# Resource Allocation for Wireless Network Virtualization in Heterogeneous Cellular Networks

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**Abstract**

In wireless network virtualization, the isolation between MVNOs which is how to divide the resources between MVNOs without affecting each other is a challenging problem. In this paper, we propose one approach to achieve this isolation problem. Fraction of radio resources is allocated to each MVNO proportionally according to its number of users which changes over time. Moreover, we consider the backhaul topology of small cell and macro cell base stations. We formulate the joint resource allocation and user association as an optimization problem to maximize the sum rate of users and solve it by nonconvex alternating direction method of multipliers (NC-ADMM) method. Then, simulation is performed to show that the proposed approach is better than the fixed allocation of radio resources.

## 1. Introduction

In wireless network virtualization, a single InP allows to share its physical resources to multiple MVNOs. It can be seen as different virtual networks are running on top of the same physical network with different resource requirements. This approach can be beneficial to both InP and MVNOs because MVNOs do not need to purchase and maintain infrastructures so capital expenditure (CAPEX) and operating expense (OPEX) can be reduced. For InPs, its resources are shared among multiple MVNOs so there might not be the waste of resources.

For resource allocation in wireless network virtualization, radio resources can be divided into slices for allocation to meet the various user requirements [1]. A particular slice should consist of all the virtual individuals sliced by each component in the infrastructure. Specifically, an entire slice is a universal wireless virtual network [2]. In previous works, [3] and [4] studied the dynamic allocation of resources in wireless virtualization.

Moreover, in heterogeneous networks where multiple small cell base stations (SBS) and macro base station (MBS) coexist together, backhaul topology should be considered because the load on one base station affects other base stations on the path where it is connected to. Limitations in a backhaul link are 'rate limitation' where the maximum amount of traffic (bits per second) is carried and 'delay limitation' where the delay is obtained for the load on the link [5].

In this paper, resource allocation and user association are jointly solved for wireless network virtualization underlying heterogeneous networks. We consider dynamic allocation where there is no pre-agreement on the resources allocated to MVNOs but they are assigned based on users' distribution of MVNOs over time. MVNO purchases the resources from InP and assigns those resources to its users which is two steps business model. We also study the rate-based backhaul limited topology. Our problem is formulated as an optimization problem, simplified steps by steps and solved by NC-ADMM proposed by [6].

## 2. System Model

A single InP owns a heterogeneous network with one MBS and multiple SBSs indexed by $j$. Each BS has limited backhaul capacity ($B_j$). Since BSs are connected by backhaul links so load on one BS is affected by other BSs on the path connected to it. These BSs are indexed by $s_j$. For example, in Fig. 1, load on BS1 also consists of the loads on BS4, BS3, BS2 and BS1.

From the perspective of MVNO, each MVNO regards the physical network as a whole virtual network even though the physical network is shared among multiple MVNOs (Fig. 2). In this paper, InP is assumed to know the number of currently active users of each MVNO so that InP can suggest how much fraction of radio resources each MVNO should buy. It is a win-win situation for both InP and MVNOs because there would not be underutilized resources for InP. For MVNO, over or under purchased of resources would not be occurred.

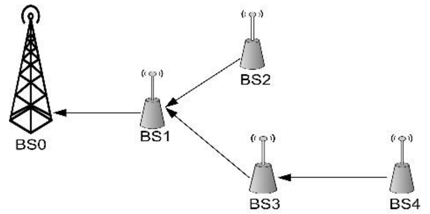


Fig. 1. Backhaul Topology

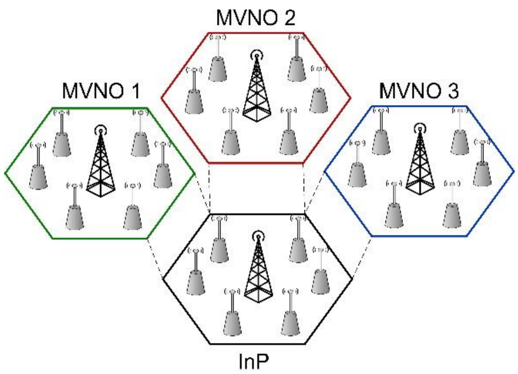


Fig. 2. System Model

## 3. Problem Formulation

The objective is to maximize the sum rate of users. The rate is calculated by Shannon-Hartley theorem where $W, g_{i_k,j}, P_j, n_0$ are total bandwidth of subcarriers, channel gain, transmit power and noise respectively.

$$R_{i_k,j} = W \log_2\left(1 + \frac{g_{i_k,j}P_j}{\sum_{l,l\neq j} g_{i_k,l}P_l + n_0}\right) \quad (1)$$

$$max \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} x_{i_k,j} z_{i_k} R_{i_k,j} \quad (2)$$

s.t.

$$\sum_{j\in J} x_{i_k,j} \leq 1 \quad (3)$$

$$\sum_{j\in J} x_{i_k,j} z_{i_k} R_{i_k,j} \geq \gamma_i \quad (4)$$

$$\sum_{k\in K} \alpha_k \leq 1 \quad (5)$$

$$\sum_{j\in J}\sum_{i_k\in I_k} z_{i_k} \leq \alpha_k \quad (6)$$

$$\sum_{i\in I}\sum_{s_j\in S_j} x_{i_k,s_j} z_{i_k} R_{i_k,s_j} \leq B_j \quad (7)$$

$$x_{i_k,j} = \{0,1\},\ 0 \leq \alpha_k \leq 1,\ 0 \leq z_{i_k} \leq x_{i_k,j}$$

First and second constraints ensure that one user can assign to only one base station and QoS requirement ($\gamma_i$). Then, fraction of resources allocated to each MVNO ($\alpha_k$) and each user ($z_{i_k}$) of each MVNO are checked. The last constraint is to make sure that BS has limited backhaul capacity. $x_{i_k,j}$ is user association variable.

