

User Association and sub-channel allocation in uplink Cognitive Smallcell Network

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Abstract

In this paper, we provide a novel solution of user association and sub-channel allocation problem in uplink cognitive smallcell network (CSN). The CSN is deployed by reusing channels of a macrocell using underlay spectrum access paradigm in cognitive radio network. In respect of user association, each cognitive smallcell base station (CSBS) has limitations on connecting the number of cognitive smallcell user equipments (CSUEs) to prevent from the CSBS overloading. Under the above setups, we formulate an optimization problem to maximize sum rate in uplink data transmission while protecting the macro base station (MBS) by an interference threshold. We use matching theory to solve the optimization problem in distributed manner. Finally, we showed the proposed framework has efficient performance through the simulations.

I. Introduction

Recently, the new paradigms are known as the heterogeneous wireless networks (HetNets) with coexistence of tiers which comprise of a macrocell under laid on smallcell [1],[2]. Due to the autonomous deployment of smallcells, interference management becomes a challenging issue. One promising solution to address the interference issue is to use orthogonal frequency division multiple access (OFDMA) for smallcells [2]. In order to utilize the limited licensed spectrum more efficiently, sub-channel in OFDMA can be reused using cognitive radio technology which can be a promising technology to realize such flexible interference management [3]. Some previous works done deploying smallcell network using underlay spectrum access paradigm in cognitive radio network [4],[5]. But they did not mention how user associate to one smallcell base station and how allocate multiple channel to multiple users which become a hard problem to solve. Our contribution in this paper as follows:

- We propose a novel solution problem of user association and sub-channel allocation problem in term of primary protection and limited quote number of user connecting to a CFBS.
- We propose distributed algorithms based on matching theory which can be deployed smallcell in distributed manner.

The remainder of this paper is organized as follows. The detailed system model and problem formulation are presented in section II. A joint user association and sub-channel allocation based on matching theory is presented in section III. Next, some the simulation

results are showed in section V. Finally, Section VI conclusions.

II. System model and formation problem

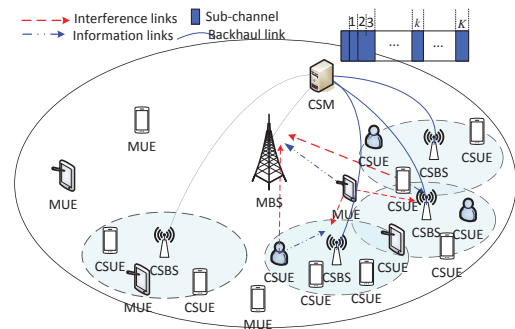


Figure 1: system model

System model.

We consider an uplink cognitive consisting of a set $\mathcal{M} = \{1 \dots M\}$ CSBSs, which serves a set of $\mathcal{N} = \{1, \dots, N\}$ CSUEs as in Fig.1. There are K sub-channels are utilized from MBS. Moreover, each CSBS are assigned K_m sub-channels where have no interference among CSBSs, and each CSUE only use one sub-channel for transmitting data. These sub-channel can overlapping at CSBSs. A cognitive smallcell management (CSM) is deployed supporting MBS protection and channel allocation.

Problem formulation.

In user association, we assume that there is a limitation number of CSUEs associating to a CSBS to avoid base station overloading as follows:

$$\sum_{n=1}^N x_{n,m} \leq q_m \forall m \quad (1)$$

Each CSUE can be assigned one sub-channel for transmitting data, then

$$\sum_{k=1}^K y_{n,k} \leq 1, \forall n. \quad (2)$$

In order to protect MBS, total received interference power at MBS has to less than a threshold as follows:

$$\sum_{m=1}^M \sum_{n=1}^N \sum_{k=1}^K g_{nm}^k P_{nm}^k \leq I_0^{th}, \quad (3)$$

Where I_0^{th} is interference threshold of MBS.

Under the aforementioned constraints, the problems of user association and channel allocation can be formulated via an optimization problem as follows:

$$\begin{aligned} \text{OPT-1: } \max_{(x,y)} & \sum_{m=1}^M \sum_{n=1}^N \sum_{k=1}^K x_{nm} y_{nk} R_{nm}^k(P_{nm}^k) \\ \text{s.t. } & (1),(2),(3) \\ & \sum_{m=1}^M x_{n,m} \leq 1, \forall n, \quad (4) \\ & P_{nm}^k = P_{nm}^{\max}, \forall n, m, k, \quad (5) \end{aligned}$$

Where P_{nm}^k is power of n-th CSUE associating with m-th CSBS on channel k; constraint (4) imply that each CSUE can be associated with only one CSBS at a given time. R_{nm}^k is rate of n-th CSUE associating with m-th CSBS on k-th subchannel as follows:

$$R_{nm}^k = B_k \log_2 \left(1 + \frac{g_{nm}^k P_{nm}^k}{g_{km}^k P_{k0}^k + \sigma^2} \right) \quad (5),$$

where B_k is bandwidth of sub-channel k; g_{nm}^k is channel gain between n-th CSUE and m-th CSBS on sub-channel k; $g_{km}^k P_{k0}^k$ is interference level of MUE k to CSBS m; σ^2 is Gaussian Noise at CSBS. In next section, we discuss solving OPT-1.

