantaneous capacity is:

$$C_{pu} = \log_2 \left(1 + \frac{p_{PU} \mid h_{pu,pu} \mid^2}{\sum_{j=1}^{M} p_j \mid h_{j,pu} \mid^2 + \sigma^2} \right) \quad (1)$$

- The j^{th} SU instantaneous capacity is given by:

$$C_j = \log_2 (1 + \mathrm{SINR}_j) ; \quad \text{for} \quad j = 1, ..., M \quad (2)$$

where

$$\mathrm{SINR}_j = \frac{p_j \mid h_{j,j} \mid^2}{\sum_{\substack{k=1 \\ k \neq j}}^{M} p_j \mid h_{k,j} \mid^2 + p_{PU} \mid h_{pu,j} \mid^2 + \sigma^2} \quad (3)$$

Binary Power Allocation: System model (2)

- The per-user cognitive capacity is given by:

$$C_{sum} = \frac{1}{\tilde{M}} \sum_{j=1}^{\tilde{M}} C_j \ , \tag{4}$$

- The optimization problem can therefore be expressed as follows:

$$\text{Find } \{p_1*, \ldots, p_M*\} = \arg \max_{p_1, \ldots, p_M} C_{sum}$$

subject to:

$$\begin{cases} p_j \in \{0; P_{max}\}, \quad \text{for} \quad j = 1, \ldots, M \\ P_{out} = Prob\{C_{pu} \leq R_{pu} \mid R_{pu}, q\} \leq q \end{cases}$$

Binary Power Allocation: Simulation Setting and results

- A hexagonal cellular system functioning at 1.8 GHz with a primary cell of radius $R = 1000$ meters and a primary protection area of radius $R_p = 600$ meters is considered.
- Channel gains are based on the COST-231 path loss model including log-normal shadowing with standard deviation of 10 dB, plus fast-fading assumed to be i.i.d. circularly symmetric with distribution $\mathcal{CN}(0, 1)$.
- p_{pu} is taken equal to $P_{max} = 1$ Watt in the uplink and 10 Watt in the downlink,

Downlink Scenario (1)

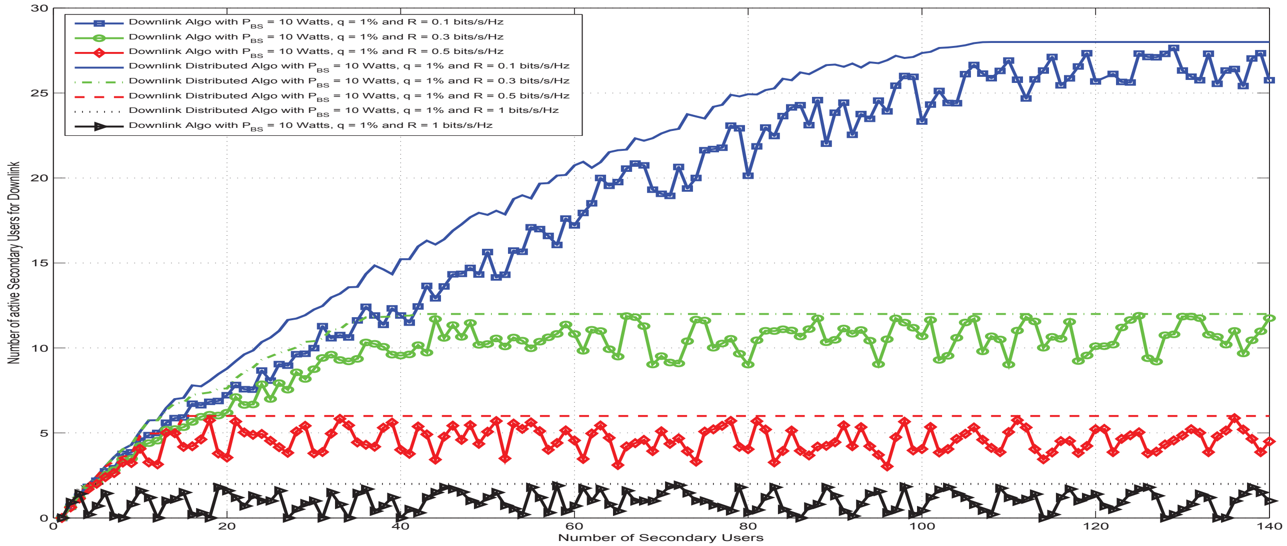


Figure 17: Number of active secondary users vs. number of SUs for different rates and outage probability in the downlink.

