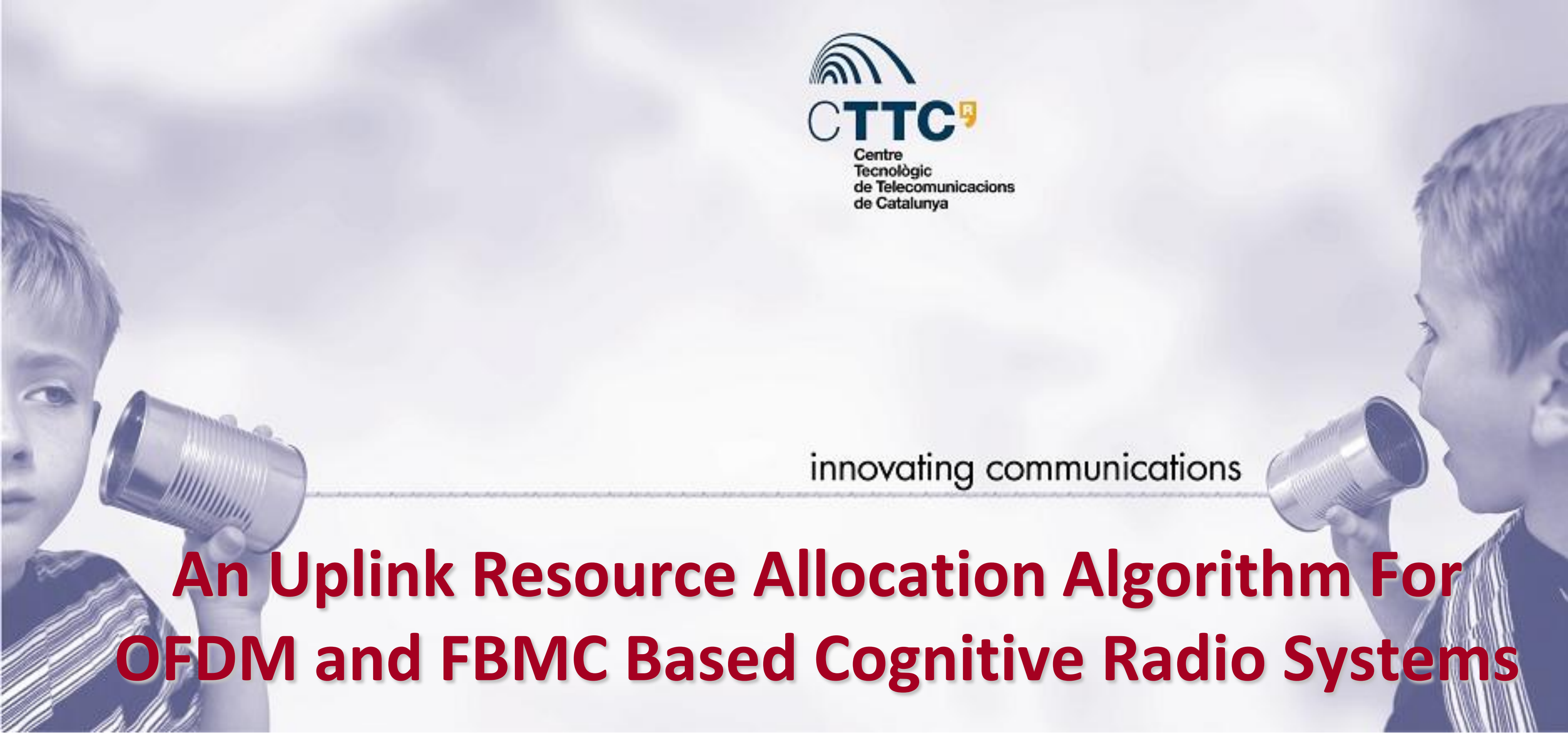

An Uplink Resource Allocation Algorithm For OFDM and FBMC Based Cognitive Radio Systems

