Joint User Association and Rate Control in LTE HetNets

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Abstract

Dense small cells along with macro cells will be a part of future cellular network architecture. User association based only on signal to interference noise ratio in such dense networks can limit the user and network throughput by associating to a heavily loaded tier of cell. We propose a joint user association and rate control scheme in which user is associated to a cell tier depending on the highest achievable data rate thus maximizing the user throughput while maintaining fairness among the users. We formulate the problem as a joint user association and rate control optimization problem but decompose the original problem and solve it using gradient method. Simulation results reveal the convergence of our proposal and proportional fairness among the users.

I. Introduction

Cellular traffic and number of connected devices have exploded in the last few years due to maturity (i.e. smart phones, novel modulation & coding schemes and etc.) and modern applications (e-banking, e-health, VoIP and etc.) availability. Currently 4th-Generation is providing broadband services to 50 million users around the globe and is expected to support two billion users by end of 2018. Similarly, the mobile traffic has increased 66 times from 2009 to 2014 with an annual rate of increase of 131 percent. In order to meet this high data rate requirement, low power small cells need to be installed with existing macro cells to enhance the capacity of cellular networks which is termed as heterogeneous networks (HetNets). This indicates that the future cellular architecture also proposed for 5G will be a mix of dense small cells (SC) network (mix of micro, femto and pico cells) under laid in a macro cell [1].

User association in Hetnets and 5G architecture [2][3][4] will be one of the biggest challenge as it would receive multiple signals for associating to different tiers (macro/pico/femto) as shown in figure 1. Associating to the optimal tier among the available can significantly improve the overall network utility. Currently, user association is done based on the received signal to interference noise ratio (SINR) value from base stations (BS) only which may result in associating to an overloaded BS.

This paper addresses the downlink user association problem for HetNets from an optimization prospective under fixed power and rate control. 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 received SINR 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 fixed power received from all the BSs, techniques such as cell biasing are available for realizing our supposition.

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

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.

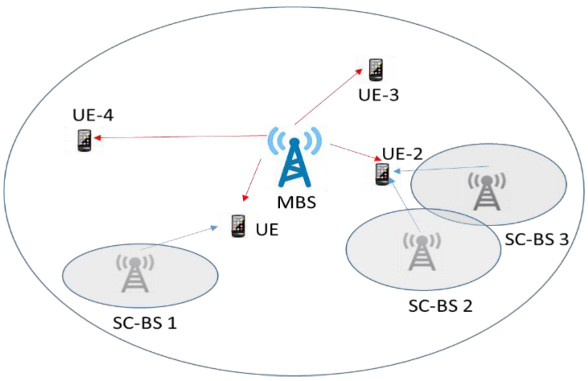

Fig.1. System model

We consider C which represents a set of channels available for communication between the UE and the BS.

Fig. 1 details the 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). We propose that these UEs can associate to the BS which will provide them with the highest throughput. The base station also considers the proportional fairness factor otherwise it can starve some users connected to the base station.

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.

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

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 joint user association and rate control optimization problem can be written as:

$$\begin{aligned} \max_{x,r}. \quad & \sum_c \sum_k \sum_j x_{kj}^c \log(r_{kj}^c) \\ \text{s.t.} \quad & \sum_c \sum_j x_{kj}^c \le 1, \forall k \\ & r_{kj}^c \le \gamma_j^c, \forall k, j, c \end{aligned} \quad (2)$$

The first constraint guarantees that a user can be associated to only one base station while the second constraint limits the data rate to the maximum available capacity on the channel which serves the rate control purpose.

III. Joint user association and rate control scheme

In order to find the solution we take the Lagrangian [4] of the above problem

$$L(\mathrm{x},\mathrm{r},\lambda,\upsilon) = \sum_c \sum_k \sum_j x_{kj}^c \log(r_{kj}^c) - \sum_k \lambda_k (\sum_c \sum_j x_{kj}^c - 1) - \sum_c \sum_k \sum_j \upsilon_{kj}^c (r_{kj}^c - \gamma_j^c) \quad (3)$$

Where λ_k and υ_{kj}^c are Lagrange multiplier corresponding to two constraints of the optimization problem. We decompose the problem in order to find the optimal solution. For a given transmission rate r_{kj}^c the association indicator can be obtained by

$$x_{kj}^c = \begin{cases} 1, & j = \arg\max_j (r_{kj}^c - \lambda_{kj}) \\ 0, & otherwise \end{cases} \quad (4)$$

The dual function corresponding to the Lagrangian for a given transmission rate r_{kj}^c

$$g(\lambda,\upsilon) = \inf_r L(\mathrm{x},\mathrm{r},\lambda,\upsilon) \quad (5)$$