Downlink Scenario (2)

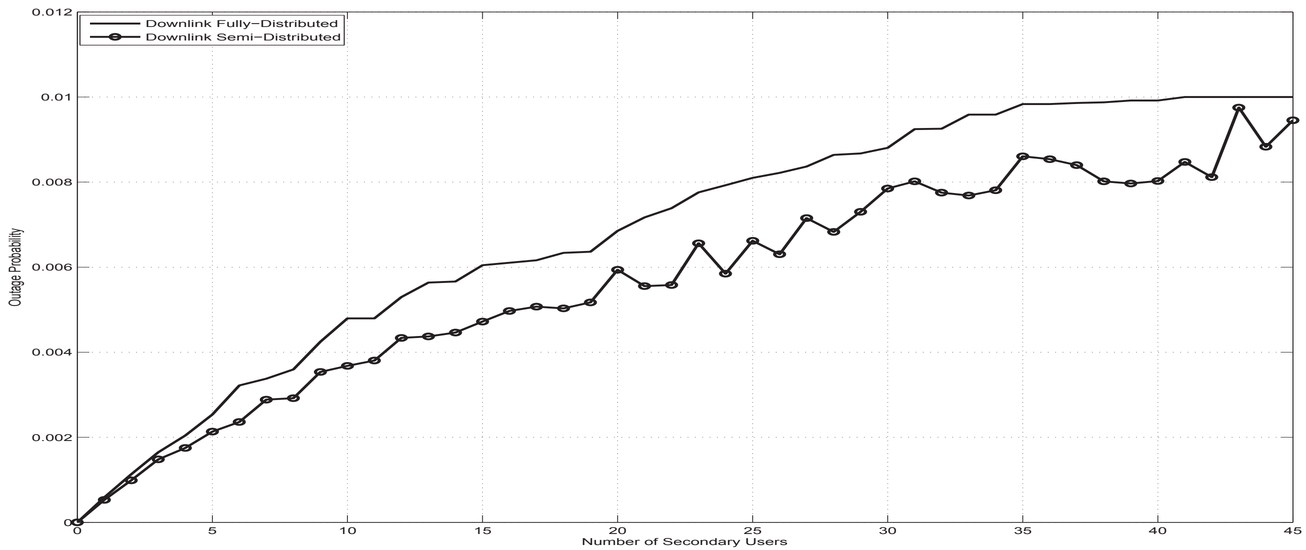


Figure 18: Outage Probability vs. Number of Secondary Users: Downlink Distributed Algo, q = 1% and rate = 0.3 bits/s/Hz.

Uplink Scenario (1)

