# Cooperative Slice Allocation for Virtualized Wireless Network: A Matching Game Approach


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## ABSTRACT

Wireless networks for next generation (5G) are envisioned to accommodate massive data with support to various novel services. One promising solution to accommodate this tsunami of data and novel services is Wireless network virtualization (WNV). Through WNV, the infrastructure providers enables resource sharing to mobile virtual network operators in a transparent manner. Moreover, each mobile virtual network operators possesses a virtual resource called slice based on its user's requirements. Thus, infrastructure provider needs to consider efficient allocation of these slices for each MVNOs. In this work, we consider a practical multiple infrastructure provider scenario and formulate a slice allocation problem. To solve this problem, we present an efficient slice allocation scheme based on the matching game theory framework. Specifically, we define how to allocate the sliced resource efficiently among MVNOs users with different service requests. Simulation results illustrate the effectiveness of our proposal in terms of average sum-rate, admitted users and convergence.


## CCS CONCEPTS

• **Networks** → Wireless access networks; Network resource allocation;


## KEYWORDS

network slicing, stable marriage problem, wireless network virtualization, resource allocation.





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## 1 INTRODUCTION

Resource allocation problem has been considered as an important issue in wireless network research area. The meaning of resource can be defined by various things, such as compute resource, physical resource, network resource and so on. In this work, we consider the resource as wireless channels which is formed by dividing the wireless network spectrum into multiple virtual slices. These slices are created by considering users demand requirement in resource allocation problem. Resource allocation which decides how to embed a virtual wireless network on physical networks is one of the challenges in wireless network virtualization [1].

Virtualization is one of the suitable methods to meet the demands of the next generation (5G) network which is expected to support massive data and accommodate a wide range of services/use cases with distinct requirements [2]. Network virtualization deploy the network resource that is independent from the physical infrastructure for virtual network operator to cover the requirement of their users. In the business point of view, in addition, network virtualization can provide new opportunities which include cost efficiency strategy through new services. In case of wireless networks, users demand has continued to increase over the past few years due to the diverse service utilization of mobile users. To tackle this problem, the method of virtualization has been extended from wired network to wireless network [3].

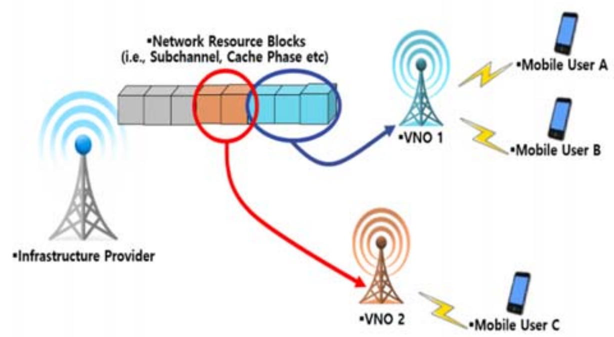


**Figure 1: Resource allocation concept in virtual wireless network.**

In WNV, Infrastructure provider (InP) has their own network resources in the base station (BS) and mobile virtual network operator (MVNO) can receive virtualized resource from an InP to satisfy the requirements of its users. Between the InP and MVNO, optimal resource allocation method should be considered to maximize the revenue and policy.

Network slicing is a novel concept that can meet the various heterogeneous requirements imposed for 5G environment. Network slicing method can also be considered as the virtual resources such as end to end logical network on the shared physical infrastructure [4]. The ultimate goals of the network slicing are flexibly allocating and reallocating resources based on dynamic user's demand or type of service. In this paper, we assume that each user use different service using their user equipment (UE) with different demand. Moreover, the resource are sliced by the InP and each sliced resource is allocated to a MVNO users to accommodate their demands.

