Downlink Power Allocation in Virtualized Wireless Networks

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***Abstract*—Virtualized wireless networks is one of the techniques to satisfy the increasing demand of mobile data services and for future wireless network. Nework virtualization enables efficient resource utilization and it also reduces capital expenditures and operational expenditures of mobile network operators (MNOs). In this paper, we present virtualized wireless network where users of each service provider (SP) are served by an infrastructure provider (InP) who owns a set eNBs. We propose the problem of power allocation of each user that belongs to service providers. We aim to maximize the total rate of mobile users with limited power. We introduce Dual decomposition technique to address the optimization problem.**

***Index Terms*—Virtualized Wireless Network, Power allocation, Dual Decomposition.**

I. Introduction

Wireless network services (e.g. IoT services, online health care system, electricity utilization) and wireless devices are increasing exponentially. Wireless virtualization is a potential technology for next generation wireless network. In wireless network virtualization, the traditional mobile network is decoupled into two entities such as infrastructure providers and service providers. Infrastructure providers own and operate the physical infrastructure (e.g. antennae, masts, transmission equipments) and radio resources. Service providers make contracts to borrow radio network from multiple infrastructure providers and then provide specific services to their mobile users. Although, there are still several research challenges before deploying virtualized wireless networks such as channels allocation, power allocation, isolation between different service providers, security and so on [1].

In virtualized wireless network, network isolation between different service providers is important issue and it enables to achieve higher network capacity. Morever, Network interfacing between InP and SPs is essential as SPs can send their resource requests to InP and InP can also provide radio resources to SPs through network interface [1]. One of the challenges in virtualied wireless network is an efficient allocation of radio resources [2]. It will help to improve resource utilization, energy efficiency, quality of service (QoS) of each user and reduce interference between service providers [3].

Basically, there are two types of virtualized wireless network models [1] :1) Two-level Business Model, as shown in Fig.1. and 2) Three-level Business Model. In this paper, we consider two-level business model.

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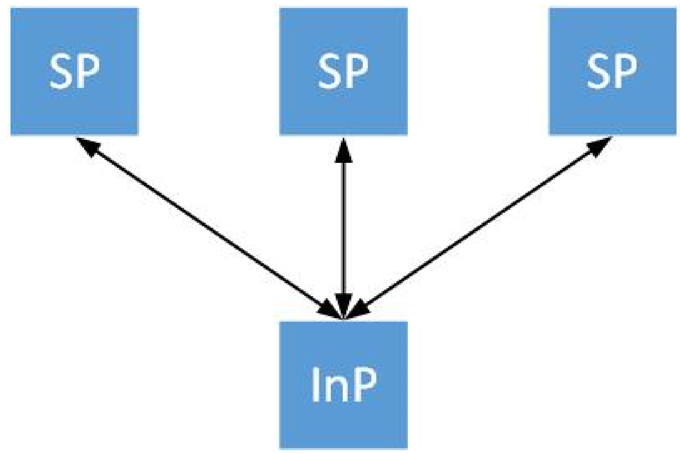

Fig. 1. Two-level Business Model

A. Contributions

Our contributions are as follows:

- We create a virtualized network model with a single infrastructure provider and multiple service providers. We aim to maximize the down-link transmission rate of each user to each service provider subject to the maximum power level of each user and the maximum tolerable interference on each channel for the other user from other service provider that belongs to other eNB.
- We formulate down-link power allocation as an optimization problem. Then, we propose the Lagrangian Dual Decomposition method to address the optimization problem.

B. Related works

Our work is the combination of multi-cell OFDMA wireless network and virtualized wireless network. There has been so many research papers that were conducted power and resource allocation wireless network networks. Channels and power allocation problem in two tired femtocell network was studied using dual decomposition method [4]. Challenges in virtualized wireless network have been introduced in [1], and the deployment of virtualized wireless network in future

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wireless network was discussed in [5]. Joint channel allocation and power control in virtualized wireless networks was discussed in [6]. Joint users admission control and channel allocation for in virtualized network was introduced in[7]. In [8], authors solved channels allocation in virtualized small cell networks by using Alternating direction method of multiplier (ADMM). Sub-channel and power allocation process in virtualized wireless network was introduced in [9]. Their objective to minimize the transmit power of the whole network.

C. Structure of Paper

Th paper is organized as follows. The network model and problem formulation will be discussed in section II. In section III, we are going to discuss the power allocation algorithm in virtualized wireless network. In section IV, we will discuss the detailed about simulation parameters, simulation results and conclude our discussion at section V.