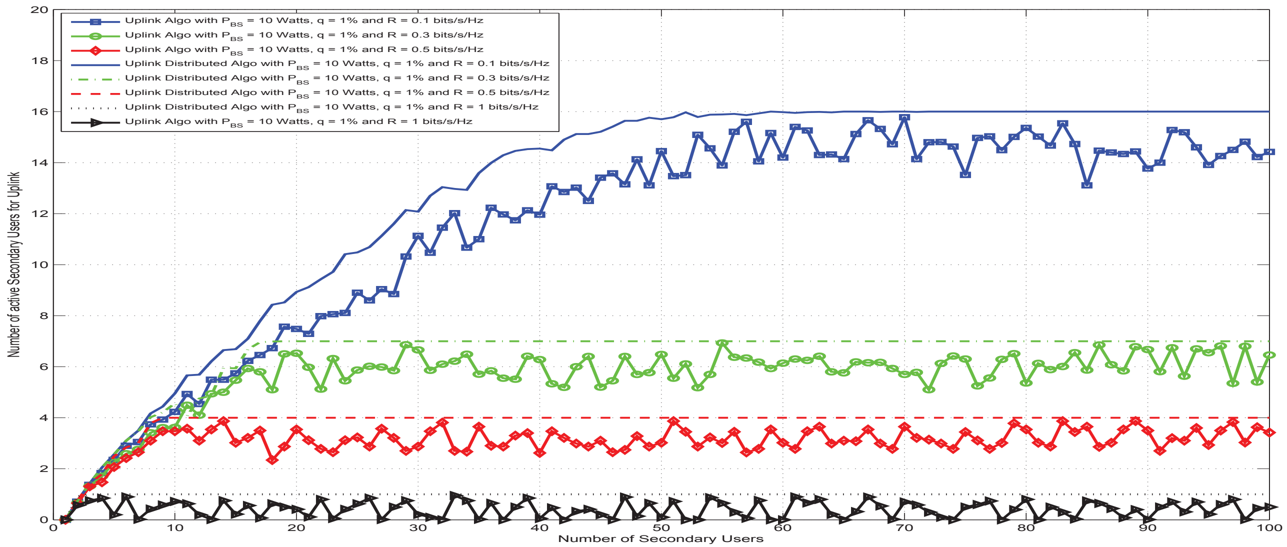


Figure 19: Number of active secondary users vs. number of SUs for different rates and outage probability in the uplink.

Uplink Scenario (2)

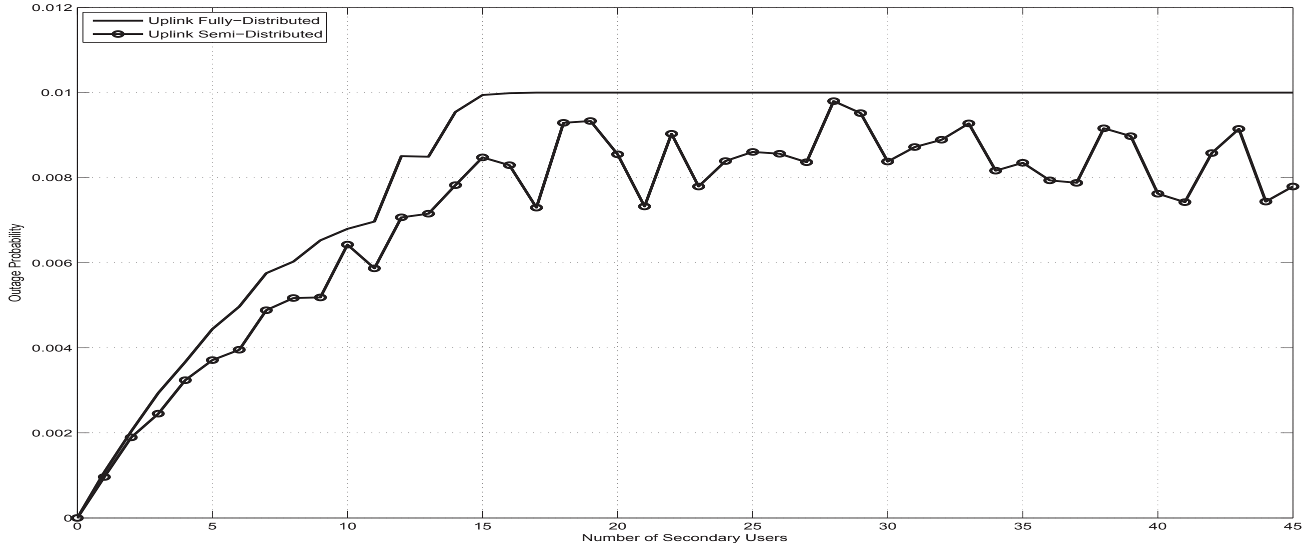


Figure 20: Outage Probability vs. Number of Secondary Users: Uplink Distributed Algo, q = 1% and rate = 0.3 bits/s/Hz.

Cognitive radio based on Beamforming Strategy

- We consider the primary uplink of a single CRN, where cognitive transmitters transmit signals to a number of secondary users (SUs) using adaptive antennas, while the primary BS receives its desired signal from a primary transmitter and interference from all the cognitive transmitters.
- With the deployment of K antennas at each cognitive transmitter, an efficient transmit beamforming technique combined with user selection is proposed to maximize the sum throughput and satisfy the signal-to-noise-and-interference ratio (SNIR) constraint thus limiting interference to the primary BS.
- In the proposed user selection algorithm, SUs are first pre-selected so as to maximize the per-user sum capacity, subject to minimization of the mutual interference. Then, the PU verifies the outage probability constraint.