III. Joint user association and sub-channel allocation.

We now present our proposal to solve the problem OPT-1 given in previous section. It is observed that OPT-1 is an NP-hard combinatorial optimization problem. In order to solve OPT-1, we using matching theory to solve OPT-1 as bellows separated steps.

Phase I: User association. First, by fixing variable y , we find variable x based on below optimization problem:

$$\begin{aligned} \text{OPT-2: } \max_{(x)} & \sum_{m=1}^M \sum_{n=1}^N x_{nm} R_{nm}^k(P_{nm}^{\max}) \\ \text{s.t. } & (1),(3),(4) \end{aligned}$$

Based on matching game theory [6], we transform finding variable x by using matching one-to-one between two sets \mathcal{M} and \mathcal{N} which satisfy constraints (1), (3), and (4). For this problem, the matching game problem is defined as follows:

Definition 1: A matching-based user association problem is defined by the tuple as a function from $(\mathcal{N}, \mathcal{M}, \succ_n, \succ_m, q_{\mathcal{N}} = 1, q_{\mathcal{M}} = q_m)$. The sought solutions is a matching function a matching game $\mu_{UA}: \mathcal{N} \cup \mathcal{M} \rightarrow \mathcal{N} \cup \mathcal{M}$

which provides the final allocation between CSUEs and CSBSs based on preference functions \succ_n and \succ_m .

In this game, quota value of each CSUE $q_{\mathcal{N}}$ and each CSBS $q_{\mathcal{M}}$ are corresponding to constraints (4) and (1). Let $U_{n,m}$ and $U_{m,n}$ denote, respectively, the utility functions of players CSUEs and CSBSs.

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CSBS utility function.

$$U_{m,n}(n) = \frac{1}{K_m} \sum_{k=1}^{K_m} R_{nm}^k - \zeta I_{n,0}^{(K_m)}, \quad (6)$$

where $U_{m,n}(n) = \frac{1}{K_m} \sum_{k=1}^{K_m} R_{nm}^k$ is average data rate of n-th CSUE associating to m-th CSBS on K_m sub-channels, $I_{n,0}^{(K_m)}$ is total interference at MBS causing by n-th CSUE on K_m sub-channels. ζ is fixed coefficient with each interference power unit.

CSUE utility function.

$$U_{n,m}(m) = \frac{1}{K_m} \sum_{k=1}^{K_m} R_{nm}^k \quad (7)$$

where $\frac{1}{K_m} \sum_{k=1}^{K_m} R_{nm}^k$ is average data rate of n-th CSUE associating to m-th CSBS on K_m sub-channels.

Based on (6) and (7), the CSUE and CSBS construct their utility functions and update to two preference list \succ_n and \succ_m in sorting deceased utility function, respectively. By using these preference list, the CSUEs will seek to be matched to the best CSBS with higher achievable rates. At the CSBS side, CSBSs will seek to be matched to the best CSUE with higher achievable data rate and lower interference power to the MBS.

An algorithm is proposed to find the best value x in stable matching based on **Algorithm 1**.

Algorithm 1: User association based on matching theory (MUA)

Inputs: $\mathcal{N}, \mathcal{M}, q_{\mathcal{N}} = 1, q_{\mathcal{M}} = q_m \cdot x$

Initialize: $\mathcal{N}_m^{req}, \mathcal{N}_m^{reject}, \mathcal{N}_m^{accepted}$

Stage I: Discovery and utility computation

- 1) CSBS broadcasts its sub-channels to CSUEs
- 2) CSUE compute its utility values and build \succ_n based on (7)

*Stage II: Swap-matching to find stable matching μ_{UA}^**

- 3) Each n-th CSUE sends a request to CSBS m, $m = \arg \max (\succ_n)$
- 4) Each m-th CSBS do:
 - a. Updates set of requested CSUEs \mathcal{N}_m^{req} .
 - b. Computes utility values and build \succ_m based on (6).
 - c. Update accepted list:
 - If $q_m^{current} < q_m$ then $\mathcal{N}_m^{accepted} \leftarrow n = \arg \max (U_{m,n}(n))$
 - Delete n in \succ_m , $x_{n,m} = 1$.
 - Else $\mathcal{N}_m^{reject} \leftarrow \mathcal{N}_m^{req} \setminus \mathcal{N}_m^{accepted}$

Delete m in $\lambda_n, n \in \mathcal{N}_m^{reject}$
 $x_{n,m} = 0$ and Go back to step 3.