**Assumption 1**: We assume that InP sells all of its resources so that equation (5) becomes $\sum_{k\in K} \alpha_k = 1$.

$$\alpha_k = \frac{\sum_{i_k\epsilon I_k} x_{i_k,j}}{\sum_{i\epsilon I} x_{i_k,j}}$$

**Assumption 2**: Resources are shared uniformly by users within MVNO.

This is similar to the idea proposed by [7].

$$z_{i_k} = \begin{cases} 0, & \sum_{i_k\epsilon I_k} x_{i_k,j} = 0 \\ \frac{\alpha_k}{\sum_{i_k\epsilon I_k} x_{i_k,j}}, & otherwise \end{cases}$$

The two assumptions already satisfy constraint (5) and (6). The final optimization problem is

$$max \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} x_{i_k,j} z_{i_k} R_{i_k,j}$$

s.t.

$$\sum_{j\in J} x_{i_k,j} \leq 1$$

$$\sum_{j\in J} x_{i_k,j} z_{i_k} R_{i_k,j} \geq \gamma_i$$

$$\sum_{i\in I}\sum_{s_j\in S_j} x_{i_k,s_j} z_{i_k} R_{i_k,s_j} \leq B_j$$

$$x_{i_k,j} = \{0,1\}$$

This problem has a convex problem nature but with binary variable. This can be solved by NC-ADMM which is a heuristic solution for the problem with convex objective and decision variables from a nonconvex set by using ADMM. The purpose of NC-ADMM is to show that the general purpose heuristic can find the pleasant solutions with minimal tuning.

## 4. Simulation Results

In evaluation, one MBS, 12 SBSs and 50 users with 3 MVNOs are considered. Total transmit powers of MBS and SBS are 40 watt and 4 watt. Total bandwidth is 20 MHz. Backhaul capacities of MBS and SBS are 10 Gbps and 2 Gbps. Thermal noise power is -174dBm/Hz. The long distance path loss model is $PL = 40\log_{10}(d_0) - 10\log_{10}(Gh_t^2h_r^2) + 10\gamma\log_{10}\frac{d}{d_0} + X_g$ where $d_0$ and $d$ are distances, $h_t$ and $h_r$ are heights of transmitter and receiver, $G$ is the gain product of transmitter and receiver and $X_g$ is normal random variable. Minimum data rate requirement of users is uniform distribution between 0.05 and 1 Mbps.

In Fig 3, sum rate of users is compared between NC-ADMM, Gurobi and Relax solution. NC-ADMM can achieve the solution very close to the optimal solution.

But, to compare the running time, GUROBI is much faster than NC-ADMM because GUROBI solves the problem in parallel whereas NC-ADMM supports minimal parallelism. But, as a general heuristic algorithm, it is incredible that NC-ADMM can achieve close to global optimal and solve the problem in polynomial time.

Fig. 4 compares the sum rate achieved by fixed and dynamic allocation of resources. Users of each MVNOs change randomly over time. Although users arrive and depart, the fraction of resources bought remains unchanged in fixed allocation which is pre-agreement between MVNO and InP. It can cause the waste of resources when the number of users of that MVNO is too low or the need of resources when users are crowded. For the dynamic allocation, MVNOs buy the resources according to its number of users at each time stamp. That is why data rate by dynamic allocation can achieve higher than by fixed allocation.

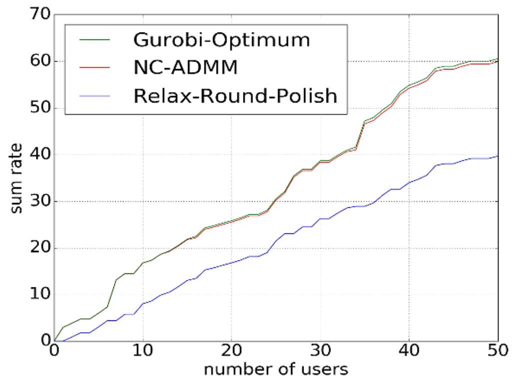


Fig. 3. Sum Rate obtained by different Optimizers

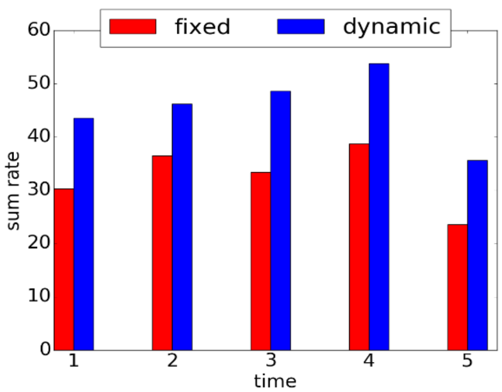


Fig. 4. Comparison of Fixed and Dynamic Resource Allocation

## 5. Conclusion

In this paper, we solved the joint resource allocation and user association for wireless network virtualization by NC-ADMM which is a heuristic solution to convex problem with nonconvex set. We proposed how to allocate resources proportionally among MVNOs over time. And, we consider the backhaul topology of base stations. In simulation, we show that dynamic allocation can achieve higher sum rate than fixed allocation.

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