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Per-subcarrier Antenna Selection for OFDMA-based Cognitive Radio Systems

M.Z. Bocus, J.P. Coon, C.N. Canagarajah, J.P. McGeehan, A. Doufexi
and S.M.D. Armour

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Talk Outline

- Motivation
- System Model
- Problem Formulation for low-complexity solutions
- Choice of objective function
- Simulation Results
- Summary



Motivation

Cognitive Radio

- Paradigm in wireless spectrum access, where secondary users (SUs) can access the spectrum of primary users (PUs).
- Interference from cognitive users, observed by primary system should be below a defined threshold.
- Efficient algorithms/systems are required that can improve the link quality of SUs while not violating constraints imposed by PUs.



Motivation

Cognitive MIMO can ...

- Improve link quality of cognitive users
- Mitigate/reduce interference to primary users, e.g., through beamforming techniques

However,...

- Requires full channel knowledge of both primary and secondary links
- High hardware and computational complexity



Motivation

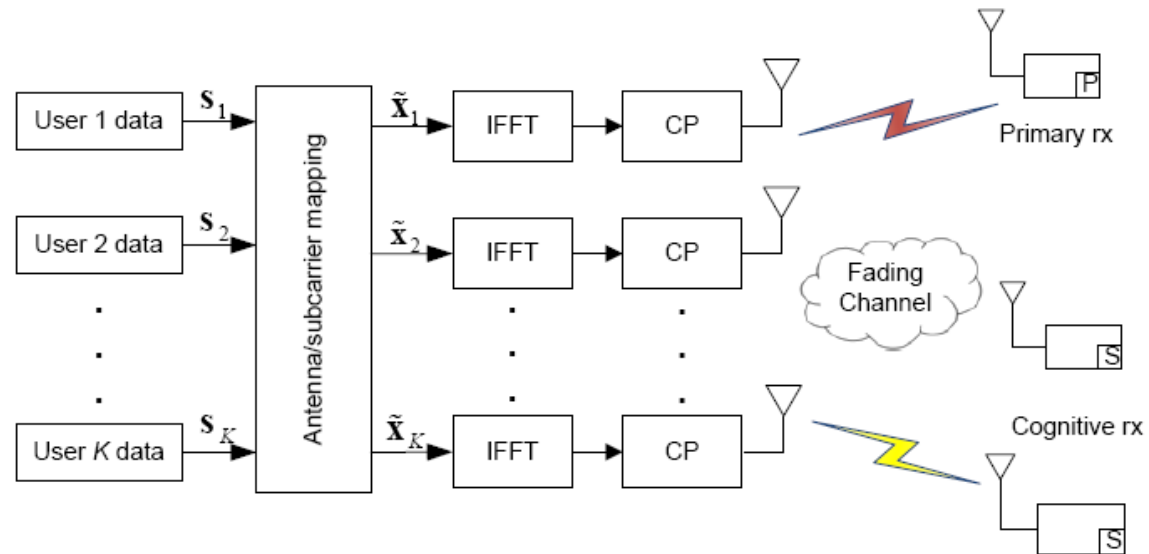
- **Cognitive MIMO techniques are impractical for rapidly changing environments**
- **Antenna Selection**
 - Only subset of antenna used for transmission/reception.
 - Does not require full channel state information (CSI)
 - More readily deployed and retains many of the benefits of MIMO systems
- **Per-subcarrier antenna selection can exploit frequency as well as spatial diversity**



🔥 System Model

- Downlink multiuser MISO OFDMA-based cognitive network considered
- Total interference power constraint imposed by primary system

- K SUs, 1 PU
- N subcarriers
- M tx antennas, 1 rx



Problem Formulation

***Objective: Improve secondary links quality,
while limiting interference***

- By performing a per-subcarrier antenna selection, i.e., every subcarrier is assigned a single transmit antenna
- Rapidly changing cognitive environments impose low-complexity algorithm



Problem Formulation

- Decision variables are integer in nature
- In general, integer programs are **NP-hard** problems
- Except when constraint matrix is **totally unimodular**, in which case, a linear relaxation of the problem is optimal

***Linear relaxation is optimal* \Leftrightarrow Low-complexity solutions**



Problem Formulation

The concepts of *unimodularity* and *total unimodularity* are related to the determinants of the (sub-) matrices that define the polyhedron.