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Outline

- Introduction.
- System model.
- Optimization problem.
- Proposed subcarrier allocation algorithm.
- Proposed power allocation algorithm.
- Simulation results.
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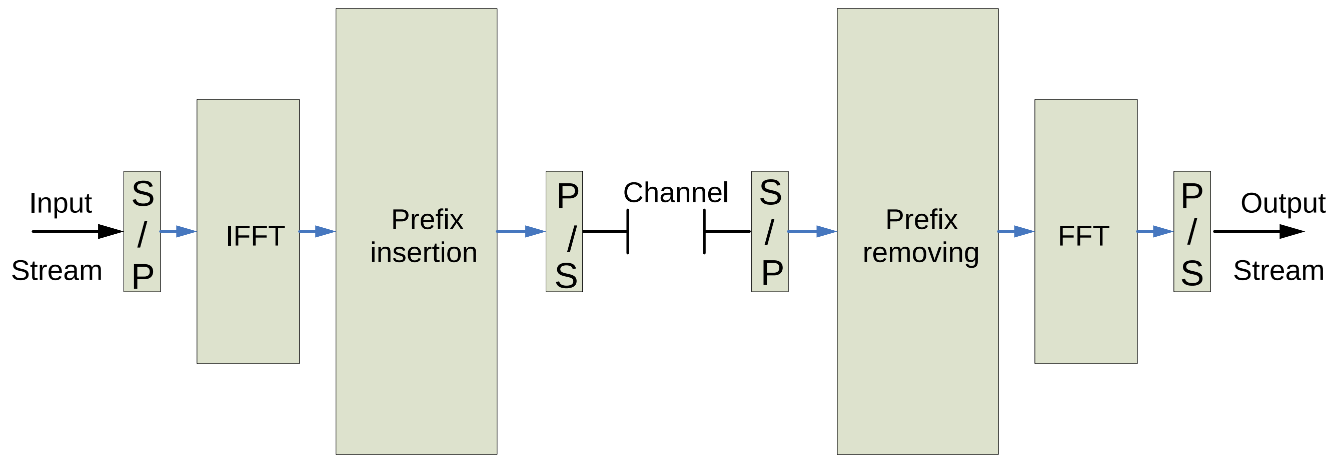
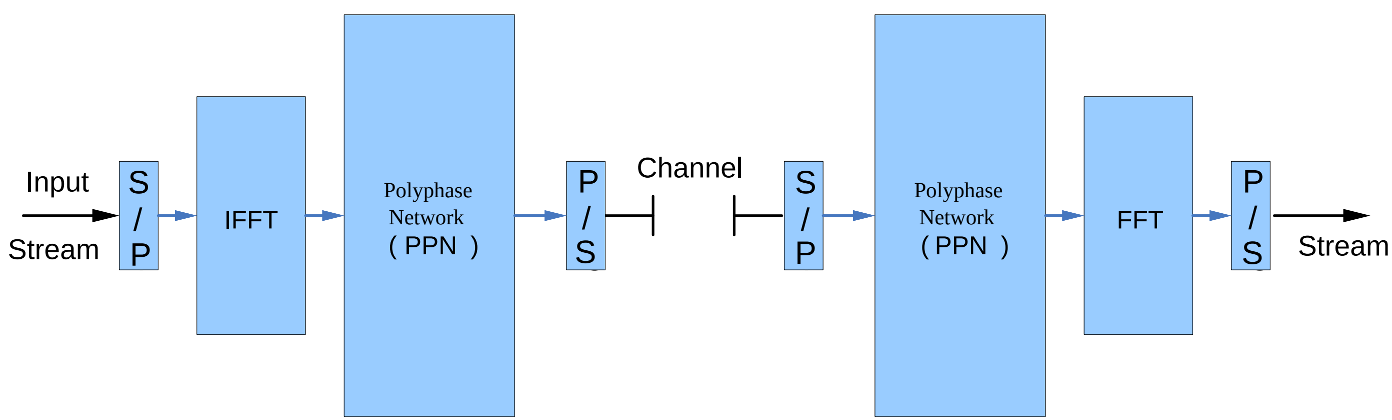
Introduction

- The spectrum scarcity is considered as one of the serious problem.
- Cognitive radio (CR) aims to increase the spectrum utilization.
- Multicarrier communication has been suggested as a candidate for cognitive radio (CR) systems.
- OFDM suffers from high interference to the primary user (PU) and the cyclic prefix insertion decreases the system capacity.
- FBMC doesn’t need any CP insertion and can overcome the interference problem.

Introduction, cont.