Beamforming Strategy: System model (1)

- The SU system structure is based on beamforming at both the transmitter (K antennas) and the receiver (K antennas) for each SU link.
- The number of secondary transmitters (SU_T) is equal to M, and is equal to the number of secondary receivers (SU_R).

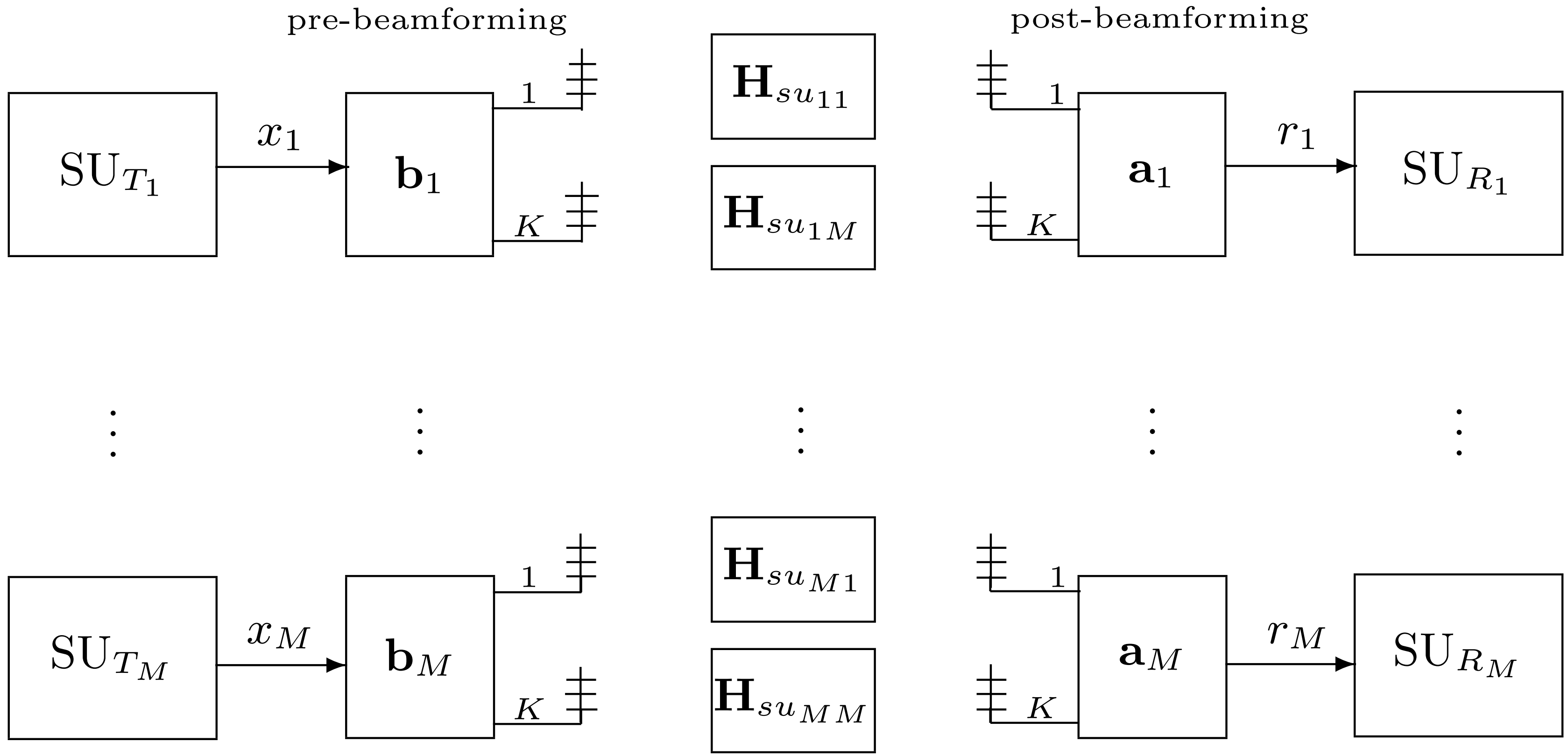


Figure 1: Multiple transmit and receive secondary users system structure.

