# Distributed User Association and Power Allocation for Small Cell Networks Sharing Unlicensed Spectrum

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## Abstract

In this paper, we study the joint user association and power allocation for uplink cognitive small cell network (CSN). This network is deployed by reusing unlicensed band that allocated for WiFi access point (AP). We formulate an optimization problem to maximize the total throughput of cellular users while protecting the WiFi system and avoiding the small cell base station' overloading. Then, we find a distributed solution based on Lagrangian relaxation and matching theory. Finally, we show the proposed framework converging to a sub-optimal solution.

## I. Introduction

Recently, the small cell network is promising solution to adapt data traffic in future model network. However, to meet such mobile data challenges and spectrum scarcity, the unlicensed spectrum using WiFi frequency band is considered as the advanced solution to boost the network capacity while continually providing high-level user experience to customers utilized to improve more spectrum usage efficiency [1,2].

In this paper, we study the joint user association and power allocation in the small cell network, in which the unlicensed spectrum usages are reused from the WiFi system. For the CDMA-based small cell network deployment, there have been some existing works studding the cell association and power control [3, 4]. Different works from [3,4], this paper consider the unlicensed band protection and overload avoidance at FBSs. In summary, our contribution in this paper as follows:

- We propose a distributed framework for joint user association and power allocation in the small cell network that utilize the unlicensed spectrum of the WiFi system.
- The join problem is formulated to maximize overall SINR while protecting the WiFi AP and avoiding the SBSs' overload.
- We propose a distributed algorithm based on Lagrangian Relaxation and matching theory to find a sub-optimal solution.

## II. System model and formation problem

### A. System model.

We consider a small cell network consisting of a set $\mathcal{N}$ = {1...N} cellular users (CUs) that is served by M SBSs. The spectrum access in the SCN is utilized from the unlicensed band B of the WiFi access point (AP) as in Fig.1. These SBSs adapt an open access mode which allows any SUEs to use the SBSs' services. We assume that all SBSs utilize the same unlicensed band.

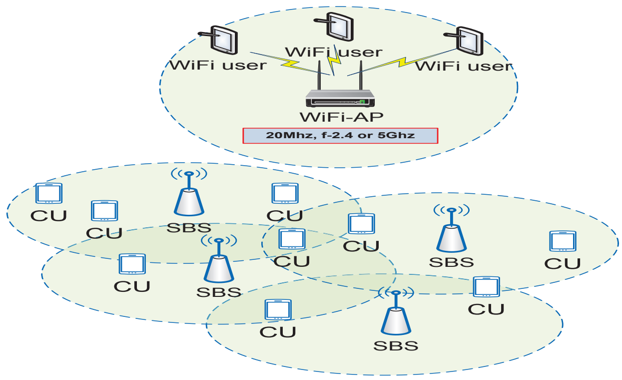


*Figure 1: system model*

### B. Problem formulation.

In our work, the joint power allocation and user association problem is formulated as follows:

$$\text{P-1:} \quad \max_{(X,P)} \sum_{n=1}^{N}\sum_{m=1}^{M} x_{nm} \log(\Gamma_{nm}(P)) \qquad (1)$$

$$\text{s.t.} \quad \sum_{m=1}^{M} x_{nm} \le 1, \ \forall n, \qquad (2)$$

$$\sum_{n=1}^{N} x_{nm} \le N_m, \ \forall m, \qquad (3)$$

$$\sum_{n=1}^{N}\sum_{m=1}^{M} x_{nm} g_{n,WiFi-AP} P_n \le I_{WiFi-AP}^{th}, \qquad (4)$$

$$x_{nm} = \{0,1\}, \forall m, n, \qquad (5)$$

$$0 \le p_n \le P_n^{\max}, \ \forall n, \qquad (6)$$

Where $\Gamma_{nm}(X,P)=\frac{g_{nm}P_n}{\sum_{n'\neq n} g_{n'm}P_{n'}+\sigma^2}$ is the SINR when the CU n transmits to the SBS m; constraint (2) represents each CU can associate to at most one SBS; The constraint (3) represent the hardware limitation of each SBS in which each SBS only serves at most $N_m$ CUs at one time; the constraint (4) represents the protection of the unlicensed band of the WiFi-AP; the constraint (5) represents user association index; $g_{nm}$ is channel gain between CU n and SBS m; $\sigma^2$ is Gaussian Noise at the receiver.