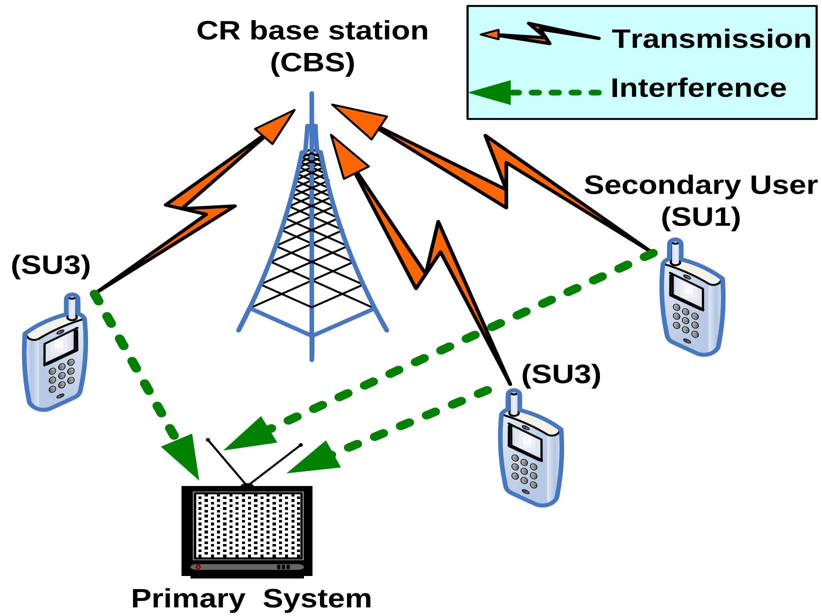


OFDM Transmitter **OFDM Receiver**



Synthesis Filter Bank **Analysis Filter Bank**

System Model



- The CR system coexist with the PU’s radio in the same geographical location.
- The Uplink scenario will be considered.
- Each of the two system causes interference to each other.

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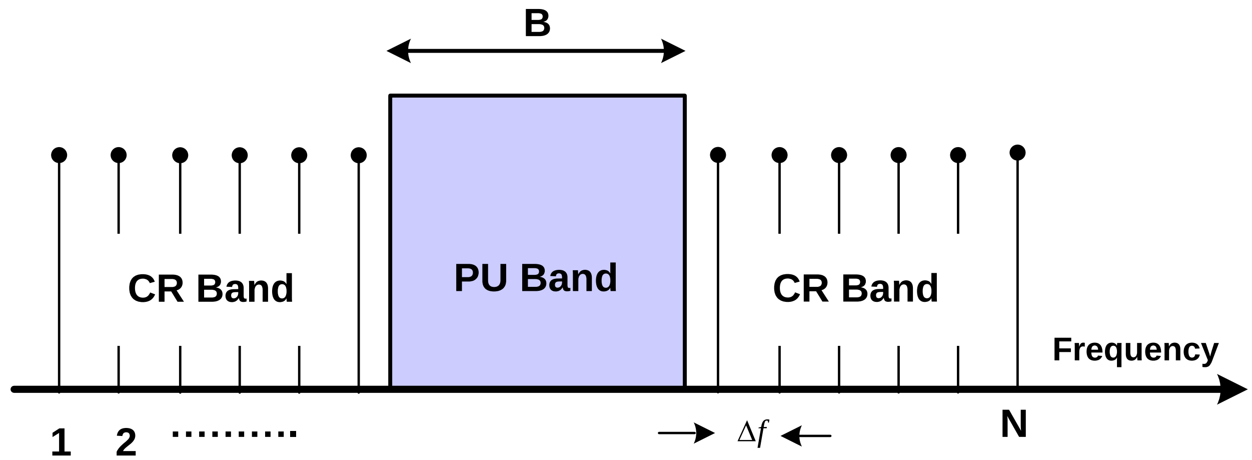
System Model, Cont.



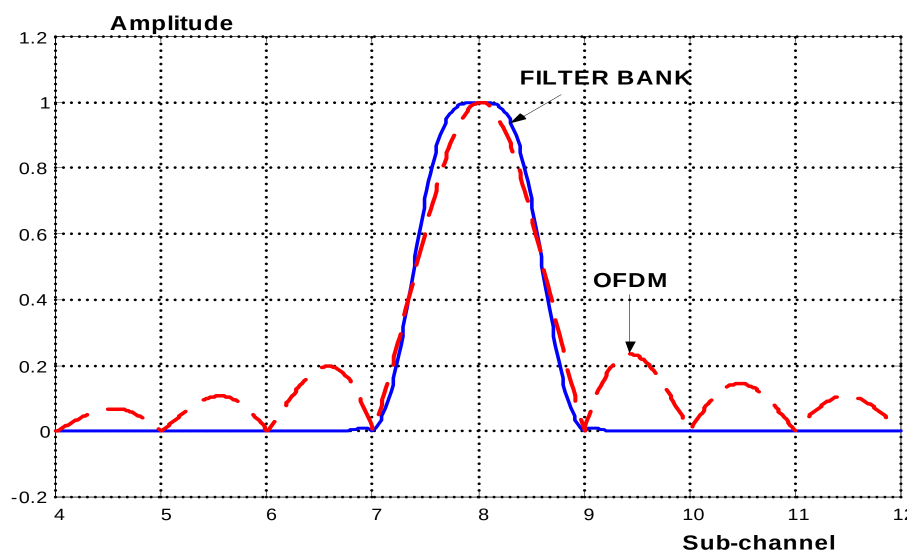
- The SU and PU band are exist side by side.
- Mutual interference is a limiting factor affect the performance of both systems.
- The CR can use non-active primary bands.
- The introduced interference to the primary band should be below $I_{th} = T_{th}B$ where T_{th} is the interference temperature limit.

