A Resource Slicing in 5G Cellular Networks

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Abstract

The introduction of heterogeneous devices in the existing networks demands the network operators to provide differentiated services according to device capabilities and requirements. Moreover, since the advent of internet of things (IoTs) and its predicted growth, differentiated services in the future network (5G) is not considered as a privilege rather it is a necessity. To cope with this challenge in 5G networks, network slicing is considered as a key technology to meet the diverse users' requirements. In this work, we present a novel scheme based on winner determination problem of auction theory for allocating slices to users with diverse demands. Moreover, we consider that each slice consists of dynamic number of physical resources based on the users demand. Simulation results are presented to verify the effectiveness of our proposal in terms of average throughput, and dynamic slice size.

I. Introduction

The massive increase and predicted tsunami of network devices with diverse service requirements demands revolutionizing the existing cellular network. However, currently the cellular networks lack the capability to provide differentiated services to its users based on the service type. All users are serviced similarly regardless of their communication requirements. It is envisioned that 5G networks will be able to support diverse users' demands via the promising approach of network slicing [1-2].

Through network slicing, a physical network, can host multiple logical networks, thus, enabling flexibility for the network operators to offer optimal support for different types of services to its users. Moreover, the recent advances and success brought by software-defined networking (SDN) [1], [3] and network functions virtualization (NFV) [1] will play a very crucial role in enabling end to end network slicing. However, in this work, we only consider the physical wireless resources (channels) of base-station (BS) to slice and allocate to users based on their demands as shown in figure 1 [4]. A resource slice is created by virtualizing the BS resources and allocating variable number of channels per slice based on the services requirements. Each slice is then allocated to a user based on its demand service. One crucial factor to take into consideration in resource slicing is the isolation among slices, i.e., change in one slice configuration does not affect the performance of other users' slices [5]. To cater this challenge, we provide a novel solution based on auction theory in which users bid for specific slices and the BS solves the winner determination problem to allocate slices to winning users. The rest of the paper is organized as follows: Section II presents the system model and problem formulation. Section III presents our solution approach whereas simulation results are illustrated in section IV. Finally, we conclude our work in section V.

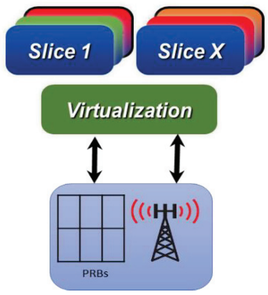

Figure 1: Resource Slicing

II. System model and Problem Formulation

We consider a network that is comprised of a base-station and a set of users (UEs) represented by K. The BS owns the infrastructure which has a capacity of C orthogonal channels. Furthermore, we assume equal power on every channel of a BS. Moreover, BS provides isolated services to its users by a set S of slice templates, where each slice template have variable number of channels based on the services it provides, i.e., enhanced mobile broad band or ultra-reliable and low latency services. In our model we consider that each UE request a slice template that matches best for its requirements from the BS. Each slice s comprises an amount of channels which are then allocated to each UE. The Slice requirements define the Service Level Agreement (SLA) between the BS and the UEs. Note that, when a BS receives a network slice request, it decides whether to accept or reject it based on network utility maximization while guaranteeing the agreed SLAs. Let r_k^s denote the rate of user using slice s as:

$$r_k^s = W \log(1 + SINR_k^s) \quad (1)$$

Where ***W*** is the bandwidth available and $SINR_k^s$ is the received SINR on slice s for user ***k***. As a slice consists of variable number of channels, we assume uniform SINR for all channels. We can consider this the worst SINR among all channels. Let x_k^s be the binary variable to represent the slice s allocated to user ***k***. Then the optimization problem can be written as:

$$\begin{aligned} &\max_{x_k^s} \sum_s \sum_k x_k^s r_k^s \\ &s.t \ \sum_s x_k^s < 1, \forall k, \\ &\quad \sum_s x_k^s r_k^s > r_k^{sla}, \forall k, \\ &\quad \sum_k \sum_s x_k^s < S, \\ &\quad x_k^s \in \{0,1\}, \forall k, \forall s. \end{aligned} \quad (2)$$

The objective of this problem states that we maximize the sum rate achieved by allocating slices by meeting the required rate of UEs. The first constraint ensures that a UE k is allocated only one slice s. The second constraint ensures that if a UE k is allocated a slice it should meet its SLA required rate. Third constraint states that the allocated slices are less than the total slices available in the network. Finally there is a binary indicator constraint. This problem is known as a combinatorial problem and thus falls in the NP hard category which can have suboptimal solution [2]. In order to solve this combinatorial problem we use the concept of auction theory [6]. In auction theory, we have three types of entries, a bidder, a seller and an auctioneer.