II. System Model and Problem Formulation

A. System Model

As shown in Fig. 2, we create a virtualized network model, which consists of an infrastructure provider (InP) who owns a set of physical eNBs, $\mathbb{M} = \{1, 2, 3, ..., M\}$, they are using the same frequency band, and a set of service providers (SPs) who have total number of users $\mathbb{N}$. The bandwidth of an eNB is divided into multiple channels, denoted by $\mathbb{K} = \{1, 2, 3, ..., K\}$ and serve users, $\mathbb{N} = \{1, 2, 3, ..., N\}$ through the orthogonal frequency-division multiple access (OFDMA) and each user requests for a minimum reserved rate R_n^{rev}, $n = 1, 2, ..., N$. So, $\mathbb{N}$ is the total number of users served by eNBs.

Let $h_{m,n,k}$ and $P_{m,n,k}$ be the channel gain on channel k from an eNB m to the user n and allocated power of eNB m to user n on channel k , respectively. Moreover, let $P = [P_{m,n,k}]_{\mathbb{M},\mathbb{N},\mathbb{K}}$ be transmit power allocation vector. We assume that one sub-channel is assigned to only one user and a user can access to only one channel. The received SINR (Signal to Interference plus Noise Ratio) of the user n on channel k can be expressed as:

$$\gamma_{m,n,k} = \frac{P_{m,n,k} h_{m,n,k}}{I_{m,n,k} + N_0 \omega_k}, \quad (1)$$

where N_0 is the noise spectral density . And then , the transmit data rate of user k is formulated as:

$$R_{n,k} = \omega_k log_2(1 + SINR), \quad (2)$$

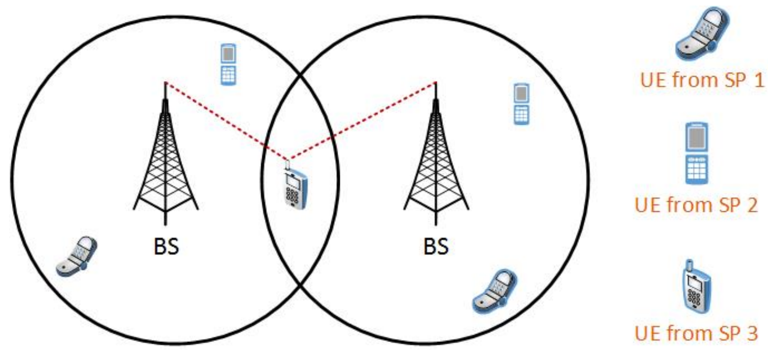

Fig. 2. Network Model. Virtualized wireless network with a single infrastructure provider who owns a set of eNBs and provides networks to a set of service providers

B. Problem Formulation

The optimization problem can be expressed as:

$$\max_{P_{m,n,k}} \sum_{m=1}^{M} \sum_{k=1}^{K} \sum_{n=1}^{N} R_{m,n,k} \quad (3)$$

subject to

$$\sum_{k=1}^{K} \sum_{n=1}^{N} P_{m,n,k} \leq P_{max}^m \quad ,\forall m \quad (4)$$

$$P_{m,n,k} \geq 0 \quad ,\forall m, n, k \quad (5)$$

$$\sum_{m=1}^{M} \sum_{n=1}^{N} P_{m,n,k} g_{m,n,k} \leq I_k^{th} \quad ,\forall k \quad (6)$$

where constraint (1) expresses the transmit power of eNB on each channel to be below P_{max}^m. According to constraint (2), I_k^{th} represents the maximum tolerable interference on channel k for the other users that belong to the other eNBs. The above problem has a non-convex structure. So, the problem cannot be solved by the convex optimization techniques. However, as the number of channels becomes very large, the duality gap tends to zero. So, the non-convex objective problem can be solved in the dual domain [10] [11] .