System Model, Cont.

- The interference introduced by the i^{th} subcarrier to PU band is the integration of the PSD of the i^{th} subcarrier across the PU band

$$I_i\left(d_i, P_i\right) = \int_{di-B/2}^{di+B/2} \left|g_i\right|^2 \Phi_i\left(f\right)\, df = P_i\,\Omega_i$$

- The PSD expression depends on the used multicarrier technique.



Problem Formulation

- The objective is to maximize the total data rate of the CR system subject to the interference introduced to the PU band and per-user power constraints

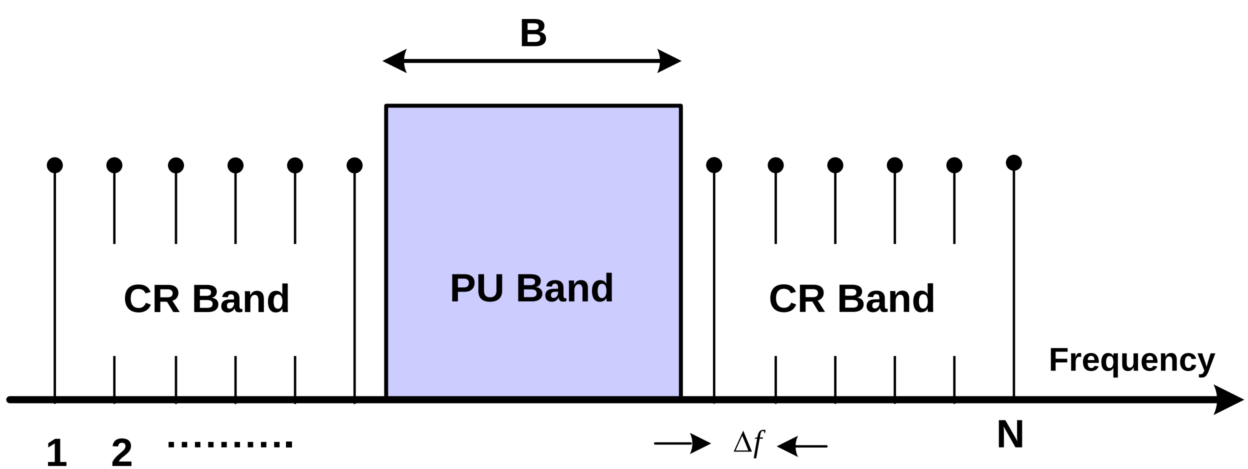
$$
\begin{aligned}
P1: \quad & \max_{P_{i,m},\omega_{i,m}} \sum_{m=1}^{M}\sum_{i=1}^{N} \omega_{i,m} R_i\left(P_{i,m}, h_{i,m}\right) \\
s.t. \quad & \sum_{m=1}^{M}\sum_{i=1}^{N} \omega_{i,m} P_{i,m} \Omega_{i,m} \leq I_{th} \\
& \sum_{i=1}^{N} P_{i,m} \leq \overline{P_m}, \qquad \forall m \\
& P_{i,m} \geq 0, \qquad \forall i,m \\
& \omega_{i,m} \in \{0,1\}, \qquad \forall i,m \\
& \sum_{m=1}^{M} \omega_{i,m} \leq 1, \qquad \forall i
\end{aligned}
$$

- where

$$
R_i\left(P_{i,m}, h_{i,m}\right) = \Delta f \log_2\left(1 + \frac{P_{i,m}\left|h_{i,m}\right|^2}{\sigma_i^2}\right)
$$

Problem Formulation, Cont.

