User Associations in Dense LTE HetNets

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Abstract

Small cells installation along with macro cells are a very promising prospect for meeting the future cellular network's or 5G goal. This installation is expected to be very dense due to the scale of users and high quality network requirements. User association based only on received signal strength indicator in such dense networks can limit the user and network throughput by associating to a heavily loaded tier of cell. We propose a user association scheme in which a user is associated to a cell tier depending on the highest achievable data rate thus maximizing the user throughput and network throughput. We formulate the user association problem as an optimization problem and then use stable matching theory to find a stable association. Simulation results reveal the convergence of our proposal in terms of rate and we provide comparison with the currently deployed received signal strength indicator association scheme.

I. Introduction

The explosion of cellular devices and bandwidth hungry modern applications over the cellular network has raised the cellular network requirement. Currently broadband services is provided by 4^{th}-Generation to around 50 million customers which will rise to two billion by 2018. The current cellular system in order to provide this high data rate requirement installs low power small cells along the currently deployed macro cell. This paradigm also known as Heterogeneous Network (HetNets) is the dominating and promising approach used by the network operators to meet the Quality of Service (QoS) for end users. As proposed for 5G the future cellular architecture will be a mix of dense small cells (SC) network (mix of micro, femto and pico cells) along with macro cells [1]. However, this installation of SC poses some new challenges which needs to be handled in order to maximize the benefit of deploying the SCs in the network.

In Hetnets and 5G architecture, user association will be one of the biggest challenge as users would receive multiple signals for associating to different base-stations (BSs) from different tiers (i.e., macro/pico/femto) as shown in figure 1 [2]. It is well known that associating to a heavily loaded tier can cause degradation in the performance and wastage of resources (for lightly loaded tier) from network point of view. Therefore, associating to the optimal tier among the available can significantly improve the overall network utility. In current practice, user are associated based on the received signal strength indicator (RSSI) values from base stations (BS) only which may result in associating to an overloaded BSs.

In this paper we address the downlink user association problem for HetNets from an optimization prospective.

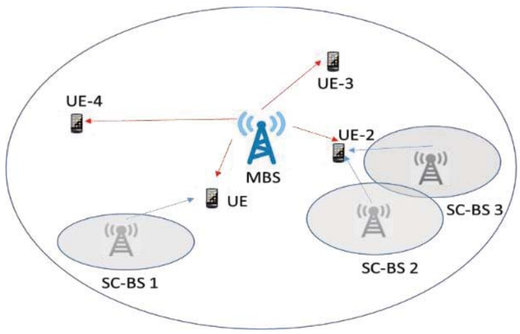

Fig.1. System model

Our aim is to maximize the utility for the complete network. User equipment (UE) will be associated to the respective macro base station (MBS) or any small cell base station (SC-BS) depending upon the highest achievable data rate instead of currently practiced RSSI values. This will give an opportunity to every user to maximize its data rate and will also maximize the overall network throughput. We in this work, suppose slowly changing transmit power (fixed power) from all the BSs during a timeslot. This problem is a combinatorial and NP-hard and a number of suboptimal solutions are presented in the literature to solve this problem. We use the concept of matching theory by developing a matching game for this problem [5].

The rest of the paper is organized as follows: Section II presents the network model and formulation of our problem and details the proposed user association scheme using matching theory. Numerical results are illustrated in section III. Finally, we conclude our work in section IV.

II. System model and Optimization Problem

We consider a downlink two-tier heterogeneous network with a MBS, a set P of SC-BS which belong to set J of BSs (macro and small cell), and K is the set of users randomly placed in the cell. We consider C which represents a set of channels available for communication between the UEs and the BSs.

Fig. 1 provides the details of the user association in a two-tier network scenario, where the large circle is the coverage area of macro cell, and small circles are the coverage areas of small cells. It can be observed that UEs can receive multiple signals if in coverage of multiple BSs (i.e. UE & UE2). In order to maximize the network utility, UEs can be associated to the BS which will provide them with the highest throughput rather than RSSI. In typical user association problem, each user also has a minimum rate requirement the threshold, which should be fulfilled by the associated BS. Let r_{kj}^{c} denote the data rate of user *k* connected to base station *j* on channel *c*. Similarly γ_{kj}^{c} represent the capacity of channel *c* for user *k* connected to BS *j* and is given by equation 1.

$$\gamma_j^c = W\log(1+SINR_j^c) \qquad (1)$$

Where *W* is the bandwidth available and $SINR_j^c$ is the received SINR on channel *c* for user *k* connected to base station *j*. Let x_{kj}^{c} be the binary variable to represent the association of user k with base station j. The typical user association optimization problem can be written as:

$$\begin{aligned}
&\max_{x_{kj}^c} . \sum_c \sum_k \sum_j x_{kj}^c \log(r_{kj}^c) \\
&s.t \sum_c \sum_j x_{kj}^c \log(r_{kj}^c) \ge \phi_{th}, \forall k, \\
&x_{kj}^c \in \{0,1\}, \forall k, \forall c, \\
&r_{kj}^c \le \gamma_j^c, \forall k, j, c.
\end{aligned} \qquad (2)$$

The first constraint guarantees that a user can be associated with the required rate threshold while the second constraint is the binary association indicator. This problem is known as a nonlinear and combinatorial and thus falls in the NP hard category which can have suboptimal solution [4]. In order to solve this combinatorial problem we use the concept of matching theory which can solve this problem in distributed manner. In order to solve the above problem we make a matching game and have two set of players i.e. users and BSs [5].