The main challenge of existing works in resource allocation for wireless network virtualization is building a strategy for allocation from one InP to various MVNOs. The work in [5], formulate their resource allocation method based on matching game and design the problem specific preference profile of each player. Through that model, they proposed stable one to many resource allocation algorithm as the optimal solution. In [6], the authors consider the pricing based power allocation from InP to VNOs for their revenue. And also, they consider the WNV transmission system that several VNOs can share the spare power from an InP. The main purpose of proposal in [5] is to find out the equilibrium point that can maximize the utility of each VNO based on the InP's power allocation. In our case, we consider the resource allocation method between InPs and multiple users which was associated with MVNOs. Usually, previous works considered one InP's resource sharing [5-7]. Note that, these approaches do not apply for multiple InPs scenarios. Additionally, it has been observed that the performance increase significantly when multiple InP scenario is considered. In [8], a two-stage matching game solution has been proposed for such a scenario. However, they considered uniform demand from UEs to MVNOs, thus, not accounting for variable demands. In this work, we consider variable demands from user devices that are fed directly to InPs for the resource allocation process.

The remainder of the work is organized as follows. Section II of this paper presents the details of our system model. In Section III, we derive the solution for the proposed slice allocation problem. In Section IV, the evaluation is presented using the proposed solution as mentioned in section III. Finally, we conclude this paper in Section V.

# 2 SYSTEM MODEL AND PROBLEM DEFINITION

In the system model, a downlink of a cellular network is considered in which we have a set of $N$ base stations (BSs), each representing a cell that is owned by an InP. The InP is responsible to serve a set of $M$ mobile virtual network operators (MVNOs). Each MVNO needs to be served based on a serve level agreement between itself and InP. Moreover, an MVNO $m \in M$ uses the bought services (i.e., from InP) to serve a set $K_m$ of subscribed user equipment's (UEs). In this work, we assume that the set of users $K_m$ are already associated to an MVNO $m$. Then, $K = U_m K_m$ represent the sum of all UEs in the network. We use notation $|K|$ to denote the cardinality of a set $K$.

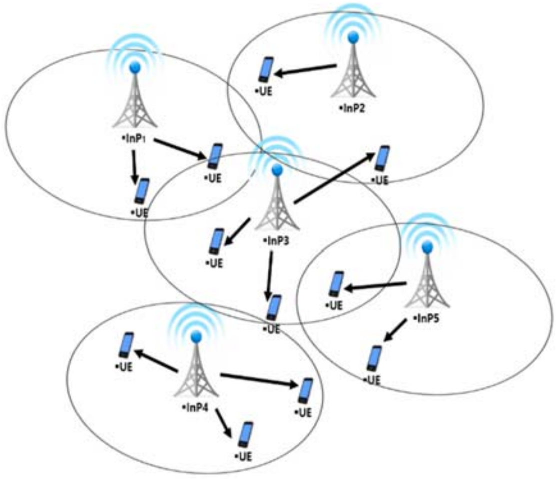


**Figure 2: System model**

## 2.1 Channel Model and Assumptions

Each InP has a set of $C_n$ orthogonal channels with bandwidth $W$. We consider fixed inter-InP interference in our model and assume it is absorbed in the background noise $\sigma^2$. Moreover, equal power is assumed on every channel of an InP $n$, i.e., $P_n = \frac{P_n^{max}}{|C_n|}$, where $P_n$ is the power on each channel and $P_n^{max}$ represents the maximum power of an InP $n$. In addition, InP $n$ provides specific services by a set of $S_n$ slices, where each slice $s_n \triangleq \{c \in C_n\}$ of InP $n$. Thus, each slice $s_n$ is built by different number of wireless channels that depends upon the requirement of MVNO's users. For slice allocation, we introduce a binary variables $y_{n,k}^{s_n}$ as follows:

$$y_{n,k}^{s_n} = \begin{cases} 1, & \text{if user } k \text{ is assigned slice } s_n \text{ from InP } n, \\ 0, & \text{otherwise} \end{cases}$$

Furthermore, we always set $y_{n,k}^{s_n} = 0$ for any user $k$, which is not assigned a slice. The rate for an MVNO UEs $k \subseteq K_m$ on a slice $s_n$ is given by:

$$R_{n,k}^{s_n} = \sum_{c \in s_n} y_{n,k}^{s_n} W log(1 + \gamma_{n,k}^{c}) \quad (1)$$

where $\gamma_{n,k}^{c} = \frac{P_n g_{n,k}^{c}}{\sigma^2}$, $g_{n,k}^{c}$ is the channel gain between InP $n$ and UE $k$. $W$ is the bandwidth of the slice $S_n$, unless otherwise specified, we assume $W = 1$ without loss of generality.