Beamforming Strategy: System model (2)

Therefore, the SNIR at the m-th SU can be formulated as follows:

$$\begin{aligned}
\mathrm{SNIR}_m &= \frac{\left(\mathbf{a}_m^H \mathbf{H}_{su_{mm}} \mathbf{b}_m\right)^H \left(\mathbf{a}_m^H \mathbf{H}_{su_{mm}} \mathbf{b}_m\right)}{\mathbf{a}_m^H \mathbf{R}_m \mathbf{a}_m} \\
&= \left(\mathbf{a}_m^H \mathbf{H}_{su_{mm}} \mathbf{b}_m\right)^H \left(\mathbf{a}_m^H \mathbf{R}_m \mathbf{a}_m\right)^{-1} \left(\mathbf{a}_m^H \mathbf{H}_{su_{mm}} \mathbf{b}_m\right) \\
&= \mathbf{b}_m^H \mathbf{H}_{su_{mm}} \mathbf{R}_m^{-1} \mathbf{H}_{su_{mm}}^H \mathbf{b}_m \qquad (5)
\end{aligned}$$

From (5), the post-beamforming vector can be expressed as follows:

$$\mathbf{a}_m = \mathbf{R}_m^{-1} \mathbf{H}_{su_{mm}} \mathbf{b}_m \qquad (6)$$

This gives us the following maximization of SNIR at the m-th SU:

$$\begin{aligned}
\mathbf{b}_m^H \mathbf{H}_{su_{mm}}^H \mathbf{R}_m^{-1} \mathbf{H}_{su_{mm}} \mathbf{b}_m &\leq \lambda_{max}(m) |\beta(m)|^2 \\
&= \mathrm{SNIR}_m|_{max} \qquad (7)
\end{aligned}$$

where $\lambda_{max}(m)$ is the maximum eigenvalue of $\mathbf{H}_{su_{mm}}^H \mathbf{R}_m^{-1} \mathbf{H}_{su_{mm}}$ and $|\beta(m)|^2 = \mathbf{b}_m^H \mathbf{b}_m$. For beamforming, the transmitted power through all the SUs for the m-th SU is proportional to $||\mathbf{b}_m||^2$. The design goal is to find the optimum transmit weight vector subject to a carrier power constraint. We consider the power allocation problem corresponding to the distribution of all the available power at the transmitter among all SUs, when the data destined from SU m is transmitted with a maximum power P_{max}. This per-user power constraint is given by:

$$||\mathbf{b}_m||^2 = |\beta(m)|^2 \leq P_{max}, \qquad \forall m = 1, ..., M \tag{8}$$

and the global power constraint is formulated as follows:

$$\sum_{m=1}^{M} ||\mathbf{b}_m||^2 = \sum_{m=1}^{M} |\beta(m)|^2 \leq M P_{max} \tag{9}$$

Beamforming Strategy: System model (3)

Concluding that the maximum eigenvalue $\lambda_{max}(m)$ must be chosen so as to maximize the capacity of SUs given a fixed transmit power. In the first step of the proposed beamforming user selection strategy, SUs are first pre-selected so as to maximize the per-user sum capacity given by:

$$\mathrm{C}_{su} = \frac{1}{\ln 2} \sum_{m=1}^{M} \ln\left(1 + \lambda_{max}(m)|\beta(m)|^2\right) \qquad (15)$$

If we maximize the per-user sum capacity (C_{su}): i.e. the sum of the SNIR averaged over all SUs under the constraint of maintaining the global power lower than MP_{max}, the problem can be written as:

$$\begin{cases} \text{maximize} & f(\beta(1), ..., \beta(M)) = \mathrm{C}_{su} \\ \text{subject to} & \sum_{m=1}^{M} |\beta(m)|^2 \leq MP_{max} \end{cases} \qquad (16)$$

In the second step of the user selection strategy, the PU verifies the outage probability constraint and a number of SUs are selected from those pre-selected SUs. The outage probability can be written as:

$$P_{out} = Prob\{\mathrm{C}_{pu} \leq R_{pu}\} \leq q \tag{17}$$

where R_{pu} is the PU transmitted data rate and q is the maximum outage probability.