- The problem is combinatorial optimization problem.
- The complexity grows with the input size.
- The problem is solved in two steps
  1. Subcarriers are assigned to the users.
  2. Power allocated to the different subcarriers (virtually as single user multicarrier system)



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Proposed Subcarrier Allocation Algorithm

- Assume that every subcarrier is allowed to introduce the same amount of interference to the primary system

$$I_{Uniform} = \frac{I_{th}}{N}$$

- The maximum power that can be allocated to the *ith* subcarrier when it is allocated to the *mth* SU is

$$P_{i,m}^{Uni} = \frac{I_{Uniform}}{\Omega_{i,m}}$$

- Let $\mathcal{U}$ to be the set of unassigned subcarriers.

$\mathcal{A}_m$ → subcarriers allocated according to **Max. Power** $P_{i,m}^{Uni}$

$\mathcal{B}_m$ → subcarriers allocated according to **Average Power**

$$(\overline{P_m} - \sum_{i \in \mathcal{A}_m} P_{i,m}^{Uni})$$

Proposed Subcarrier Allocation Algorithm, Cont.

- The assigning procedures of a particular subcarrier $i^* \in \mathcal{U}$ are as follows:

1. For every User m , Evaluate $P_{Test} = \dfrac{\overline{P_m} - \sum_{r \in \mathcal{A}_m} P^{Uni}_{r,m}}{|\mathcal{B}_m|+1}$

If $P_{Test} \geq P^{Uni}_{i^*,m}$ ⟶ $\mathcal{A}'_m = \mathcal{A}_m \cup \{i^*\}$ and $\mathcal{B}'_m = \mathcal{B}_m$

else ⟶ $\mathcal{B}'_m = \mathcal{B}_m \cup \{i^*\}$ and $\mathcal{A}'_m = \mathcal{A}_m$

2. Compute the amount of increment in the data rate Δ_m when the subcarrier $\{i^*\}$ is assigned to the m^{th} SU

$$\Delta_m = R^{new}_m - R^{old}_m$$

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Proposed Subcarrier Allocation Algorithm, Cont.

- Find m^* satisfying $m^* = \arg\max_m (\Delta_m)$ and set

  $\omega_{i^*,m^*} = 1,\ \mathcal{A}_{m^*} = \mathcal{A}'_{m^*}$ and $\mathcal{B}_{m^*} = \mathcal{B}'_{m^*}$.

- Remove the subcarrier i^* form the set $\mathcal{U}$ and repeat until the set $\mathcal{U}$ is empty.

- The final set of allocated subcarriers to the m^{th} SU is

$$\mathcal{N}_m = \mathcal{A}_m \cup \mathcal{B}_m$$

Proposed Power Allocation Algorithm

- Once the subcarriers are allocated to the users, the multiuser system can be viewed virtually as a single user multicarrier system. The problem can be reformulated as follows:

$$
\begin{aligned}
P2: \quad & \max_{P_{i,m}} \sum_{i=1}^{N} R_i \left(P_{i,m}, h_{i,m}\right) \\
s.t. \quad & \sum_{i=1}^{N} P_{i,m}\Omega_{i,m} \leq I_{th} \\
& \sum_{i \in \mathcal{N}_m} P_{i,m} \leq \overline{P_m} \quad \forall m \\
& P_{i,m} \geq 0 \qquad \forall i
\end{aligned}
$$

- Where m in $P_{i,m}$, $h_{i,m}$ and $\Omega_{i,m}$ refers to the user who's already got the subcarrier i .

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Proposed Power Allocation Algorithm, Cont.

- Problem P2 is convex with the Lagrangian :

$$G = -\sum_{i=1}^{N} R_i\left(P_{i,m}^{*}, h_{i,m}\right) + \alpha\left(\sum_{i=1}^{N} P_{i,m}^{*}\Omega_{i,m} - I_{th}\right) + \sum_{m=1}^{M}\beta_m\left(\sum_{i\in\mathcal{N}_m} P_{i,m}^{*} - \overline{P_m}\right) - \sum_{i=1}^{N} P_{i,m}^{*}\mu_i$$

- Applying KKT condition and solving for the optimal

$$P_{i,m}^{*} = \left[\frac{1}{\alpha\Omega_{i,m} + \sum_{m=1}^{M}\beta_m} - \frac{\sigma_i^2}{\left|h_{i,m}\right|^2}\right]^{+} \qquad (*)$$

- Can be solved numerically using ellipsoid or interior point method with a polynomial time complexity.