III. Power Allocation Algorithm

In this section, we propose dual decomposition method to solve power allocation problem [12].The corresponding Lagrangian function is given by :

$$\begin{aligned} L(P_{m,n,k}, \lambda, \mu) = & \sum_{m=1}^{M} \sum_{k=1}^{K} \sum_{n=1}^{N} R_{m,n,k} \\ & + \sum_{m=1}^{M} \lambda_m (P_{max}^m - \sum_{k=1}^{K} \sum_{n=1}^{N} P_{m,n,k}) \\ & + \sum_{k=1}^{K} \mu_k (I_k^{th} - \sum_{m=1}^{M} \sum_{n=1}^{N} P_{m,n,k} g_{m,n,k}) \end{aligned} \quad (7)$$

where λ, μ are dual variables for the constraints $1, 2$. The dual function can be formulated as:

$$D(\lambda,\mu) = \max_{P_{m,n,k}} L(P_{m,n,k},\lambda,\mu) \tag{8}$$

The dual problem can be expressed as :

$$\min_{\lambda,\mu\geq 0} D(\lambda,\mu) \tag{9}$$

We decompose the Lagrangian function into $M \times K$ subproblems. The Lagrangian function in (7) can be rewritten as :

$$\begin{aligned} L(P_{m,n,k},\lambda,\mu) = & \sum_{m=1}^{M}\sum_{k=1}^{K} L_{m,k}(P_{m,n,k},\lambda,\mu) \\ & + \sum_{m=1}^{M}\lambda_m P_{max}^{m} + \sum_{k=1}^{K}\mu_k I_k^{th} \end{aligned} \tag{10}$$

where

$$\begin{aligned} L_{m,k}(P_{m,n,k},\lambda,\mu) = & \sum_{n=1}^{N} R_{m,n,k} - \sum_{n=1}^{N}\lambda_m P_{m,n,k} \\ & - \sum_{n=1}^{N}\mu_k P_{m,n,k} g_{m,n,k} \end{aligned} \tag{11}$$

The dual problem in (9) can be decomposed in $M \times K$ independent subproblems. So,

$$D_{m,k}(\lambda,\mu) = \max_{P_{m,n,k}} L_{m,k}(P_{m,n,k},\lambda_m,\mu_k) \tag{12}$$

According to the KKT conditions, the optimal solutions of the subproblems, $P_{m,n,k}$, can be calculated as:

$$\begin{aligned} L'_{m,k}(P_{m,n,k},\lambda,\mu) = & \frac{1}{ln2}\frac{\omega_k h_{m,n,k}}{I_{m,n,k}+\sigma^2+P_{m,n,k}h_{m,n,k}} \\ & - \lambda_m - \mu_k g_{m,n,k} \end{aligned} \tag{13}$$

We solve the dual problem in (9) by using the sub-gradient method [1] , and update the dual variables according to the following equations:

$$\lambda_m(t+1) = [\lambda_m - \theta(t)(P_{max} - \sum_{k=1}^{K}\sum_{n=1}^{N} P_{m,n,k})]^{+} \tag{14}$$

$$\mu_k(t+1) = [\mu_k - \theta(t)(I_k^{th} - \sum_{m=1}^{M}\sum_{n=1}^{N} P_{m,n,k}g_{m,n,k})]^{+} \tag{15}$$

where $\theta(t)$ is step size of the iterations and we can define the step size as :

$$\theta(t) = \frac{a}{\sqrt{t}},\ a > 0. \tag{16}$$

The eNB needs local information to update $\lambda_m(t+1)$. To update $\mu_k(t+1)$, it needs the received interference from users in SPs that belong to other eNBs.

Algorithm 1 Power Allocation Algorithm

1: Initialize the power vector $(P_{m,n,k})$ on each subchannel with the uniform distribution and the Lagrangian multiplier vectors λ_m and μ_k .
2: **for** $m = 1$ to M **do**
3: **for** $k = 1$ to K **do**
4: **for** $n = 1$ to N **do**
5: eNB updates the Lagrangian multiplier vectors λ_m and μ_k according to (14) and (15)
6: **end for**
7: **end for**
8: **end for**
9: Repeat step (2)
10: Run until convergence (Lagrangian multiplier vectors $\lambda_m(t+1) = \lambda_m(t)$and $\mu_k(t+1) = \mu_k(t)$ where $t = 1, ..., T_{max}$)