Outputs: $\mathcal{N}_m^{req} = \emptyset, x^*$ and Stable matching μ_{UA}^* [6]

Phase II. Sub-channel allocation and MBS protection.

Given λ_m and x^* in algorithm 1, by the same previous work each CSBS m allocates sub-channel to its CSUEs and protects MBS by using matching game for sub-channel allocation as follow basic steps:

At the CSBS:

1. Each CSBS m constructs a list of K_m sub-channels with decreased interference power from MUEs in K_m to CSBS m) (denoting by $\lambda_{m,k}$)
 2. Each CSBS m assigns CSUE $n^* = \max(\lambda_m)$ to sub-channel $n^* = \min(\lambda_{m,k})$.
- By do this, the CSUE will be selected with criteria that have the highest average data rate. The sub-channel that allocate to this CSUE has lowest interference to the CSBS.
3. Each CSBS sends a proposal $[U_{m,n}(n^*), n^*]$ to CSN.

At the CSN (MBS protection):

Denoting admission control variable \mathcal{A} by a set of CSUEs that are permitted to transmit data.

1. Update $[U_{m,n}(n^*), n^*]$ from CSBSs to \mathcal{A} .
 2. Update current interference level ($I_0^{current}$) from MBS
 3. Admission control and MBS protection:
 - If $I_0^{current} < I_0^{th}$ then update value $y_{n,m}^{k*} = 1$
 - Else $\mathcal{A} \leftarrow \mathcal{A} \setminus \{n^*\}$, where $n^{rejected} = \arg \min_{n \in \mathcal{Q}_k} \{U_{m,n}(n) - S_{n0}^k P_{nm}^k\}$

Send a request to delete transmit data CSUE $n^{rejected}$ at CSBS m on channel k . We note that this CSUE will be considered at next transmission.
 Go back to step 2
- End

Results: The best subchannel allocation y^* and constraint (3) is hold.

IV. Simulation results

In this section we present our simulation with Matlab to evaluate the performance of our proposals. We consider an indoor environment where $M=5$ CSBSs are located with a MBS as in Fig. 1. Some parameters are installed as follows: $N=100$; $q_m=10$; $P_{nm}^{max}=20$ dBm; $I_0^{th}=80$ dBm; $\sigma^2=-105$ dBm; $B_k=180$ kHz; $K=20$ sub-channels. 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. In Fig. 1, we compare three schemes composed of user association based on matching theory combined with sub-channel allocation using matching theory (UA-MC&CA-MC-utility); user association using matching theory but random choose channel under primary protection (UA-MC&CA-random); and, user association using matching but random allocating channel without MBS protection (UA-MC&non-QoS). The results is represented in Fig.1 with 1000 iterations. By taking results with cumulative distributed function (CDF), clearly, our proposal is best in term of MBS protection with threshold less than -96 dBm. In order to estimate our proposal in phase I, we increase number of CSUEs and compare with others schemes: UA-max-SINR (CSUEs choose CSBSs based

on max-SINR level, UA-random (CSUEs randomly choose CSBSs). In Fig. 2, clearly the average data rate of CFUEs in our proposal (UA-MC) is greater than other schemes (Fig.2a) while guaranteeing total interference level threshold (Fig.2b).

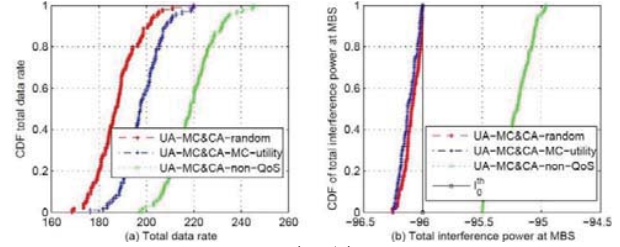


Fig.1. CDF of total data rate (Mb/s) in CSN and total interference power (dBm) at MBS.

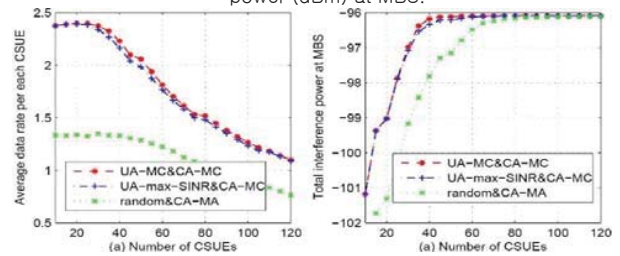


Fig.2. Estimation of average data rate (Mb/s) and total interference power (dBm) following number of CSUEs.

V. Conclusions

In this paper, we proposed a user association and sub-channel allocation solution to maximize total throughput in uplink CSN. Problems of user association, subchannel allocation are considered in quota of each CSBS and primary protection via the NP-hard optimization problem. We solved the optimization problem by applying matching theorem and proposed two distributed algorithms. The proposed framework is tested based on the simulation results and shown to perform efficiently.

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