In user association the two set of players are the users and the BSs, both of the set of players make a preference profile to evaluate each other. The preference profile in our case is the rate function and given by the following equation:

$$U = W\log(1+\gamma_j^c), \qquad (3)$$

where U is the utility of users and according to which it ranks all the BSs. This is a many to one match as one BS can support many users and one user can only be associated to a BS. The process starts by each user I proposing to the most preferred BS along with the achievable rate. The BSs will collect all the rate information along with the proposal and rank each user according to maximum rate. The second consideration each BS needs to make is the quota information before allowing a user to associate. In summary, users will propose and BS will accept the proposal. Our problem which is a many to one matching problem can be solved by applying the well-known gale-shapely algorithm to [3]. The output would be the vector x which is the objective of the defined optimization problem (2).

III. Numerical Results

In order to validate our proposed scheme we compare our proposal with currently used RSSI scheme for user association.

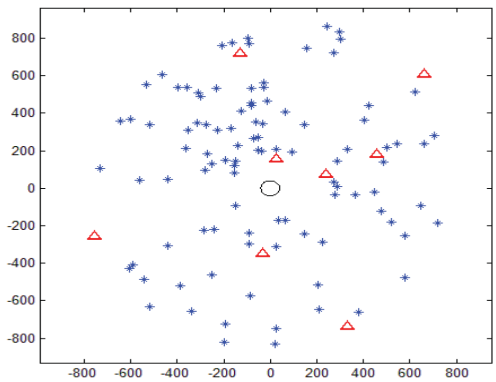

Fig.2. Simulation topology

The network topology for our simulations contains BSs and UEs which are randomly located inside a square area of 1 km × 1 km with the MBS at the center as shown in figure 2, where the circle represents the MBS, the red triangles present the SC-BSs and blue dots present the randomly distributed UEs in the network. Furthermore, we consider a total of eight SC-BSs distributed randomly and have a limited quota per BS, in our simulation we consider the quota of 10 UEs. We assume that the channel experience Rayleigh fading with propagation loss. The transmit power of the MBS and the SCBSs are assumed to be 40dBm and 25dBm, respectively. It is to ne noted that the results presented here are averaged over a large number of independent runs for different locations and channel gains. Figure 3 shows the performance of the proposed scheme when compared to the RSSI in terms of average utility with varying number of users in the system. The x-axis represent the number of users in the system while the y-axis represent the average utility (throughput). It can be inferred from the figure that the utility decreases as the number of users increase in the system. This is because of sharing of resources and quota limitation for each BS. Furthermore, it can be observed that a significant gain in average utility per user can be observed when compared to RSSI scheme, i.e. especially when users increase in the system.

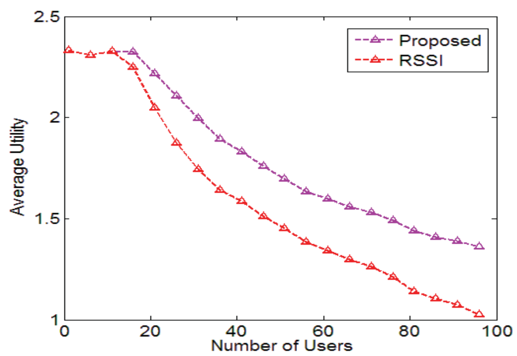

Fig.3. Average Utility per Users

Figure 4 shows the number of iterations for the proposed scheme to find a match when number of users in the system are varied. It is very evident as the number of UEs in the system increase the number of required iterations also increase. This trend will also be visible if the number of SC-BSs in the system increase but is not shown in the figure. The reason of increase in the iterations is due to the fact that the number of players to be matched are increasing. However it can be seen that the proposed user association technique converges in a finite number of iterations and thus has a reasonable convergence time.

IV. Conclusions

The deployment of small cells in the current cellular architecture leads to a higher network capacity but association of a user with optimum small cell can further improve the performance of the system in terms of user and network throughput. We in this work, propose a joint user association and rate control problem for hetnets which is solved using convex optimization techniques under fixed power received from all BSs. Our proposal will allow users to associate to the BS which will allow the maximum throughput for the user while maintaining proportional fairness among the users. Simulation results reveal the convergence in terms of user throughput which validates our preposition. In future, we intend to keep variable power levels for different BSs and would study the effect of user association.

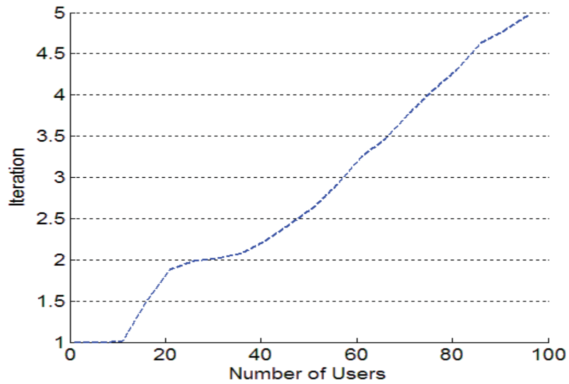

Fig.4. Average Utility per Users

Acknowledgement

This research was supported by Basic Science Research Program through National Research Foundation of Korea(NRF) funded by the Ministry of Education(NRF-2014R1A2A2A01005900). Dr. CS Hong is the corresponding author.

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