***Total unimodularity* \Leftrightarrow polyhedron is integral**

We used this theorem in our work on antenna selection.

- For total unimodularity, entries in the constraint matrix can only take values 0 or 1



Problem Formulation

- Thus, interference constraint not included to avoid increasing the complexity

$$\sum_{k=1}^K \sum_{n=1}^N \sum_{m=1}^M \left| \tilde{g}_{n,m} \right|^2 \rho_{k,n,m} P_s \leq \mathbf{I}_{th}$$

- where
 - $\left| \tilde{g}_{n,m} \right|^2$ is the channel gain between the secondary transmitter and primary receiver on the n th subcarrier from the m th antenna
 - P_s is the transmit power on the n th subcarrier
 - \mathbf{I}_{th} is the received interference power limit
- Instead constraint included in the objective function



🔥 Problem Formulation: Constraints

- **Selection Variable**

$$\rho_{k,n,m} = \begin{cases} 1, & \text{if user } k \text{ is transmitting on the } n \text{ subcarrier from the } m\text{th antenna} \\ 0, & \text{otherwise} \end{cases}$$

- **Exclusive use of subcarrier/antenna pair to one SU**

$$\sum_{k=1}^K \sum_{m=1}^M \rho_{k,n,m} \leq 1, \quad \forall n$$

- **Minimum number of subcarriers to assign to each user**

$$\sum_{n=1}^N \sum_{m=1}^M \rho_{k,n,m} \geq n_{\min}, \quad \forall k$$



Problem Formulation

- Problem Formulated as

$$\begin{aligned} & \text{maximise} && f(\mathbf{H}_1, \dots, \mathbf{H}_k, \mathbf{G}, \rho) \\ & \text{subject to} && \sum_{n=1}^N \sum_{m=1}^M \rho_{k,n,m} \geq n_{min}, \quad \forall k \\ & && \sum_{k=1}^K \sum_{m=1}^M \rho_{k,n,m} \leq 1, \quad \forall n \\ & && \rho \in \{0, 1\} \end{aligned}$$

- where $f(\mathbf{H}_1, \mathbf{H}_2, \dots, \mathbf{H}_K, \mathbf{G}, \rho)$ is a function of the channel gain matrix between the SU tx –SU rx, \mathbf{H}_k , channel gain matrix between SU tx – PU rx, \mathbf{G} , and the decision variables, ρ



Choice of Objective Functions

Two possibilities to trade-off interference to PU and sum channel gain of SUs

- **Ratio of channel gains**

$$f(\mathbf{H}_1, \dots, \mathbf{H}_K, \mathbf{G}, \boldsymbol{\rho}) = \sum_{k=1}^K \sum_{n=1}^N \sum_{m=1}^M \rho_{k,n,m} \frac{|\tilde{h}_{n,m}^k|^2}{|\tilde{g}_{n,m}|^2}$$

- **Weighted difference of channel gains**

$$f(\mathbf{H}_1, \dots, \mathbf{H}_K, \mathbf{G}, \boldsymbol{\rho}) = \delta \sum_{k=1}^K \sum_{n=1}^N \sum_{m=1}^M \rho_{k,n,m} |\tilde{h}_{n,m}^k|^2 - (1 - \delta) \sum_{k=1}^K \sum_{n=1}^N \sum_{m=1}^M \rho_{k,n,m} |\tilde{g}_{n,m}|^2$$