Beamforming Strategy: Simulation results (1)

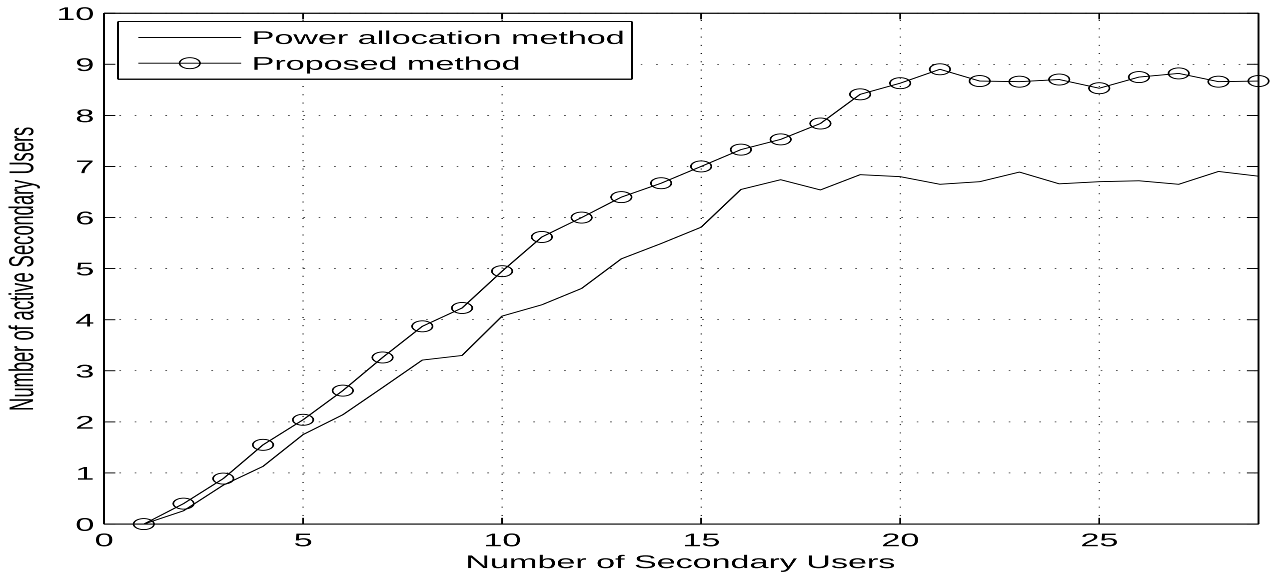


Figure 2: Number of active SUs vs. number of SUs at rate = 0.3 bits/s/Hz and an outage probability = 1% in the uplink (the uplink centralized binary power allocation method and the proposed method).

Beamforming Strategy: Simulation results (2)