## 2.2 Economic Model

The physical substrate such as BS and spectrum is owned by the InP. It creates slices based on the request from MVNOs, and assigns slices to its associated users. In this paper, we also study the affect when players in the system act egoistically which is critical for network virtualization. Moreover, one of the main motivation behind network virtualization is cost saving factor of the network, such as maximization of revenue for InPs and cost minimization for the MVNOs. The business model for the InP is that InP sells its own spectrum and charges a price i.e., $\beta_n^I$ (per unit of slice i.e., $|s_n|$) to the MVNO users. The goal of the InP lies in maximizing its revenue by setting the suitable price to satisfy the demand of users while guaranteeing the service level agreement. Therefore, the utility of our system represents the network sum rate (SLA for MVNO users) and InP revenue as follows:

$$U(y) = \sum_{m \in M} \sum_{s_n \in S_n} \sum_{k \in K_m} R_{n,k}^{s_n} + \omega y_{n,k}^{s_n} \beta_n^I \, |s_n|, \tag{2}$$

The utility in (2) represents the network sum rate and revenue obtained by InP. $\omega$ is a weight that represents the trade-off between network sum rate and InP's revenue.

## 2.3 Problem Formulation

The objective in our problem is to maximize the total system utility from the prospective of InP and MVNOs users. Therefore, our aim is to maximize the revenue attained by InP while simultaneously meeting the demands of MVNO's users. Then, the considered network slice allocation problem is:

$$\text{P1}: \quad \max_{y_{n,k}^{s_n} \in \{0,1\}} \sum_{n \in N} U(y) \tag{3}$$

$$\text{s.t.} \quad \sum_{k \in K_m} \sum_{s_n \in S_n} y_{n,k}^{s_n} \leq |S_n|, \ \ \forall n \in N \tag{4}$$

$$\sum_{s_n \in S_n} y_{n,k}^{s_n} R_{n,k}^{s_n} \geq d_k, \ \ \forall k \in K_m, \tag{5}$$

where $y_{n,k}^{s_n} \in Y$ is the slice selection binary decision variable of InP with $y_{n,k}^{s_n} = 1$ stating InP $n$ accepts the slice $s_n$ proposal made by user $k$ and $d_k$ represents the UE $k$ demand from InP. In WNV, isolation among different MVNOs is a fundamental requirements. This can be achieved by guaranteeing certain predetermined requirements or contract service agreement (e.g., minimum share of resource or data rate) by the InP. In this work, physical resource level isolation is considered, i.e., wireless channel. Through (4) we ensure that the allocated number of slices are less than total available slices in the network. Finally, we provide isolation constraint in (5) that ensures a minimum data rate for all UEs $k$.

The optimization problem **P1** is an integer linear programming problem and has a combinatorial nature [9-10]. Finding an optimal solution in a central manner for this problem is difficult as it incurs heavy computation, and raises privacy concerns [8]. Therefore, we provide a distributed approach which can cope with the aforementioned challenges and present an efficient solution.

# 3 SOLUTION FOR SLICE ALLOCATION

We choose the concept of matching game to solve this problem. We will discuss the details of our solution in this section. Matching theory is one of the famous mathematical frameworks which can be used to solve various network problems such as energy, compute resource allocation problem [10-13].