where $|h_{n,m}|^2$ is the SU-SU channel gains and δ is the weight variable

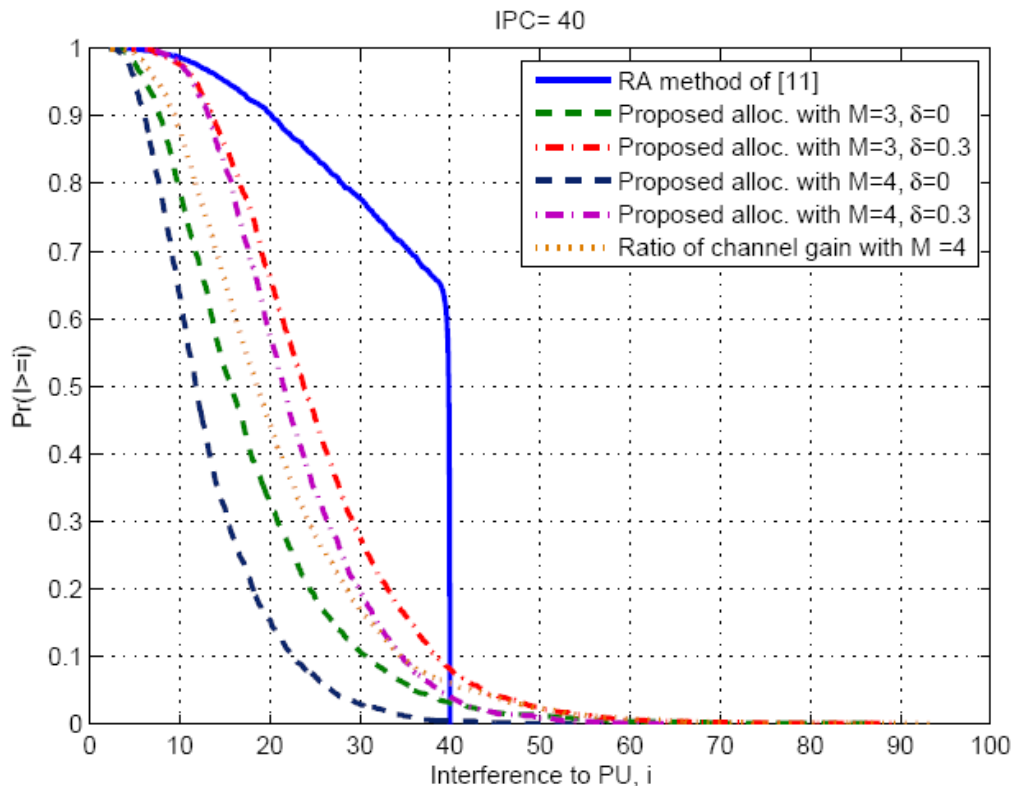


Simulation Results



Simulation Results

ccdf of interference to PU



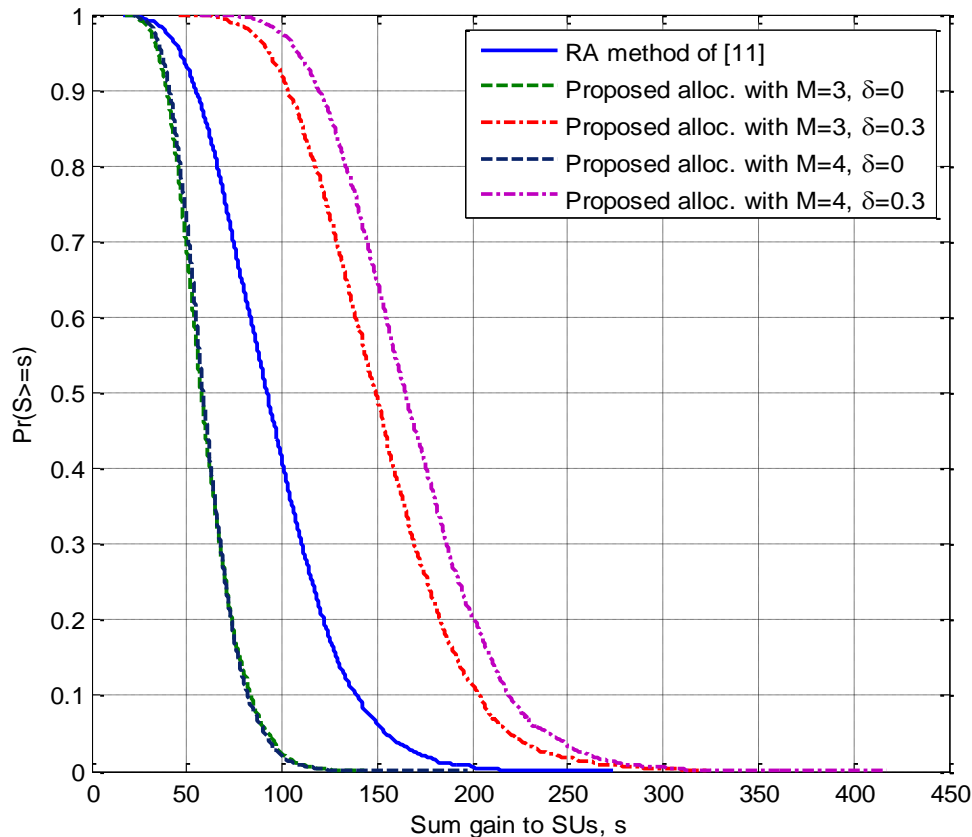
- $N=128$ subcarriers
- $K=4$ SUs
- Interference power constraint = 40 units
- **Observations:**
 - Low probability of exceeding interference constraint
 - Ratio of channel gains offers less control

