User Association in Wireless Virtualization Networks using Canonical Matching Game

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Abstract

Network virtualization is one of the most promising trends for a forthcoming fifth generation (5G) cellular networks, where the virtualization technology enables resource sharing for each service. Thus, the most important issue in this research area is a resource allocation for each service. So, in this paper, we proposed a solution to maximize the utility of mobile virtual resources by applying canonical matching. Finally, we prove that the proposed algorithm can converge into stable matching.

1. Introduction

Virtualization is an approach to satisfy the development of next generation cellular wireless networks. The main idea of virtualization is to permit resource sharing and to decouple the infrastructure from the services it provides. The InP provides the infrastructure as a service to mobile virtual network resources (MVNO) while SP leases virtual network from MVNOs to provide specific services to end users. Specifically, the physical resource of a base station (BS) owned by an InP is abstracted into isolated virtual resources (i.e. slices) which are then transparently shared among different MVNOs. MVNO plays a key role in the future mobile network, and it exists as a "connector" in the network. So the benefits of MVNO should be carefully guaranteed. [1], [2].

With virtualization, firstly, the resource utilization can be improved through customizing the dynamic requirements of users from MVNOs. Second, wireless network virtualization provides easier migration to new technologies while supporting legacy technologies by isolation part of network. The capital expenses (CapEx) and operation expenses (OpEx) can be reduced through sharing [2].

Resource allocation plays a very important role in wireless virtualization. The challenge in resource allocation is how to slice the physical resource for virtual networks of MVNOs to accommodate the dynamic demand of their subscribed users, while satisfy the requirement of efficient resource allocation, isolation [2].

Recently, matching theory has emerged as a promising technique for wireless resource allocation which can overcome some limitations of game theory and optimization [3].

In this paper, we formulate the virtual resource allocation as an optimization problem, which maximizes the utility of mobile virtual network operators (MVNOs). And then, to overcome the computation complexity, we formulate the problem as a matching game with static preference list for players. To solve the problem, we propose an algorithm that converges to a two-sided stable solution.

The rest of this paper is organized as follows. Section 2 describes the system model and problem. Section 3 presents our distributed approach and the proposed algorithm to solve the problem. Section 4 provides the simulation results and Section 5 concludes the paper.

2. System Model

We consider the mobile cellular network comprising J BSs. The set of BSs is denoted by J, and j is used to indicate one of the BSs. These BSs belong to different InPs with different leasing prices. Let I denote the set of users belong to different SPs. In practical scenario, each user can only associate with one BS at any time. We define user association indicator x_{ij}=1 if user i is associated with BS j, and x_{ij}=0 otherwise.

The spectrum bandwidth allocated to BS j is B_j. Achievable rate of user i with BS j:

$$R_{ij} = x_{ij} \frac{B_j}{K_j} \log(1+\gamma_{ij}) \qquad (1)$$

Where γ_{ij} is the signal to interference-plus-noise ratio (SINR) between user i and BS j. K_j is the number of users associate with BS j. We assume the backhaul bandwidth usage of user i is the same as achievable data rate Rij. Because each BS is limited of backhaul bandwidth, it must be hold:

$$\sum_i R_{ij} \le W_j \quad (2)$$

Because MVNO will receive payment from user according users' data rate and pay for InP for MVNO's backhaul renting and bandwidth usage. The utility function of MVNO is:

$$a^{sp} R_{ij} - b^{bh} R_{ij} \quad (3)$$

Where a^{sp}, b^{bh} is the price for SP payment, radio resource cost and backhaul cost, respectively.

So, we have to find the user association (a part of resource allocation) x_{ij} so that

$$\text{Max: } a^{sp} R_{ij} - b^{bh} R_{ij}$$

$$\text{s.t } \sum_i R_{ij} \le W_j$$

$$x_{ij} = \{0,1\}$$

To solve this problem, we propose matching game based distributed algorithm as follow.

3. Matching Game

A matching game is a two-sided assignment problem between two disjoint sets of players in which the players of each set are interested to be matched to the players of the other set, according to some preference relations. A preference relation ≻ is defined as a complete, reflexive, and transitive binary relation between the elements of a given set. Here, we denote $\succ_m$ as the preference relation of player m and denote a $\succ_m$ b, if player m prefers a more than b.

Here, the matching game will occur between the user i and BS j. We introduce a two-sided one to many matching game in which each user will be match with maximum one BS, while BS can be assigned to one or more users. We can define the matching game as follow:

Definition 1: Given the two disjoint finite sets of players I and J, a matching game μ is defined as a function from I→ J from which we have

1. ∀j ∈ J, μ(j) ∈ I,
2. ∀i ∈ I, μ(i) ⊆ J ,
3. μ(i) = j, if and only if j ∈ μ(i).