Our game can be modeled as a two sided game, one side represents the MVNOs UEs while the other side represent the InPs. In our game, we assume that each UE can be associated to a single InP whereas each InP can support multiple UEs which corresponds to one to many matching game design as follows:

***Definition 1****: A matching* $\mu$ *is defined by a function from the set* $\mathcal{K} \cup \mathcal{N}$ *into the set of elements of* $\mathcal{K} \cup \mathcal{N}$ *such that:*

1) $|\mu(k)| \leq 1$ *and* $\mu(k) \in \boldsymbol{\mathcal{N}}$
2) $|\boldsymbol{\mu(n)}| \leq \boldsymbol{q_n}$ ***and*** $\boldsymbol{\mu(n)} \in \boldsymbol{\mathcal{K}} \cup \boldsymbol{\phi}$
3) $\boldsymbol{\mu(k) = n}$ ***if and only if k is in*** $\boldsymbol{\mu(n)}$

where $\mu(k) = \{n\} \Leftrightarrow \mu(k) = \{k\}$ for $\forall n \in N, \forall k \in K$ and $|\mu(.)|$ represents the cardinality of matching outcome $\mu(.)$. Condition 1 and 2 represent that our design corresponds to a one-to-many relation such that a UE *k* can be associated with one InP *n* only and InP *n* can have multiple UEs upto $q_n$, if the required SLA is achieved.

Here, represents the quota of InP n which represents the number of UEs that can be accepted to guarantee the SLA agreement. Additionally, there are also cases when a user k is not feasible for a slice as it may violate constraint (5).

**Algorithm** Cooperative Matching Game Algorithm

**Input** $t = 0$, $q_n^{(0)} = |S_n|$, $P_k^{m(0)} = P_k^m$, $P_n^{(0)} = P_n$, $\forall k, m, n.$
**repeat**
  $t \leftarrow t + 1$
  $\forall k \in k_M$, propose to *n* according to $P_k^{m(t)}$.
  **while** $k \notin \mu(n)^{(t)}$ and $P_k^{m(t)} \neq \emptyset$ **do**
    **if** $q_n^{(t)} \leq |\gamma_{n,k}|$ **then**
      $P'^{(t)}_m = \{k' \in \mu(n)^{(t)} | k \succ_n k'\}$.
      $k'_{lp}$ ←the least preferred $k' \in P'^{(t)}_n$.
      **while** $(P'^{(t)}_n \neq \emptyset \cup q_n^{(t)} \geq |\gamma_{n,k}|)$ **do**
        $\mu(n)^{(t)} \leftarrow \mu(n)^{(t)} \setminus k'$
        $P'^{(t)}_n \leftarrow P'^{(t)}_n \setminus k'_{lp}$.
        $q_n^{(t)} \leftarrow q_n^{(t)} + |\gamma_{k', n_{lp}}|$,
        $k'_{lp} \leftarrow k' \in P'^{(t)}_n$.

**if** $q_n^{(t)} \le |\gamma_{n,k}|$ **then**

$P''^{(t)}_n = P'^{(t)}_n \cup \{k\}$

**else**

$\mu(n)^{(t)} \leftarrow \mu(n)^{(t)} \cup \{k\}$

$q_n^{(t)} \leftarrow q_n^{(t)} - |\gamma_{n,k}|$

**for** $l \in P''^{(t)}_n$ **do**

$P_l^{m(t)} \leftarrow P_l^{m(t)} \setminus \{n\}$

$P_n^{(t)} \leftarrow P_n^{(t)} \setminus \{l\}$

**else**

$\mu(n)^{(t)} \leftarrow \mu(n)^{(t)} \cup \{k\},\ q_n^{(t)} \leftarrow q_n^{(t)} - |\gamma_{n,k}|$

**until** $\mu^{(t)} = \mu^{(t-1)}$

**output:** $\boldsymbol{Y} \leftarrow \mu^*$

Once we define the matching game, our next goal is define the preference profile for each side of players. The preference of UEs towards an InP is derived by the achievable rate from an InP n as given in (1). Each UE ranks all InPs in decreasing order with respect to its rate. On the other hand, each InP finds a set of UE that can maximize its profit and network sum rate. Therefore, the preferences of an InP is given by (2). An InP ranks all UEs in decreasing order in its preference profile.