Resource allocation in [11] explicitly includes IPC in formulation – *NP-hard*

Simulation Results

Ccdf of sum channel gains of SU

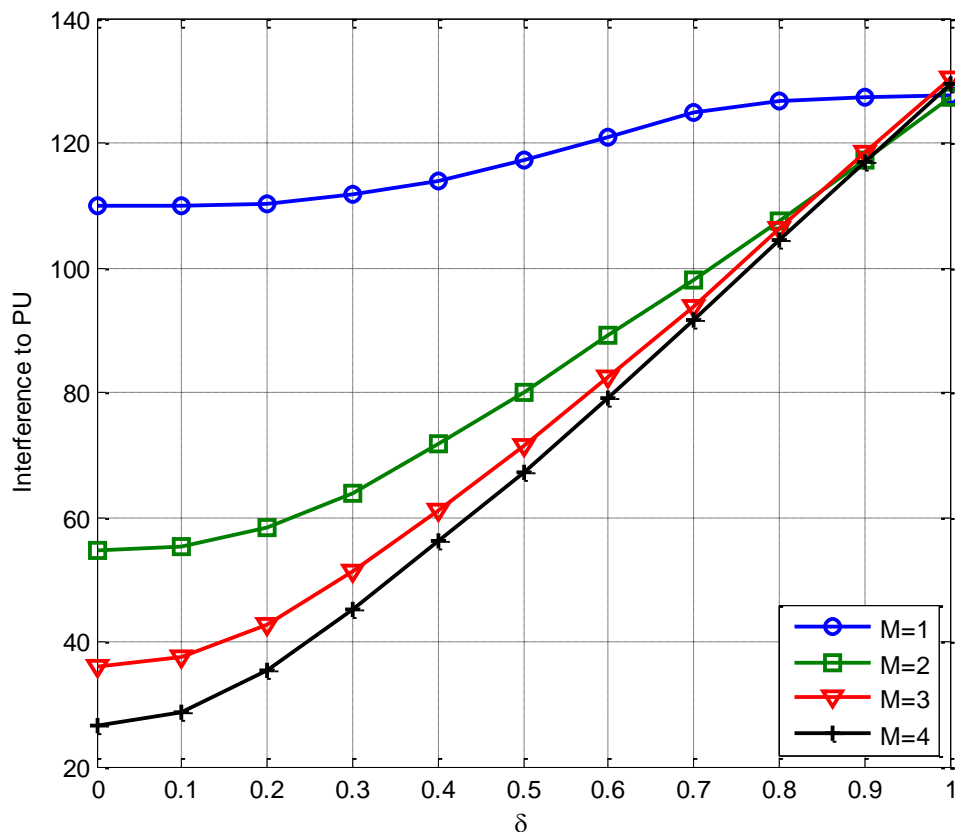
IPC = 40



- N=128 subcarriers
- K=4 Sus
- Interference power constraint = 40 units

Simulation Results

Interference to PU for different δ



- N=128 subcarriers
- K=4 Sus
- Interference power constraint = 40 units

Summary

- Antenna selection provides a good trade-off between benefits of cognitive MIMO and hardware/computational complexity
- Proposed algorithm can be solved using linear programs, leading to low complexity solutions
- Weighted difference of channel gains provides more control through parameter δ



