Downlink and Uplink Scheduling in Heterogeneous Small-cell Networks

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Abstract

The use of heterogeneous small cells in cellular networks increases the complexity of scheduling which constitutes interference mitigation, user association and resource allocation. These problems are formulated as an optimization and analyzed using a non-cooperative game. A log-linear learning based scheduling algorithm is then proposed to solve the game. Simulations results show that the proposed algorithm can effectively solve the scheduling problem.

1. Introduction

The demand for wireless data traffic has increased considerably in the past decade and is expected to continue to grow in the near future. However, mobile operator revenues are flattening due to saturated markets, flat-rate tariffs and competitive and regulatory pressure [1]. This decoupling of network traffic and operator revenue has led the mobile operators to increase the network efficiency in order to maximize their revenue. One viable solution is the deployment of multi-tier dense small cell base stations (SBSs) overlaid on the existing macro cells. Economically, deploying and operating SBSs cost only a small fraction of the macro base stations (MBSs) in terms of both CAPEX and OPEX.

2. System Model

Consider the downlink and uplink of a HetNet consisting of fixed BSs and randomly located UEs. In the downlink, transmitters (Tx's) are the set of BSs, B, and the receivers (Rx's) are the set of UEs, U. In the uplink, the Tx's are the set of UEs, U, and the Rx's are the set of BSs, B. Whether it is downlink or uplink, each Tx i has a limited power budget $\hat{P}_i$ which will be allocated to a number of subcarriers as follows:

$$\sum_{s\in S} P_{is} \le \hat{P}_i \ , \tag{1}$$

where $P_{is} \in \{0, (1/N^P)\hat{P}_i,\ (2/N^P)\hat{P}_i, \dots, \hat{P}_i\}$.

We consider a log-distance path loss model and the positive channel power gain between Tx i and Rx j which can be calculated as: $h_{ij} = 10^{-\xi/10}$. Let $T_{is}^I \subseteq T$ be the set of Tx's that interfere with Tx i on sub-carrier s. Then, the instantaneous signal-to-interference-plus-noise-ratio (SINR) received at Rx j from Tx i on sub-carrier s is given as:

$$\Gamma_{ijs} = \frac{h_{ij}P_{is}}{\sum_{m\in T_{is}^I} h_{mj}P_{ms} + WN_0} \ , \tag{2}$$

where W is the bandwidth of the sub-carrier and N_0 is the thermal noise spectral power. Accordingly, the achievable data rate from Tx i to Rx j on sub-carrier s is given by:

$$C_{ijs} = W\log_2(1+\Gamma_{ijs}) \ . \tag{3}$$

However, the resources are allocated via resource blocks (RBs) in a LTE frame in which $N^S = 12$ sub-carriers constitute a RB. Given a data rate demand ψ_{ij} between Tx i and Rx j, the number of required RBs can be calculated as:

$$N^S N_{ij}^R = \left\lceil \frac{\psi_{ij}}{C_{ijs}} \right\rceil = \sum_{r\in R} x_{ij} y_{is}, \forall i \in T, \forall j \in R, \tag{4}$$

where $x_{ij} \in \{0,1\}$ is the association variable, $y_{is} \in \{0,1\}$ is the allocation variable and $\lceil\cdot\rceil$ denotes the ceiling function. Since, a Rx can only successfully receive from only one Tx at any one time,

$$\sum_{i\in T} x_{ij} \le 1, \forall j \in R \ . \tag{5}$$

Depending on the interference levels between Tx's i and m, we define the sets of conflict and reuse Tx's for sub-carrier s as:

$$\forall i, m \in T, \forall j, n \in R, \forall s \in S, T_i^I = \{m\}, T_m^I = \{i\},$$

$$T^C = \{(i,m) | \min\{\Gamma_{ijs}, \Gamma_{mns}\} \le \tilde{\Gamma}\} \ , \tag{6}$$

$$T^R = \{(i,m) | \min\{\Gamma_{ijs}, \Gamma_{mns}\} > \tilde{\Gamma}\} \ , \tag{7}$$

where $\tilde{\Gamma}$ is the SINR threshold. T^C represents the set of Tx pairs that conflict with each other due to their high-interference links. T^R represents the set of Tx pairs that do not conflict with each other because of their low-interference links, and thus, they can reuse the same sub-carriers and RBs. Then, the interference constraints for resource allocation are:

$$x_{ij}y_{is} + x_{mn}y_{ms} \le 1, \forall (i,m) \in T^C, \forall s \in S, \tag{8}$$

$$x_{ij}y_{is} + x_{mn}y_{ms} \le 2, \forall (i,m) \in T^R, \forall s \in S. \tag{9}$$

3. Problem Formulation

Our downlink and uplink utility functions are given as:

$$D(P,x,y)=\sum_{u\in U}\sum_{b\in B}\sum_{s\in S}x_{bu}y_{bs}(C_{bus}-\lambda_b P_{bs}), \qquad (10)$$

$$U(P,x,y)=\sum_{u\in U}\sum_{b\in B}\sum_{s\in S}x_{ub}y_{us}(C_{ubs}-\lambda_s P_{us}). \qquad (11)$$