Next, our goal is to design an efficient algorithm which achieves a stable solution. The notion of stability is a key concept for matching theory and in order to find a stable solution, the deferred-acceptance algorithm is typically employed [14]. However, our matching game involves an additional challenge of variable quota opposed to standard static quota [12]. In our game, a UE can have variable demand thus accommodating variable number of channels per slice. Therefore, our game involves a variable quota for each InP which limits us to adopt the standard deferred-acceptance algorithm. The blocking pair for our formulated game is formally stated as:

***Definition 2:*** *A matching* $\mu$ *is stable if there exists no blocking pair (k, n), where* $k \in \mathcal{K}$, $n \in \mathcal{N}$, *such that* $n \succ_n \mu(k)$ *and* $k \succ_n \mu(n)$, *where* $\mu(k)$ *and* $\mu(n)$ *represent, respectively, the current matched partners of user k and InP n.*

To address this challenge, it is required to have a novel stable matching algorithm which we are presenting. Initially, both sides make their preference profiles based on their local information. Then, at each iteration t each UE starts proposing to its most preferred InP based on its preference profile $P_k^m$. On receiving the proposal all InPs first calculate the required channels to build a slice. If enough channels available to fulfil the QoS it accepts the proposing UEs. However, if enough channels are not available, it rejects the current matched UEs that rank lower than the proposing UE. If still sufficient resources are not available the proposing UEs are rejected along with the previously removed UEs. Note that, all rejected UEs and InPs then update their preference profile. The rejected UEs then re-propose to the second best InPs in its preference profile. This iterative procedure stops if all UEs are either accepted by InPs or there are no further InPs to propose. By this process, it is guaranteed that our solution converges to a stable solution as we are removing the blocking pair at each iteration [10]. The final output is a set of UEs that are allocated slices by InPs given by the allocation vector **Y**.

# 4 SIMULATION RESULTS

**Table 1: Simulation Parameters [15]**

| Simulation Parameters | Values |
|---|---|
| Carrier Frequency | 2 GHz |
| Frame Structure | Type 1 (FDD) |
| Transmission Time Interval | 1ms |
| Total Transmit power of BS | 46 dBm |
| Bandwidth of each RB(W) | 180kHz |
| Path Loss(cellular link)[16] | Okumura-Hata model |
| Shadow Fading Standard | 3 dB |
| Thermal noise for 1 Hz at 20 °C | -174 dBm |

In order to simulate our proposal, we consider the parameters as shown in table 1. In addition, a network consisting of 5 MVNOs that buy slices from 5 InPs to serve their subscribed randomly located $k$ UEs. We consider a simulation topology inside the coverage area of 5000 × 5000 m. For the demand we consider, each UE $k$ has a random demand distributed in the range of $d_k = \{1\sim10\}$ bps/Hz. In addition, we set the prices for InPs that is also uniformly distributed in the range of $\beta_n^l = \{2\sim4\}$ units per bps per Hz. Furthermore, all results of our paper are calculated by averaging over 500 simulation runs, each of which realizes random resource demands, pricing of InP-BSs, random UEs locations. For comparison, we select the different system bandwidth in each InP-BS, 1.4 MHz and 3 MHz which has different number of physical resource blocks.

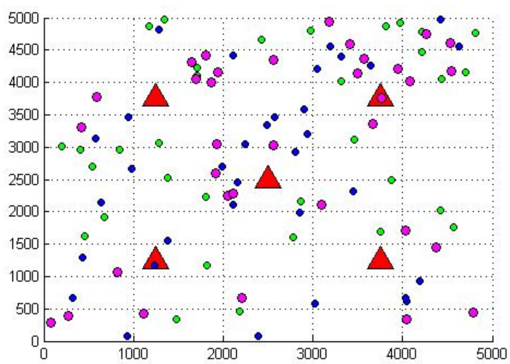


**Figure 3: Simulation topology**

Figure 3 is presents the simulation topology which has 5 InP-BSs and several MVNO's users. Based on this topology, we perform the simulations to demonstrate effectiveness of the resource allocation algorithm using two different system bandwidth. The InPs are represented by solid red triangles whereas the same colored circles represent UEs belonging to same MVNOs. We can see that our system considers five MVNOs, thus five types of color circles representing all UEs in the network.