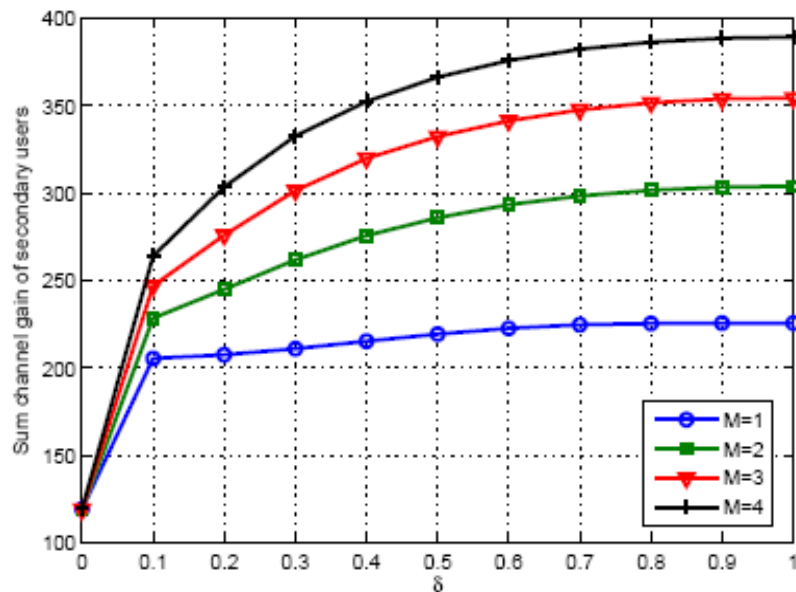
THANK YOU





Simulation Results

Sum Channel gains of SUs



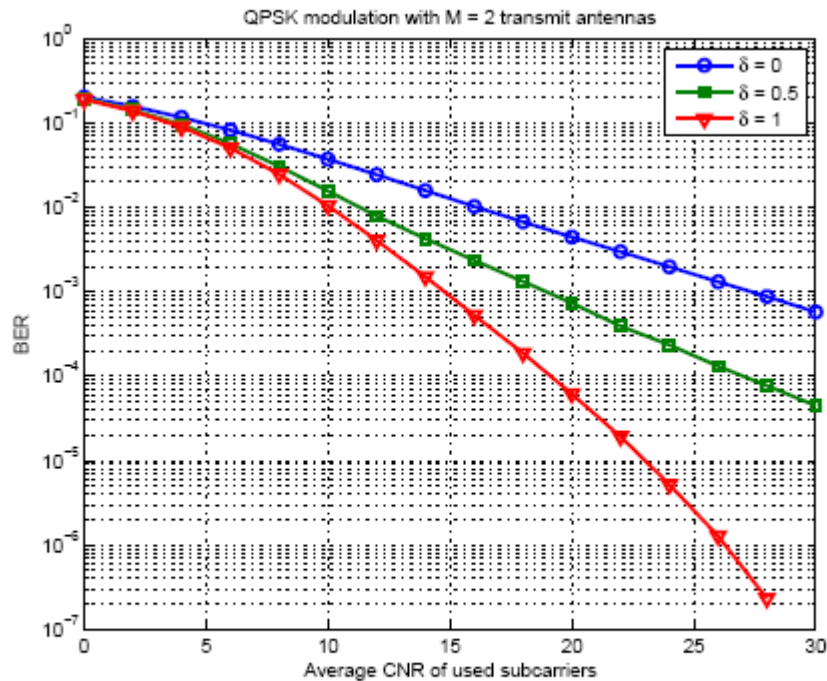
- $N=128$ subcarriers
- $K=4$ SUs
- Interference power constraint = 40 units

