# An Online Spectrum Market in Wireless Small Cells Networks: An Advanced Auction Approach

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**Abstract**

A major challenge in the operation of wireless communication system is the efficient use of radio resources. In this paper, we propose downlink resource allocation problem in heterogeneous wireless networks (HetNet) where base stations have limited number of available channels or resource blocks (RBs) to allocate to their associated users. Moreover, we develop an advanced auction framework to address the proposed problem. Upon receiving online spectrum requests from mobile users, base stations decide how many resource blocks will allocate to each mobile user. Simulation results show that our method can increase over all network capacity and our problem converge to the unique Nash Equilibrium.

Keywords – Heterogeneous Wireless Network, Resource Allocation, Advanced Auction.

## 1. Introduction

Current trend suggests massive increase in wireless network services as wireless with the overwhelming growth of wireless devices. In order to work out with this scenario, 3GPP has been studying heterogeneous wireless network (HetNet) that aims to increase spectral efficiency per unit area [1][2]. HetNets are composed of macro base stations (MBs) and small cells such as micro, pico, femto cells and relay base stations.

Because of the increase of type and number of BSs, we need to face with many challenges in heterogeneous networks. Among them, most of the important challenges are cell association, interference management, and resource allocation and so on. In this paper, we address the problem of radio resource blocks' allocation with the help of advanced auction framework.

## 2. System Model

As shown in Fig.1, we consider heterogeneous wireless network with a single macro base station (MBS) and a set of small cells. The set of all small cells is denoted by, $M = \{1, 2, 3, ..., N_M\}$ ,and each small cell has a set of subscribers (users), $S = \{1, 2, 3, ..., N_S\}$ . Moreover, each small cell has total number of resource blocks (RBs), $R$, and we model the RBs allocation problem with an advanced auction mechanism , Generalized Kelly Mechanism[3]. Our approach of implementing this technique is to simplify system's complexity issues by minimizing interaction between seller and buyers. In each round of allocation, under this mechanism the buyers (bidders) will at first submit their bidding values for evaluation to the auctioneer. That means the auctioneer can now choose allocation of resources in order to improve (maximize) social welfare of the system. In our model, we consider mobile users as bidders, and each small cell as an system's auctioneer. In each round, mobiles users, $s \in S$ will report the bidding values $b_s$ to small cell. And according to the bidding values from all the users, small cell will define the allocation of RBs to users.

## 3. Problem Formulation

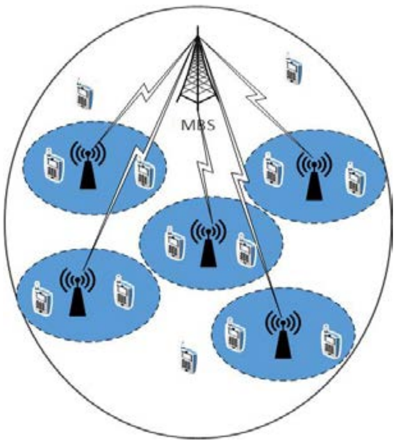


**Fig.1. System Model**

As per the QoS requirement, each user, $s \in S$ decides the required amount of RBs. We define valuation function of user by $v_s(.)$, in which $v_s(r_s(b))$ corresponds to the valuation of a user when $r_s$ is allocated RBs as per it's bidding value, $b_s$. So the data rate (defined as valuation function here) of each subscriber (user) can be expressed as:

$$v_s(r_s(b)) = r_s \omega_{r_s} \log_2(1 + \frac{p_{r_s m} g_{r_s}}{I_{macro} + N_0}) \qquad (1)$$

where $\omega_{r_s}$ for RB $r_s$ is the bandwidth, $p_{r_s m}$ is the corresponding transmitted power, $g_{r_s}$ is user's channel gain on RB $r_s$, $N_0$ denotes noise power and $I_{macro}$ is the interference by the macro base station. From the perspective of small cell, the objective is to maximize the sum of user's valuation. Therefore, our RBs allocation problem of small cell $m \in M$ becomes as follows:

$$\max_{r_s} \sum_{s \in S} v_s(r_s(b)), \qquad \forall m \in M. \qquad (2)$$

**Subject to:**

$$r_u \cap r_s = \varnothing, \quad when\ u \neq s, \text{ and } u, s \in S. \qquad (3)$$

$$\sum_{s=1}^{N_S} r_s(b) \leq R, \qquad \forall s \in S. \qquad (4)$$

$$r_s(b) \geq 0, \qquad \forall s \in S. \qquad (5)$$

In constraint (1), we can see that there is no interference among different users. Similarly, constraint (2) that guarantees cumulative allocation of RBs to all mobile users cannot be more than the available total RBs of the small cell. As we know, the valuation function is each buyer's private information. For instance, the users might falsify their true valuation in order to maximize their own utility. This creates challenge for auctioneer to maintain maximal social welfare while solving RBs allocation problem. For this case, we formulate a truthful mechanism of bidding, and correspondingly resource allocation scenario. We determine the resource allocation to user, $s \in S$ by the following equation:

$$r_s(b) = \frac{b_s}{\sum_{s=1}^{N_S} b_s} R, \qquad \forall s \in S. \qquad (6)$$