## III. Distributed algorithm for optimal joint subchannel and power allocation.

We can see that P-1 problem is an NP-hard problem. In order to solve it, first, we use logarithm change to transform the objective function into a convex function ($\tilde{p}_n=\log(p_n)$). After that, the reformulated problem is a convex function in $\tilde{p}_n$. After that, the Lagrangian function is obtained by augmenting the objective function with a weighted sum of the constraint (4), as follows:

$$L=\sum_{n=1}^{N}\sum_{m=1}^{M} x_{nm}\log(\Gamma_{nm}(e^{\tilde{P}_n}))-\lambda\Big(\sum_{n=1}^{N}\sum_{m=1}^{M} x_{nm}g_{n,WiFi-AP}e^{\tilde{P}_n}-I^{th}_{WiFi-AP}\Big) \quad (7)$$

The dual function $\mathrm{D}(\lambda)$ for the P-1 is addressed as follows:

$$\mathrm{D}(\lambda)=\max_{\mathrm{X},\mathrm{P}} L\left(\mathrm{X},\tilde{\mathrm{P}},\lambda\right) \quad s.t.(2),(3),(5) \quad (8)$$

By using dual decomposition mechanism, the problem (8) can be decomposed into two sub-problems due to variables x, P appear in the sum of products. Then, by taking $\partial L/\partial\tilde{P}_n=0$, the optimal power of the CU n can be obtained as follows:

**Optimal power allocation:**

$$\mathrm{P}^*_n=\Big[\frac{1}{\lambda g_{n,WiFi-AP}+\sum_{n',m'} x_{n',m'}\tau_{n'm'}g_{nm'}}\Big]^+ \quad (9)$$

where $\tau_{n'm'}=\Gamma_{n'm'}/(g_{n'm'}P_{n'})$ denoting by transferable value from other user association.

**User association assignment:**

Given the fixed transmit power in (9), the problem (8) is equivalent to a maximum weighted matching problem as follows:

$$\max_{\mathrm{X}}\sum_{n=1}^{N}\sum_{m=1}^{M} x_{nm}[\log(\Gamma_{nm}(P_n))-\lambda g_{n,WiFi-AP}P_n)] \quad (10)$$
$$s.t.(2),(3),(5)$$

Clearly, the optimization problem (10) can be solved in distributed manner by modelling the problem as the one-to-many matching game. In this game, the CU is the proposal side with utility function is $U_n(m)=\log(\Gamma_{nm}(P_n))$. The acceptance side is the SBS that depend on the quota at each SBS. Then, user association phase can be determined based on DDA algorithm [5], named matching for user association (MUA) algorithm.

Finally, by solving primal-dual problem, we propose the algorithm to find sub-optimal solution of the P-1 as follows:

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Joint user association and power allocation algorithm (JUP-MUA)

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1. Algorithm at the CU:

1.1 *Power update.* Given the user association, the optimal power allocation for the n-th CU pair is obtained based on (9).

1.2 User association phase. Given power allocation in (9), the sub-optimal solution for user association is determined by on DDA-UA algorithm

2. Algorithm at the WiFi-AP:

*2.1 Update price of WiFi-AP:*

$$\lambda^{(t+1)}=\left[\lambda^{(t)}-s_1^{(t)}\left(\sum_{n=1}^{N}\sum_{m=1}^{M} x_{nm}P_n g_{n,WiFi-AP}-I^{th}_{WiFi-AP}\right)\right]^+ \quad (13)$$

Results: the sub-optimal allocation $X^*, P^*$

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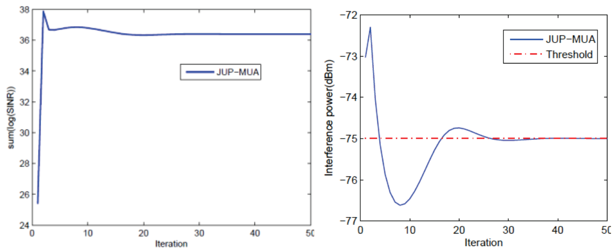
where the dual variables updated using sub-gradient method; $s_1^{(t)}$ is the step size of iteration

## V. Simulation results

In this section we present our simulation with Matlab to evaluate the performance of our proposals. We consider an indoor environment where M= 10 CUs are randomly located inside the area coverage of 5 SBS each one has $N_m$ = 2 CUs. $P_n^{\max}$ = 20 dBm; $\sigma^2$ =-105 dBm. The channel gain is assumed to be iid Rayleigh random variables with mean value $h(d) = h_0(d/15)^{-4}$ where $h_0$ is a reference channel gain at a distance 15 m; $I^{th}_{WiFi-AP}=-75dBm$,

In Figure 2a, we can see that our proposal can achieve a sub-optimal solution after around 35 iteration. Moreover, we can clearly see that by performing user association and power allocation, the unlicensed band that used by the WiFi AP is protected under the total interference threshold.




(a) Utility value (b) Unlicensed band protection

Fig.2. Numerical results to estimate our proposal.

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