

Orchestrating SDN-based Resource Allocation for Cognitive Small Cells with Limited Backhaul Capacity

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Abstract

In this paper, we provide a solution for allocating sub-channels and power in uplink small cells network. The cognitive smallcell base stations (SBSs) are deployed by reusing channels of a macrocell using underlay spectrum access paradigm. An optimization problem is formulated to maximize sum rate in uplink data transmission while protecting the backhaul link and macro base station (MBS). Then, an SDN-based architecture is proposed to achieve a sub-optimal solution. Finally, the proposed framework is evaluated through the simulation.

1. Introduction

The network paradigm of the small cells coexisting with macrocell network is a promising solution to improve data rate in the future wireless network [1]. In order to utilize the limited licensed spectrum more efficiently, sub-channel in small cells can be reused from macrocell network. Due to the autonomous deployment of smallcells, interference management is a challenging issue in co-channel deployment [2].

Nowadays, the proliferation of new applications exacerbates the demand for high data rate services with a possible bottleneck in various backhaul solutions, e.g., xDSL, non-line-of-sight (NLOS) microwave, and wireless mesh networks [3]. When the radio access technologies are constantly improving, it is argued that the backhaul network will emerge as a major performance bottleneck, and proposed frameworks that ignore the backhaul load and topology can lead to poor performance.

Some previous works done deploying smallcell network using underlay spectrum access paradigm in cognitive radio network [4], [5], and [8]. But they did not mention how to protect backhaul link constraint that become an important role in the small cell deployment in future wireless network. Our contribution in this paper as follows:

- A problem of joint subchannel and power allocation in cognitive small cell network is formulated considering the backhaul capacity limitation.
- In order to solve the proposed problem, we develop an algorithm based on SDN architecture to avoid congestion for the backhaul core network flow of heterogeneous wireless networks. In details, channel allocation and power allocation are controlled to avoid the congestion at base station' backhaul links while guarantee primary system's tolerant interference power.

In the rest of this paper, we provide a system model in section 2. Following the problem formulation presents in Section 3, we solve the proposed problem in Section 4. Next, in section 5, we develop the algorithm with an SDN-architecture. Then, the proposed scheme is evaluated in Section 6. Finally, we conclude proposals in Section 7.

2. System model.

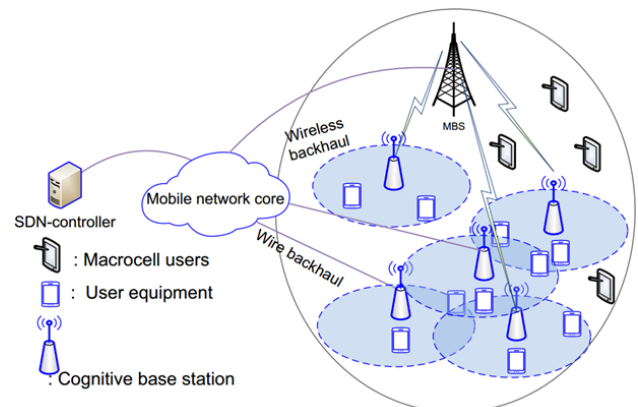


Figure 1: system model

We consider a two-tier cognitive heterogeneous network including of a macrocell and a set of M cognitive base stations (BSs). Each cognitive base station is requested to serve a set of I_m users. We use $I = \cup_{m \in M} I_m$ to denote the set of all UEs in the small cell network. We denote K is a set of sub-channels that corresponding to K macrocell users (MUE). The information of these sub-channels are observed and collected by the SDN-controller. We assume that at most one UE to be allocated to subchannel k and at most one subchannel k to be allocated to one UE at any time instant.

3. Problem formulation.

3.1. The UE's data transmission model:

When the UE i in the cognitive BS m transmits its data, the data rate of the UE will be given by

$$R_{mi}(\mathbf{Y}, \mathbf{P}) = \sum_{m \in \mathbf{M}, i \in I_m} W y_{mi}^k \log\left(1 + \frac{h_{mi}^k p_{mi}^k}{h_{ki}^k p_{k0}^k + N_0}\right),$$

where y_{mi}^k is a binary variable ($y_{mi}^k = \{0, 1\}$) that represents the channel allocation index for transmission from UE i to cognitive BS m on subchannel k ; h_{mi}^k is the power channel gain from UE i in BS m on subchannel k ; p_{mi}^k is the transmit power of UE i in the cognitive BS m on subchannel k ; N_0 is the background noise.