Simulation Results

- **Optimal:** the subcarriers are allocated by exhaustive enumeration while the power is allocated by (*)
- **Wang:** the method proposed in $\in \left[\mathcal{O}\left(N^2 M\right), \mathcal{O}\left(N^3 M\right)\right]$

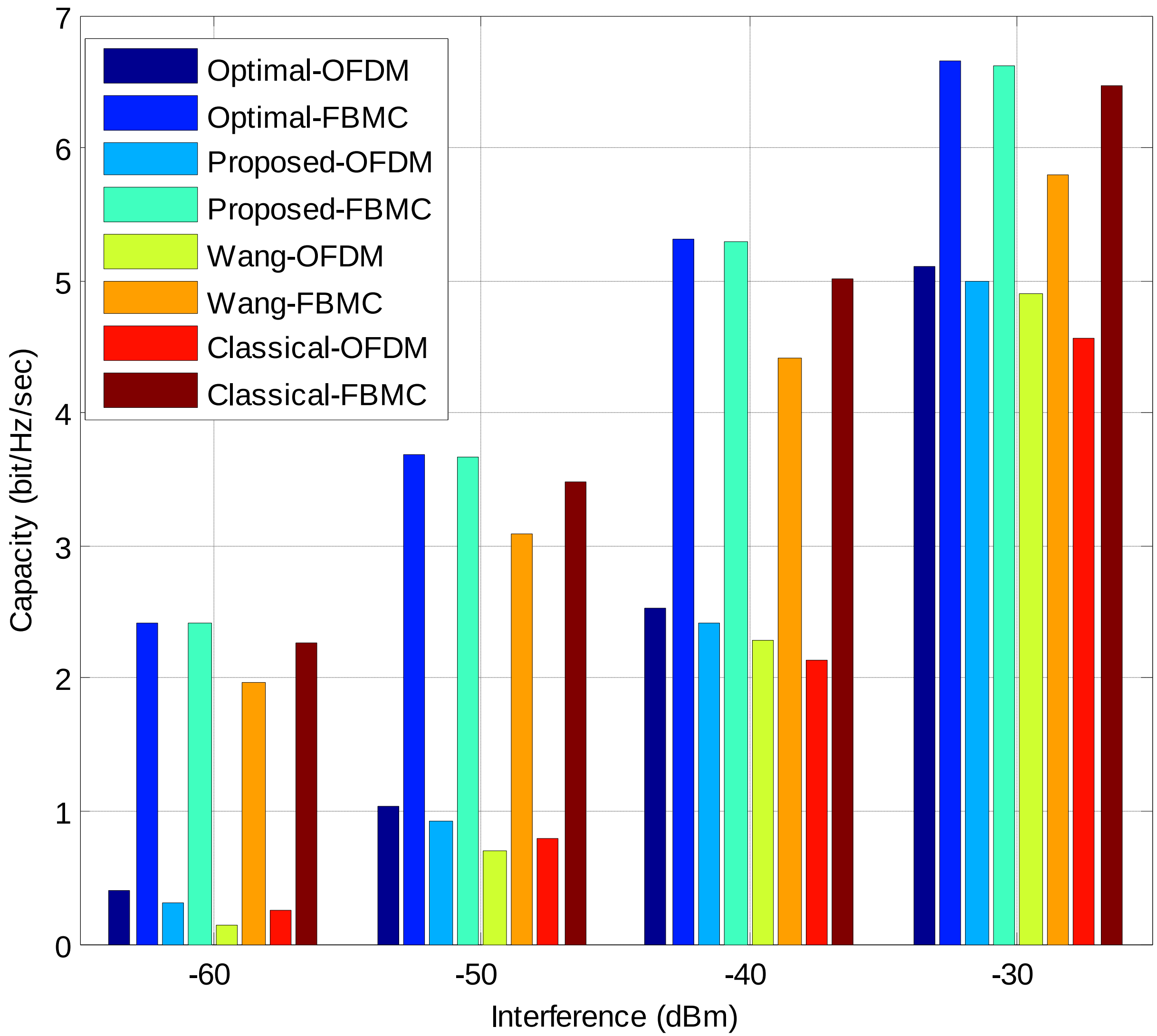
  Wang et al., "An uplink resource allocation scheme for OFDMA-based cognitive radio networks," *International Journal of Communication Systems*, vol. 22, no. 5, pp. 603–623, 2009.

- **Classical:** the subcarriers are allocated according to the scheme used in non-cognitive OFDM while the power is allocated by (*).