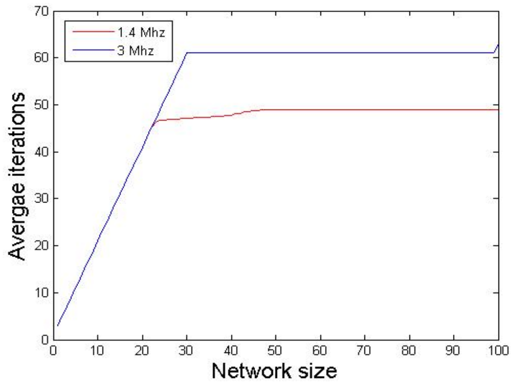


**Figure 4: Average iterations**

Figure 4 shows the convergence of our algorithm with respect to number of users, i.e., network size. Algorithm converges when the InP-BSs resource and users achieve the stable match. In case of 1.4MHz of system bandwidth, the network size for average iteration is smaller than 3MHz system bandwidth. The main reason is that under 1.4MHz scenario the number of resource blocks are less compared to 3MHz, thus less number of proposals to InPs.

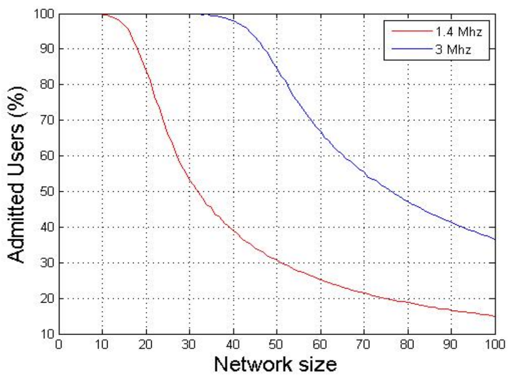


**Figure 5: Admitted users (%)**

Figure 5 shows the percentage of admitted users with respect to varying number of users in the simulation environment. When the system bandwidth is 1.4MHz, it accepts a relatively small number of users. Because there are fewer resources to allocate compared to 3MHz. Furthermore, all InP-BSs cannot admit all users due to the limited number of resources available.

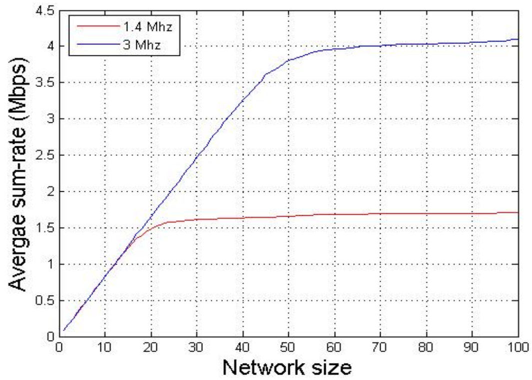


**Figure 6: Average sum-rate in whole network**

For an average sum-rate over the entire network, the result in the figure 6 when the system use the 3MHz as the bandwidth is higher than 1.4MHz. As shown in figure 4 and figure 5, each bandwidth has maximum acceptance point of user after which it gets saturated. Thus, for the case when there exists enough allocable resource in the system, the maximum point is increased and sum-rate increases.

# 5 CONCLUSION

In this work, we have studied cooperative slice resource allocation method using multiple InP-BSs for MVNOs' users. For the practical point of view, we have considered the complex environment which has the multiple InP-BSs in the mobile network. Based on the matching game, we built the cooperative slice allocation algorithm and simulated using different two system bandwidth. As the result, the algorithm work well to meet the dynamic demand of MVNOs' users through cooperation. As a future extension, we intend to consider dynamic pricing and power levels on a slice.

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