where $\sum_{s=1}^{N_S} b_s = B$ is the total bidding value received by small cell. Considering the bidding value $b_s$, we can evaluate the cost function, $c_s(b)$, of each user as $(q_s \times b_s)$, where $q_s$ is defined as the penalty parameter that is related to bidding value. Then, the payoff function of user, $s \in S$, can be expressed as:

$$u_s(b) = v_s(r_s(b)) - c_s(b), \quad \forall s \in S. \qquad (7)$$

$$u_s(b) = v_s(r_s(b) - q_s b_s, \qquad \forall s \in S. \qquad (8)$$

we can calculate the unit penalty parameter for each subscriber according to the following equation:

$$q_s = \frac{1}{\beta} v_s^{'}(r_m)(1 - \frac{r_s}{R}), \qquad \forall s \in S. \qquad (9)$$

$$\beta = \frac{\sum_{s=1}^{N_S} b_s}{R} \qquad (10)$$

**Proof:**

$$\frac{\partial u_s}{\partial b_s} = \frac{1}{\beta} v_s^{'}(r_s)(1-\frac{r_s}{R}) - q_s = 0$$

$$= \frac{1}{\beta} v_s^{'}(r_s)(1-\frac{r_s}{R}) = q_s$$

Our formulation for RBs allocation problem well fits as a competition game where each user chooses its own strategy $b_s$ so as to maximize their payoff $u_s(b)$:

$$u_s(b_s : b_{-s}, q) = v_s(r_s(b)) - q_s b_s, \; s \in S. \quad (11)$$

The existence of Nash equilibrium for RBs competition game, for each user is defined by the following condition:

$$u_s(b_s^*, b_{-s}^*, q) \geq u_s(b_s, b_{-s}^*, q), \;\; \forall s \in S. \quad (12)$$

## 4. Simulation Results

In Fig.2, we can see the valuations of users with different numbers of allocated RBs. When we increase the number of RBs of base station, the valuations of users also increase which means each user gets more RBs.

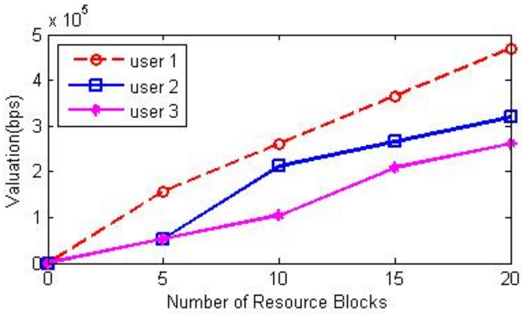


Fig.2. Valuation of users with different numbers of RBs

Moreover, we simulate RBs allocation of different users in SC1 and SC2 at different time intervals when they arrive and depart. Depending on users' bidding, each SC allocates RBs to users. In Fig.3, we can see that allocated RBs to user-2 is zero from time slot 1 to 4 because user-2 is not in the system at that time. For user-3, the allocated RBs is also zero from time slot 1 to 3. In Fig.4, we can see RBs allocation result of SC2. We can see in fig.4 that allocated RBs to user-1 is zero from time slot 9 because user-1 leaves the system starting from time slot 9. For user-2, it leaves system at time slot 8.

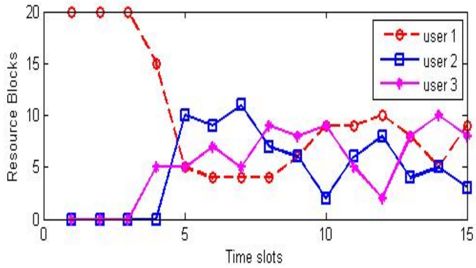


Fig.3. RBs Allocation in Small Cell 1

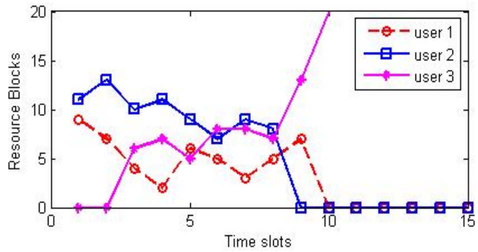


Fig.4. RBs Allocation in Small Cell 2

## 5. Conclusion

In this paper, we have discussed resource blocks allocation problem in wireless small cells networks. Then, we have developed an advanced auction technique to address our proposed RBs allocation problem and our objective is to maximize overall network capacity.

ACKNOWLEDGEMENT

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.

## REFERENCES

[1] R. madan, J. Borran, A. Sampath, N. Bhushan, A. Kandekar, and T. Ji, "Cell Association and Interference Coordination in Heterogeneous LTE-A Cellular Networks," *IEEE Journal of Selected Areas in Communication,* Vols. vol.28, no.9, pp. pp.1479-1489, Dec 2010.

[2] A. Damnjanovic, J.Montojo, Y. Wei, T.Ji, T.Luo, M. Vajapeyam, T.Yoo, O.Song, and D. Malladi, "A Survey on 3GPP Heterogeneous Networks," *IEEE Wireless Communication,* Vols. 18, no.3, pp. 10-21, Jan 2011.

[3] R. T. Ma, "Efficient Resource Allocation and Consolidation with Selfish Agents: An Adaptive Auction Approach," *IEEE 36th International Conference on Distributed Computing Systems,* 2016.