  Gao et al., "“Efficient subcarrier, power, and rate allocation with fairness consideration for OFDMA uplink," *IEEE Trans. Wireless Communications, vol. 7, no. 5, pp. 1507–1511, May 2008.*

Simulation Results (Interference. Vs. Capacity)

$$N = 8 \qquad \overline{P_m} = 1m\text{Watt}$$
$$M = 2 \qquad B = 2.5 \text{ MHz}$$



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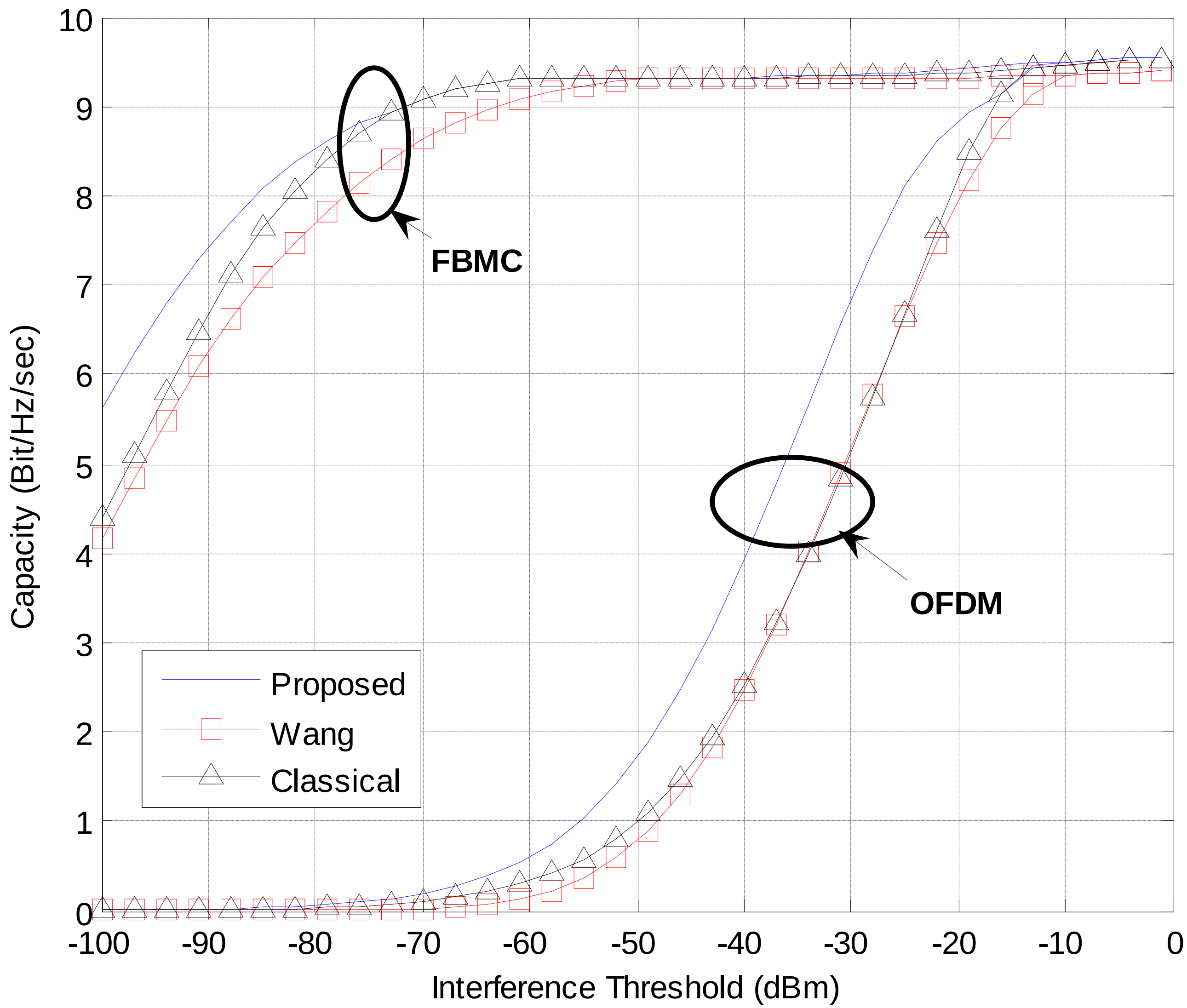
Simulation Results (Interference. Vs. Capacity)

$$M = 10 \qquad \overline{P_m} = 1m\text{Watt}$$
$$N = 64 \qquad B = 10 \text{ MHz}$$