Fig. 3. Aggregate gain of SUs with $N = 128$, $K = 4$, $n_{min} = 30$ and $p_s=1$



Simulation Results

BER Analysis for Different delta

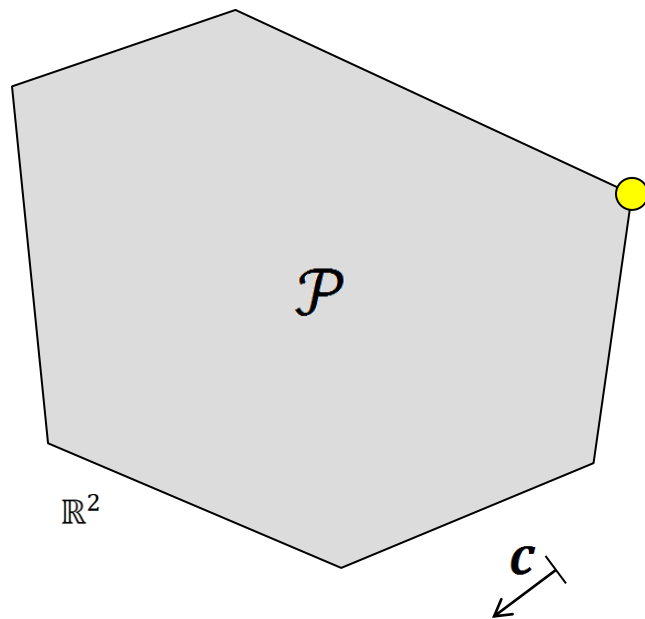


- N=128 subcarriers
- K=4 SUs
- Interference power constraint = 40 units

Fig. 4. BER plot for a system with 2 transmit antenna and QPSK modulation

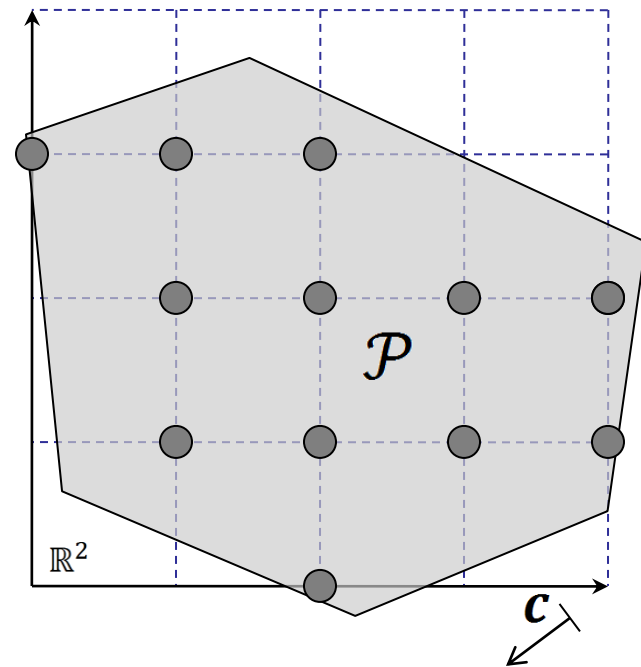
🔥 What is Integer Optimization?

Linear optimisation



minimise $\mathbf{c}'\mathbf{x}$
subject to $\mathbf{x} \in \mathcal{P}$

Integer optimisation



minimise $\mathbf{c}'\mathbf{x}$
subject to $\mathbf{x} \in \mathcal{P} \cap \mathbb{Z}_+^2$

Totally Unimodular Matrices

- Definition: *A matrix is totally unimodular if all its square submatrices have determinant ± 1 or 0.*
- Theorem: *If C is totally unimodular and u is an integer vector, the integer optimisation problem is solved by linear relaxation*
- Corollary: *The constrained antenna selection problem can be solved by linear relaxation, which means simpler solutions*