3.2 Backhaul link constraint

We assume the backhaul links of cognitive BS are considered to be constrained with limited capacity. In order to guarantee the end-to-end QoS for backhaul core network follow, the following constraints should be kept:

$$\sum_i R_{mi}(\mathbf{Y}, \mathbf{P}) \leq R_m^{bh}, \forall m,$$

Where R_m^{bh} is a predefined parameter representing the maximum data traffic flows emitting from cognitive BS m .

3.3 Macrocell base station protection

We assume that the maximum tolerable interference at the MBS on each sub-channel is $I_{0,th}^k$. To protect MBS, the following constraint have to satisfy:

$$\sum_{m,i} y_{mi}^k g_{mi,0}^k p_{mi}^k \leq \pi_0^k I_{0,th}^k, \forall k,$$

Where π_0^k is channel sensing result of sub-channel k that is estimated by SDN controller and cognitive BSs. Here, $\pi_0^k = 1$ if sub-channel k is used by MBS, otherwise $\pi_0^k = +\infty$ when sub-channel is not occupied by the MBS.

Our designed goal is to maximize the whole uplink data traffic while guaranteeing the end-to-end data rate of network flows, protecting the MBS, and avoiding congestion in the backhaul core network flow. This goal is represented by the following optimization problem:

$U(\mathbf{Y}, \mathbf{P}) = \sum_{i,m,k} R_{mi}(\mathbf{Y}, \mathbf{P})$	Maximizing the total uplink network flows traffic
$\sum_i R_{mi}(\mathbf{Y}, \mathbf{P}) \leq R_m^{bh}, \forall m$	Backhaul core network flow constraints

$\sum_{m,i} y_{mi}^k g_{mi,0}^k p_{mi}^k \leq \pi_0^k I_{0,th}^k, \forall k,$	Macrocell protection
$\sum_{i \in I_m} y_{mi}^k \leq 1, \forall k$	Resource isolation constraints for each UE at the BS
$\sum_{k \in K} y_{mi}^k \leq 1, \forall m, i$	Resource isolation constraints for each sub-channel
$p_{mi}^{\min} \leq p_{mi}^k \leq p_{mi}^{\max}, \forall m, i$	Power transmission constraints.

The JCPA problem is a mixed integer non-linear non-convex optimization problem, which is generally NP-hard. In the following sections, we focus on solving the JCPA problem in a distributed manner based on the Lagrangian relaxation approaches.

4. Solution for the JCPA problem.

Using the Lagrangian relaxation method to solve the JCPA problem. Defining the β_m and ϑ_k are multipliers of the constraints (2) and (3), respectively. Then, the partial Lagrangian of the JPCA is obtained by augmenting the objective function with a weighted sum of the constraints (2), (3), and (4) as follow:

$$L(\mathbf{Y}, \mathbf{P}, \lambda_{im}, \vartheta_k, \beta_m) = U(\mathbf{y}, \mathbf{P}) + - \sum_m \beta_m \sum_i R_{mi}(\mathbf{Y}, \mathbf{P}) - \sum_k \vartheta_k \sum_{m,i} y_{mi}^k g_{mi,0}^k p_{mi}^k$$

Then, the Lagrange dual function $D(\vartheta_k, \beta_m)$ is given by:

$$D(\lambda_{im}, \vartheta_k, \beta_m) = \max_{(\mathbf{Y}, \mathbf{P})} L(\mathbf{Y}, \mathbf{P}, \vartheta_k, \beta_m)$$

s.t.

$$\begin{aligned} \sum_{i \in I_m} y_{mi}^k &\leq 1, \forall k \\ \sum_{k \in K} y_{mi}^k &\leq 1, \forall m, i \\ p_{mi}^{\min} &\leq p_{mi}^k \leq p_{mi}^{\max}, \forall m, i \end{aligned}$$

After that the subchannel and power allocation can be found by solving two sub-problem in the following.

a. Power control phase: Regardless of subchannel allocation \mathbf{Y} and Lagrangian multipliers value, the power variable p_{mi}^k can be determined as follow:

$$p_{mi}^{k,*} = \left[\frac{1 - \beta_m}{\vartheta_k g_{mi,0}^k \ln 2} - \frac{1}{\gamma_{mi}^k} \right]_{p_{mi}^{\min}}^{p_{mi}^{\max}},$$