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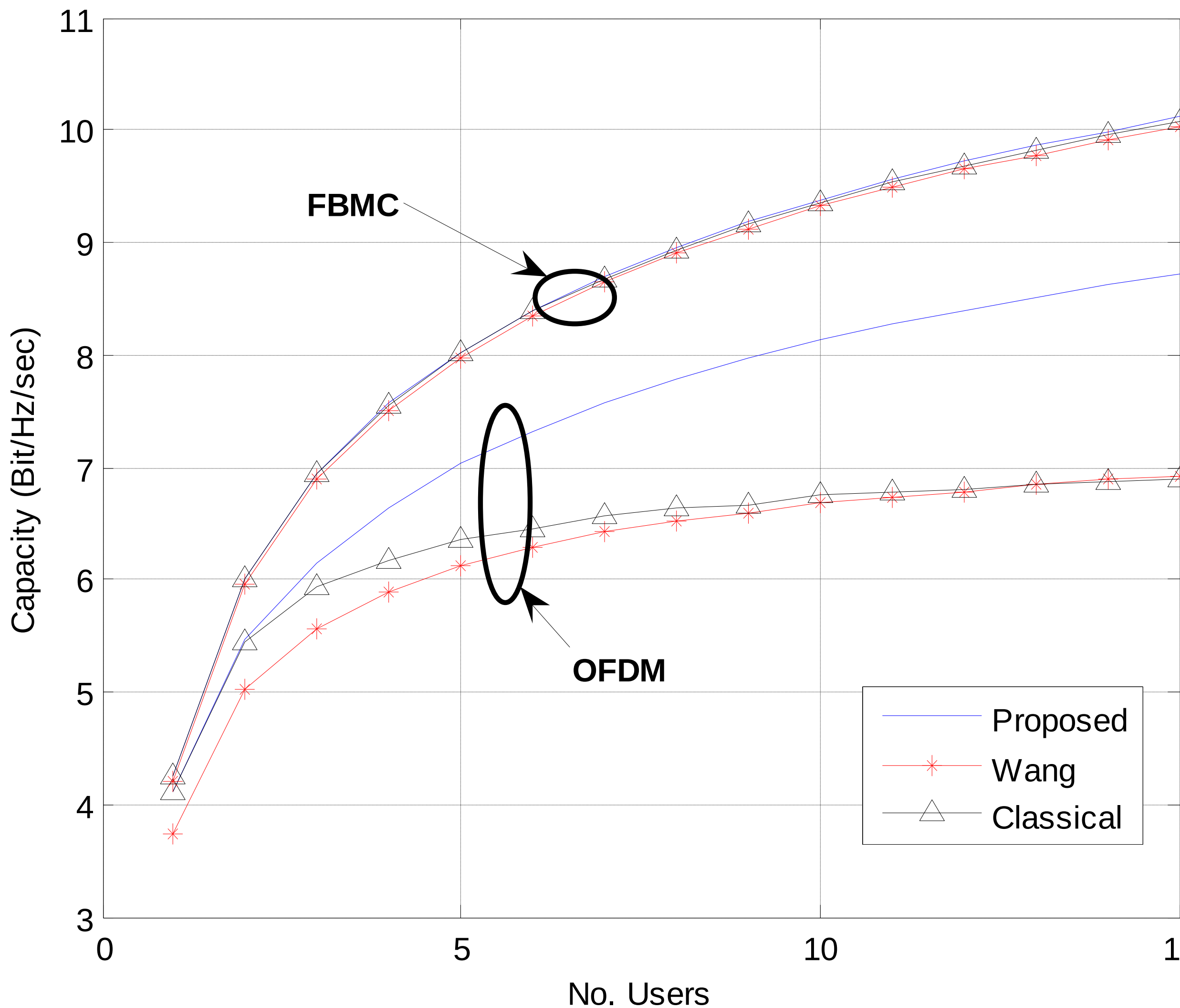
Simulation Results (No. of Users Vs. Capacity)

$$I_{th} = -25 \text{ dBm} \qquad \overline{P_m} = 1m\text{Watt}$$

$$N = 64 \qquad B = 10 \text{ MHz}$$



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Conclusions

- Efficient resource allocation algorithm for uplink in multicarrier based CR networks was presented.
- The allocation process is separated into two steps.
    1. In the first step, the subcarriers are allocated to the users .
    2. In the second step, the per-user power budget is distributed among the subcarriers .
- The proposed algorithm with low computational complexity outperforms other algorithms and achieves a very good performance.
- The obtained results contribute in recommending the use of FBMC physical layer in the future cognitive radio systems.
- Developing a resource allocation algorithm that considers many interference constraints as well as the users quality of service (QoS) will be the guideline of our future research.

Thanks for your kind attention!

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