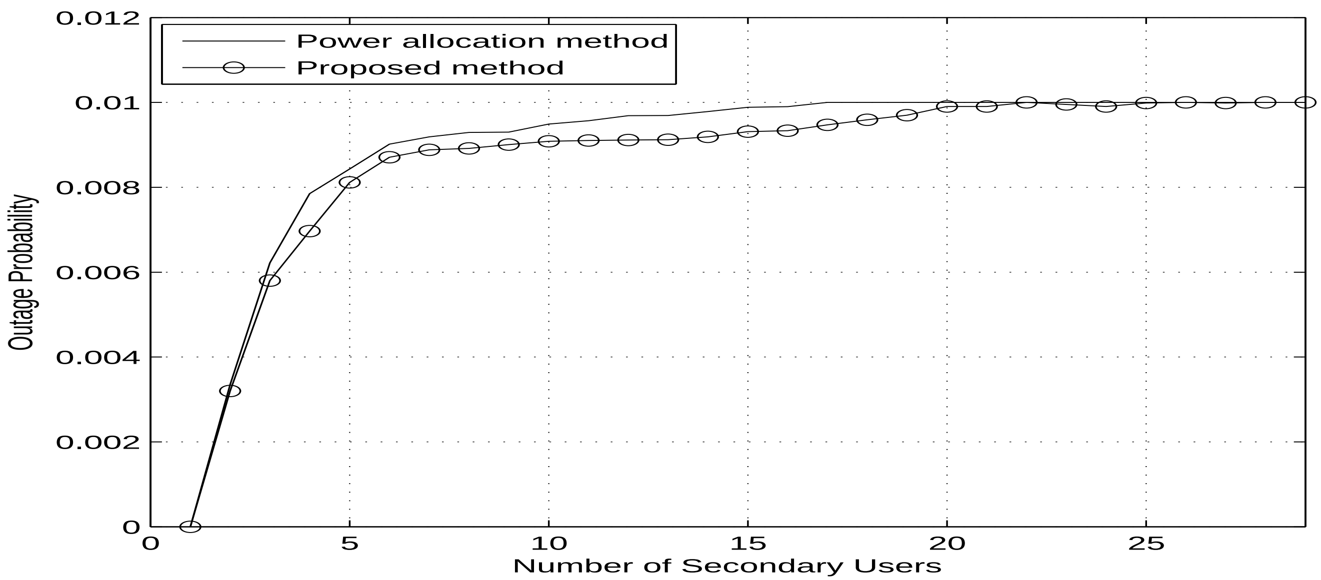


Figure 3: The uplink outage probability as function of the number of SUs for a target outage probability = 1% and a rate = 0.3 bits/s/Hz (the uplink centralized binary power allocation method and the proposed method).

Beamforming Strategy: Simulation results (3)

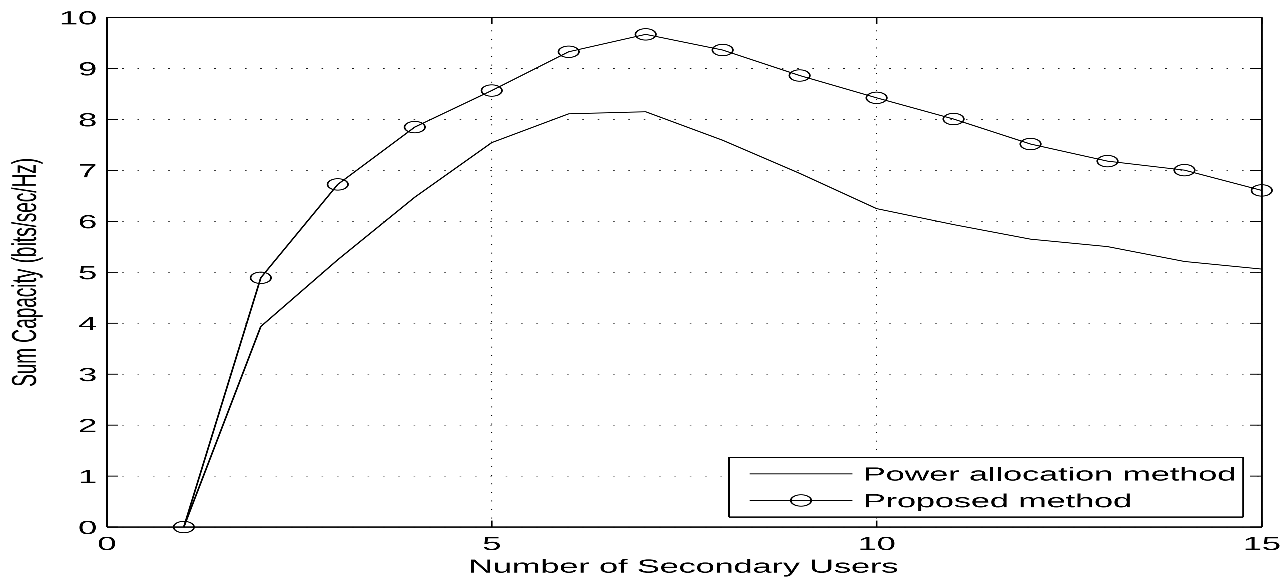


Figure 4: Sum capacity vs. number of SUs at rate = 0.3 bits/s/Hz and an outage probability = 1% in the uplink (the uplink centralized binary power allocation method and the proposed method).

Conclusion

- In this work, we have explored the idea of combining multi-user diversity gains with spectral sharing techniques to maximize the secondary user rate while maintaining a QoS to a primary user,
- We proposed and compared two techniques: Binary Power allocation and Beamforming based power allocation.
- We showed that the beamforming technique provides better results in terms of secondary system performance while minimizing the interference to the primary system.

Resource Allocation Strategies for Cognitive Radio Networks

References

[1] B. Zayen, A. Hayar and G. Oien "Resource allocation for cognitive radio networks with a beamforming user selection strategy ," *IEEE Asilomar 2009,* November 2009,

EURECOM
Sophia Antipolis

THANK YOU!

Questions?