III. Game Formulation

In our model, the UEs play the role of bidder. Each UE bids for a slice which comprises of a number of resources based on its valuation.

$$v_k = r_k^s - \alpha d_k \quad (3)$$

The valuation of a slice depends upon the achievable rate on slice s and the cost incurred α to a UE k to fulfil its demand d_k. Once the BS receives the bids, it plays the role of the seller and auctioneer in our game model. It decide the allocation process based on its utility. In our game, the utility of a BS is to maximize the network rate by selling its resources. To solve this problem, we derive a heuristic approach [6]. The goal is to solve the winner determination problem from the received bids such that the network utilization is maximized. The main idea is to sort the received bids in decreasing order of resource efficiency and allocate the network slices to the first k users which satisfy constraint 3, i.e., allocated slices are less than the total slices available in the network.

Algorithm 1: Slice Allocation Algorithm

Initialization: set *temp*=|C|, $L = \phi$, $X = \phi$;
Each UE k submits bid to BS;
BS sorts all bids in decreasing order based on resource efficiency $L = \left\{ k \in K \mid \frac{d_{k_1}}{r_{k_1}^s} < \frac{d_{k_2}}{r_{k_2}^s} < \ldots < \frac{d_{k_K}}{r_{k_K}^s} \right\}$
while L is not empty
  Choose first UE k request of slice s from set L;
    if *temp*<|s|
      Allocate slice s to UE k
      Update temp by subtracting slice size |s|, temp= temp-|s|;
      Update admitted set X by adding UE k, $X = X \cup k$;
    end
  Update the set L by removing k;
end while

Finally, we get the slice allocation vector X that represents all the winner of the game.

IV. Numerical Results

In order to study the performance of our proposed scheme, we simulate a network with one BS who serves 20 UEs randomly located inside the coverage area of 500 × 500 m. We assume each UE k has a random demand in the range of $d_k = \{1{\sim}15\}$ bps/Hz. Note that, here we assume the each UE demand represents a service. In our future work, we will consider specific services and map the UEs demand based on its service. Moreover, we use a normalized pricing for BS, i.e., 1 units per physical resource block (PRB). The main wireless parameters follows the system guidelines given in [7]. Note that, all results are calculated by averaging over 100 simulation runs with random resource demands and random UEs locations. For comparison, we use different system bandwidth, i.e., 1.4, 3 and 5 MHz which has different number of PRBs. Fig. 2 and 3 presents the average throughput and average number of accepted users in the network, respectively. It can be seen that the throughput increases with network size and system bandwidth which however saturates as the resources exhaust. We also observe the high throughput at 5 Mhz due to more number of resources compared to the 1.4 Mhz. This is also evident in fig.3 as more number of users are accepted due to more resource availability in the network.

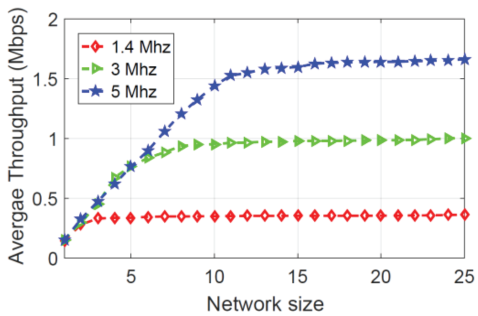

Figure 2: Average network throughput.

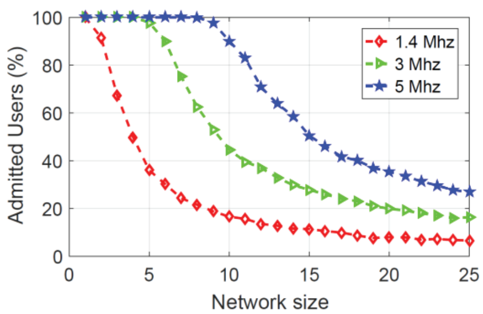

Figure 3: Average admitted users in network.

Fig. 4 presents the slice size provided to each UE against its demands. It can be observed that at 5 Mhz, we have 25 PRBs so nine users are provided the slice with variable size based on its demand whereas only two users that maximize the network efficiency are provided slices for 1.4 Mhz.

V. Conclusions

Network slicing can enable differentiated services for the 5G networks. In this paper, we propose a novel slice allocation approach based on users service demand. Our approach is based on auction theory. Simulation results show the effectiveness of our approach and reveal the dynamic slicing based on users demand. As future work, we intend to enable slice sharing among users while guaranteeing the isolation.

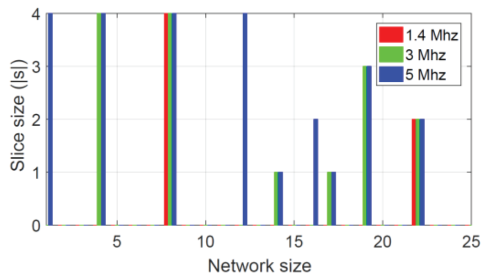

Figure 3: Slice size

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (NRF-2017R1A2A2A05000995). *Dr. CS Hong is the corresponding author.

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