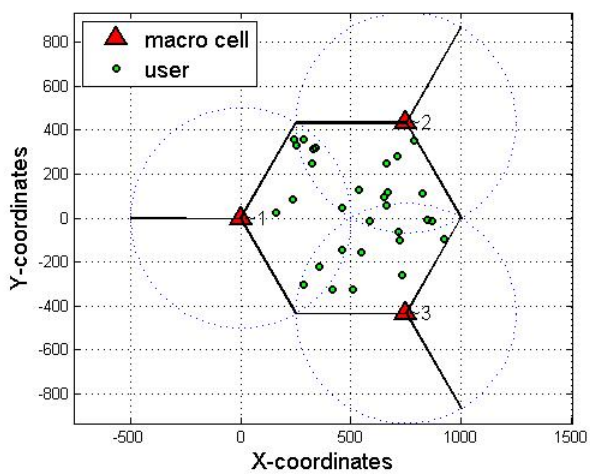

Fig. 3. Network Topology

IV. Performance Evaluation

In this section, we perform simulation under proposed power allocation algorithm. The network topology for our simulations contains three macro BSs, with a set of users who are randomly located in the circle with radius $r = 500m$. We present virtualized wireless network with 30 users and 30 channels as shown in Fig (3). Transmit power of a macro cell is 40 watts $(10 \times log_{10}(40 \times 1 \times e^3))$, total bandwidth of each channel is 180kHz, the thermal noise is -174 dBm/Hz $((30 + 10 \times log_{10}(bandwidth) + thermalnoise)$ dB) and we use rayleigh fading. The long distance path loss of each user is $PL = 40log_{10}(d_0) - 10log_{10} \times (Gh_t^2 h_r^2) + 10 \times \lambda log_{10}\frac{d}{d_0} + X_g$ where d_0 and d are the reference distance and actual distance between transmitter and receiver, h_t and h_r are heights of transmitter and receiver respectively and X_g is normal random variable and minimum data rate requirement is 0.1Mbps. Finally, the maximum interference power level on each channel is $-70dbm$.

In $Fig.4$, the achievable sum-rate of all service providers

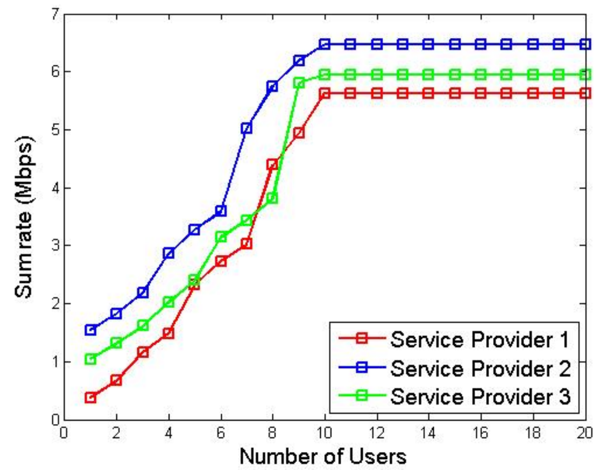

Fig. 4. Sumrate of Service Providers

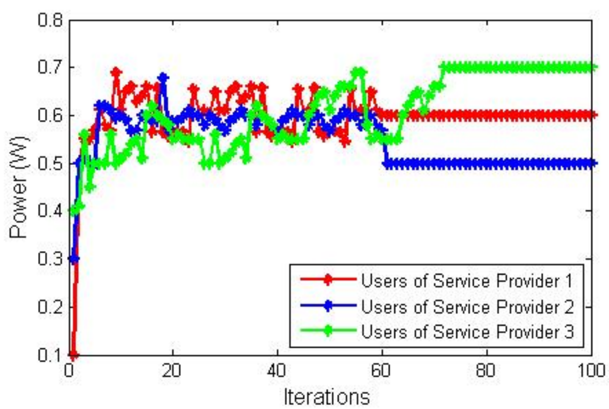

Fig. 5. Transmit Power for Users of each Service Provider

are shown . As we have discussed above, each service provider has a set of users. In this simulation,when we increased the number of users we observed that sum-rate increased with more users but it stopped increasing as the number of users became sufficiently large. The reason is the limited number of channels (30) available for the users of all service providers (SPs). In order to satisfy the QOS requirement of each user and to protect the interference from the neighboring cells , each cell update the transmit power levels that are shown in Fig. 6. In $Fig.6$, We can see the convergence of the transmit power for users in each service provider. The transmit power for users in service provider (1) converges at iteration 59 . Moreover, the transmit power for users in service provider (2) and (3) converges at iteration (60) and (76).

V. Conclusion

Virtualized wireless nework is one of the solutions to solve the scarcity of mobile network capacity and the increasing demand of mobile data services. In this paper, We proposed power allocation in OFDMA based virtualized wireless networks. And then, we expressed the resource allocation problem as an optimization problem, which maximizes the data rate of each user in each service provider. Simulation results were pretended to show the total data rate of service providers and data rate of each service provider. Our future work is to consider multiple infrastructure providers(InPs),allocation of multiple resources (power , channels, and backhaul) and multiple service providers (SPs).

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