Where $\gamma_{mi}^k = \frac{g_{im}^k}{h_{ki}^k p_{k0}^k + N_0}$.

b. Channel allocation phase: Given the fixed \mathbf{P} and Lagrangian multipliers, the Lagrange dual problem is reduced as follows:

$\max_{(\mathbf{Y})} \sum_{i,k} y_{mi}^k [\Phi_{mi}^k(p_{mi}^k)]$	(7)
$\sum_{i \in I_m} y_{mi}^k \leq 1, \forall k$	(8)
$\sum_{k \in K} y_{mi}^k \leq 1, \forall m, i$	(9)

Where $\Phi_{mi}^k(p_{mi}^k) = (1 - \beta_m)W y_{mi}^k \log\left(1 + \frac{h_{mi}^k p_{mi}^k}{h_{ki}^k p_{ko}^k + N_0}\right) - \vartheta_k p_{mi}^k g_{mi,0}^k$

The optimal subchannel allocation in (10) can be solve based on Hungarian matching algorithm [6]. The optimal Lagrangian multipliers can be obtained using the projected gradient-descent method [7].

5. Orchestrating resource allocation based on SDN architecture.

From the above analysis, we develop an algorithm based on SDN architecture to guarantee end-to-end QoS for backhaul core network flow of heterogeneous wireless networks as follows:

Algorithm 1 JCPA: Sub-optimal joint sub-channel and power based on SDN-architecture.

Algorithm at the MBS:

1. Measure the interference $\sum_{m,i} y_{mi}^k g_{mi,0}^k p_{mi}^k$ on subcarrier k;
2. Update and broadcast the interference price $\vartheta_k(t + 1)$;

Algorithm at BS agent:

3. Update and broadcast the backhaul link's congestion price $\beta_m(t + 1)$;

Algorithm at SDN controller:

4. Calculate the weighted $\Phi_{mi}^k(p_{mi}^k)$
5. Update and broadcast channel allocation (Y) using Hungarian matching algorithm

Algorithm at the UE agent:

6. Update transmit power on each sub-channel $p_{mi}^{k,(t+1)}$ using (6).

Until: Convergence

6. Simulation results

In this section we present our simulation using Python to evaluate the performance of our proposals. Some parameters are installed as follows: M = 4; $P_{mm}^{max} = 20$ dBm; $I_0^{th} = 75$ dBm; $\sigma^2 = -105$ dBm; $B_k = 180$ kHz; $N_m = 2$ users; $K = 2$ sub-channels; Z_{th} equals to 5 Mbps. 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. 2, we present the results of the proposals to the cognitive small cell network. In Figure 2.a, we can see that, in order to protect MBS, the controller will controller channel and power allocation, which are allocated to users, to reduce interface power. By controlling interference price $\vartheta_k(t + 1)$, the interference power at the MBS on both subchannel 1 and 2 are guaranteed after few iterations as showed in

Figure 2.a. Additionally, in order to protect backhaul link capacity of cognitive BSs, the controller will control congestion price $\beta_m(t + 1)$ by reducing transmit power or changing the channel allocation at the user agent. As shown in Figure 2.b, we can see that, after few iterations, all backhaul link capacity are guaranteed less than the predefined threshold.

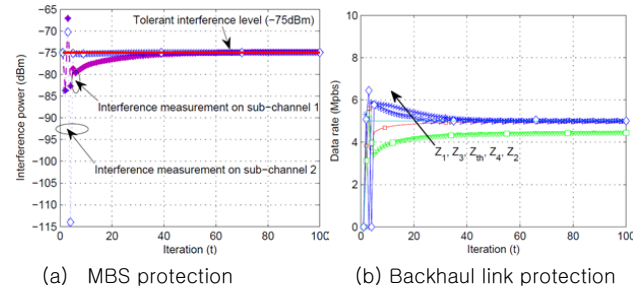


Fig.2. Macrocell and backhaul link protection of the proposed solution.

7. Conclusions

We have provided a solution for allocating sub-channels and power in uplink small cells network. An optimization problem have formulated to maximize sum rate in uplink data transmission while protecting the backhaul link and macro base station (MBS). Then, a SDN-based architecture have proposed to achieve a sub-optimal solution. Finally, the proposed framework have evaluated through the simulation.

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