In matching theory, the quota of a player is defined as a maximum number of players, that a player can be matched to. Here, the quota of user is set to one, while there is no predetermined quota for BS. Let V_{ij} and U_{ji} denote, respectively, the utility function of players in I and J. Hence, user I prefer BS j1 to j2 if and only if $V_{i,j}(j1) > V_{ij}(j2)$.

The utility of user i is:

$$V_{ij} = a^{sp} R_{ij} \quad (4)$$

The utility of BS j is:

$$U_{ji} = -b^{bh} R_{ij} \quad (5)$$

To solve the proposed matching game, one suitable concept is the so-called two-sided stable matching between the user and BSs, defined as follows [3].

Definition 2: A pair (i, j) ∈ / μ is said to be a *blocking pair* of the matching μ, if and only if i ≻i μ(i) and i ≻jμ(j). Matching μ∗ is stable, if there is no blocking pair.

The classical approach used to solve a matching game is by applying the called deferred acceptance algorithm which is known to converge to a stable matching, given fixed preference relations and fixed quotas [3]. In our problem, however, we cannot fix the quotas for D-BSs, since it has constraint in backhaul traffic. Therefore, the approach of are inapplicable and a new algorithm must be developed to find a stable matching. The algorithm consist of 3 phases:

Initially, each UE is associated to a randomly selected BS j (max SINR).

In the second phase, the user ranks the BSs, based on the given prices and the achievable rate of the links, as per (4). Furthermore, each user i applies for its most preferred BS, j^* = argmax V_{ij}, from the set Si, then removes j^* from Si, in order to avoid applying for the same BS multiple times.

In the third phase, BS receives the applications and calculate the corresponding utility values, using (5). Each BS accepts the most preferred user, i⋆ = argmax U_{ij}. At first, the BS j adds the achievable rate from that link to i into sum of rate it can provide. If the total rate is less than, BS will accept user i. Otherwise, BS j will delete the user that BS already accepted previous but has the lowest rank in BS's preference list and subtract the rate of this link from total rate . After that, BS checks their total rate again and deletes the least preferred user if total rate greater than BS's backhaul bandwidth. This procedure repeated until total rate of BS less or equal its bandwidth constraints. The players iterate based on phase 2, phase 3 until a stage in which, each user, associated with the most prefer BS or S_i=∅.

Theorem 1: The proposed algorithm is guaranteed to converge to a two-sided stable matching between users and BSs.

Proof: The convergence of the proposed algorithm in is guaranteed, since a user never applies for a certain BS twice. Hence, in the worst case, all users will apply for all BSs once, which results Si= ∅, ∀i ∈ I. Next, we show that once the algorithm converges, the resulting association between users and BSs is two-sided stable. Let's assume that there exists a pair (i, j) ∈ / μ that blocks the outcome of the algorithm. I would not replace any of j' ∈ μ(i) with j, since j' >i j. Otherwise, I would propose earlier for j. If I has applied for j and got rejected, this mean μ(j) >j i, which contradicts (i, j) to be a blocking pair. When S_i = ∅ implies that i has got rejected by j, which means μ(j) >j i and (i, j) cannot be a blocking pair. This proves the theorem.

4. Simulation Results

In the simulations, we consider two RAN InPs, two backhaul InPs, one MVNO and three SPs. RAN InP1 owns one macro BS and 5 small BSs .RAN InP 2 owns only 5 small BSs. The price of backhaul InPs 1 for macro BS and small BSs of RAN InP 1 is 1 units/Mbps, while the price of backhaul InP 2 for small BSs of RAN InP 2 is 1.2 units/Mbps. The prices for requesting virtual resources are 15units/Mbps, 20 units/Mbps and 18 units/Mbps, respectively. The channel modeling parameters are defined in table 1:

The result is in the table 2, where we compare our algorithm with max-SINR and proportional fairness (PF). According to table 2, utility of MVNO of our algorithm is better than the scheme of max SINR and PF.

TABLE 1
Simulation Parameters

Bandwidth	20 MHz
Transmit Power	49dBm for marco, 20 dBm for small BS
Path loss	L(d)=34+40logd for marco cell L(d)=37+10logd for small cell
Shadowing	Lognormal - standard deviation 8 dB for marco, 4 dB for small cell
Background Noise PSD	-169 dBm/Hz
Backhaul capacity	10 Gbps for macro BS 2 Gbps for small cell BS

TABLE 2
Utility values for 2 schemes

Number of users	60	120	180	240	300
Our algorithm	1.6765	2.2528	2.2873	2.9468	2.8269
Max SINR+ PF	0.2870	1.9840	1.1380	1.2138	1.4434

5. Conclusions:

In this paper, we apply the canonical matching game to solve the problem of user association in wireless virtualization networks. By simulation, our proposed scheme is better than the traditional user association (max SINR+ PF).

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