The primal problem can be solved by solving the dual problem [4].

$$\begin{aligned} \max_{\lambda,\upsilon}. \quad & g(\lambda,\upsilon) \\ \text{s.t.} \quad & \upsilon_{kj}^c > 0, \lambda_k > 0, \forall k, j, c \end{aligned} \quad (6)$$

According to [4], an explicit expression of the dual function can be calculate using its conjugate function as

$$\mathrm{g}(\lambda,\upsilon) = \sum_c \sum_k \sum_j \upsilon_{kj}^c \gamma_j^c - \sum_k \lambda_k (\sum_c \sum_j x_{kj}^c - 1) + \inf_{r_{kj}^c} \sum_c \sum_k \sum_j (-\upsilon_{kj}^c r_{kj}^c + x_{kj}^c \log(r_{kj}^c)) \quad (7)$$

$$= \sum_c \sum_k \sum_j \upsilon_{kj}^c \gamma_j^c - \sum_k \lambda_k (\sum_c \sum_j x_{kj}^c - 1) - \sum_c \sum_k \sum_j \left(x_{kj}^c (1 - \log(x_{kj}^c) + x_{kj}^c \log(\upsilon_{kj}^c) \right) \quad (8)$$

where the conjugate function $U(n) = x\log(n)$ is $U^*(y) = x(1-\log(x)) + \mathrm{x}\log(\mathrm{y})$. We use the gradient based method to solve the dual problem. The direction of the multiplier υ_{kj}^c is given as

$$\Delta\upsilon_{kj}^c = \frac{\partial g(\upsilon)}{\partial \upsilon_{kj}^c} = \gamma_j^c - \frac{x_{kj}^c}{\upsilon_{kj}^c} \quad (9)$$

We can update the multiplier υ_{kj}^c along the direction as follows

$$\upsilon_{kj}^{c\,(t)} = \upsilon_{kj}^{c\,(t-1)} - \alpha^{(t)} \Delta\upsilon_{kj}^{c\,(t)} \quad (10)$$

Where α is the step size, and (t) is update iteration. The transmission rate can be obtained as follows:

$$\frac{\partial L}{\partial r_{kj}^c} = \frac{x_{kj}^c}{r_{kj}^c} - \upsilon_{kj}^c = 0 \quad (11)$$

$$r_{kj}^{c\ (t)} = \frac{x_{kj}^{c\ (t)}}{\upsilon_{kj}^{c\ (t)}} \quad (12)$$

The direction of the multiplier λ_k is as follows

$$\Delta\lambda_k = \frac{\partial g(\lambda)}{\partial \lambda_k} = \sum_c \sum_j x_{kj}^c - 1 \quad (13)$$

We can update the multiplier λ_k along the direction as follows

$$\lambda_k^{(t)} = \lambda_k^{(t-1)} - \alpha^{(t)} \Delta\lambda_k^{(t)} \quad (14)$$

We can update the association indicator as follows

$$x_{kj}^{c\ (t)} = \begin{cases} 1, & j = \arg\max_j (r_{kj}^{c\ (t)} - \lambda_k^{(t)}) \\ 0, & otherwise \end{cases} \quad (15)$$

IV. Numerical Results

In order to validate our scheme we show the convergence of throughput in the simulation setup. We keep the number of users $K = 100$ and number of Base stations $M = 10$ for our simulation setup. The step size is assumed to be $\alpha = 0.3$. The capacity of each BS is chosen randomly, from a uniform distribution on [0, 1].

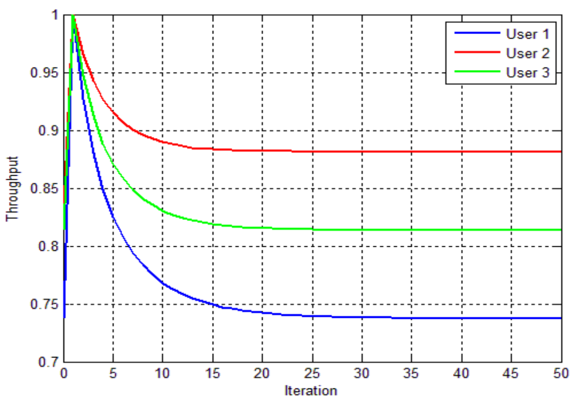

Fig.2. Convergence in throughput

Figure 2 shows the simulation result of the proposed scheme. The x-axis represent the number of iterations while the y-axis represent the throughput of each user. It can be inferred from the figure that after some iterations throughput of three different users have converged validating the convergence of all users. Secondly, user converge to their optimal throughput depending upon their channel capacity indicating proportional fairness among the users.

V. 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.

Acknowledgement

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