Given that there are Z available RBs in a LTE frame, the joint downlink and uplink utility function is given as:

$$F(P,x,y,\alpha)=\alpha Z\cdot D(P,x,y)+(1-\alpha)Z\cdot U(P,x,y) \qquad (12)$$

where $\alpha\in\{0,(1/Z),\ (2/Z),\dots,Z\}$. Then, the scheduling problem is then formulated as:

$$\begin{aligned}\text{max:}\quad & F(P,x,y,\alpha)\\ \text{s.t.}\quad & (1),\ (4),\ (5),\ (8),\ (9).\end{aligned} \qquad (13)$$

(13) is a NP-hard combinatorial optimization problem. Thus, we propose a game-theoretic approach.

Algorithm 1: Log-linear Scheduling Algorithm (LSA)

Let $\{U^p\times B^p\}\subseteq\{U\times B\}$ be set of participating UEs and BSs.
Initialization: $U^P\coloneqq U, B^P=B$, for each UE-BS pair $l\coloneqq(i,j)$,
  Measure pilot signals for each link l.
  Calculate # of RBs required using (4).
  Associate all UEs with MBS, $l_d=(1,j), l_u=(i,1)$.
  Assign $\alpha=0.5$.
  Calculate network utility using (12).
for $t\in\{1,2,\dots\}$, and $(i,j)\in\{U^p\times B^p\}$ **do**
  Exploration: If (i,j) did not explore in iteration t,
    With prob. ω, do
      Randomly choose $x_i\in X_i$ that satisfy (5).
      Allocate RBs that satisfy (4)(8)(9)
      Calculate network utility using (12).
    With prob. $(1-\omega)$, repeat previous configuration.
  Exploitation: If (i,j) explored in iteration t,
    Calculate $q_{f(t-1)\to f(t)}$ using (15).
    Choose either $f(t-1)$ or $f(t)$ as follows:
      $f(t+1)=f(t)$ with prob. $v_{f(t-1)\to f(t)}$.
      $f(t+1)=f(t-1)$ with prob. $1-v_{f(t-1)\to f(t)}$.
  Updates resource usage matrix, Υ.

$$\alpha(t+1)=\left\lceil\frac{D}{(D+U)}\right\rceil\cdot\frac{1}{Z}.$$

end for

4. Game Theoretic Model

(13) can be modeled by a non-cooperative, strategic game, defined as follow:

$$G=\left(\{U\times B\},\{X_i,Y_j\}_{i\in U,j\in B},\{V_{ij}\}_{i\in U,j\in B}\right) \qquad (14)$$

where $X_i=\{x_i^1,x_i^2,\dots,x_i^{N_x}\}$ and $Y_j=\left\{y_j^1,y_j^2,\dots,y_j^{N_y}\right\}$. We can employ log-learning [2] with exploration rate ω and the exploitation rate, $v_{f(t-1)\to f(t)}$ as given by

$$v_{f(t-1)\to f(t)}=\frac{\exp(\beta F_{f(t-1)})}{\exp(\beta F_{f(t-1)})+\exp(\beta F_{f(t)})} \qquad (15)$$

where $F_{f(t)}$ and $F_{f(t-1)}$ represent the joint utility functions with network configuration $f(t)$ and $f(t-1)$ at time t and $(t-1)$, respectively. The scheduling algorithm is given in Algorithm 1.

5. Simulation Results

Simulation results depict the LSA outperforms other schemes in scheduling. Figure (1) shows the total cost of the network.

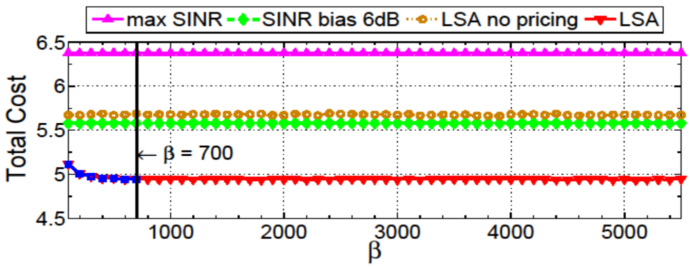

Fig.(1) Total cost versus β, $|U|=100, |B|=20$, $\lambda=1000$.

6. Conclusion

In this paper, we discussed about the downlink and uplink scheduling in heterogeneous small-cell networks. We formulate the scheduling as an optimization and provide an equivalent game formulation. Then we employ a log-linear learning to propose a scheduling algorithm. Simulation results show that our proposed algorithm outperforms other schemes in terms of total cost incurred.

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References

[1] B. Molleryd, J. Markendahl, J. Werding and O. Makitalo, "Decoupling of revenues and traffic – is there a renenue gap for mobile broadband?," in *9th Conference on Telecommunications Internet and Media Techno Economics*, Ghent, Belgium, 2010.

[2] J. Marden and J. Shamma, "Revisiting log-linear learning: Asynchrony, completeness and payoff-based implementation," in *48th Annual Allerton Converence on Communication, Control, and Computing*, Monticello, IL, Sepetember 2010.