Distributed Resource Allocation For Spatially Distributed Irregular Cells

Hashim Safdar, Norsheila bt Fisal, Rahat Ullah
UTM-MIMOS, Centre of Excellence for Telecommunication Technology
Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM)
Johor Bahru 81310, Malaysia
Email: eng.hashim.s@ieee.org, sheila@fke.utm.my, eng.rahat.u@ieee.org

Abstract— **It is expected that the number of mobile users will increase rapidly in the coming future for uplink communication. Therefore, the future cellular network should accommodate large number of these mobile users and their resource allocation. The frequency reuse concept being used massively to overcome this resource constraint issue. The massive reuse of frequency creates serious interference problem. To overcome the interference issue from frequency reuse, the fractional frequency reuse concept has introduced for hexagonal/regular cells and recently for irregular cells with sectoring. The problem of resource allocation for the irregular cell edge users is critical due to not fixed cell size and location which dramatically reduce the spectrum efficiency of the system. The proposed scheme provides a new way to analyze the resource allocation by spatially partitioning a cell edge coverage into multiple regions with different dynamic resource distribution for cell edge users. The noncooperative game for subcarrier allocation is considered aiming at maximizing the cell edge users throughput and error free transmission by reducing the impact of interference to and from neighboring cells. This proposed scheme enhances the system performance by reducing improved data rate.**

Keywords— Resource allocation, Game theory, OFDMA, Voronoi Cells

I. Introduction

Resource allocation is one of the important part of the wireless network. Indeed, through an intelligent design of resource allocation schemes the performance of a wireless network may be enhanced to a relevant parameters such as data rate, the transmission power, the accommodated users and many more. The resource allocation issue is crucial when the consideration is the uplink, where the uplink transmitting devices are the battery powered mobile user.

Due to the limitation of the wireless spectrum and increasing demand for resources (i.e. capacity), the frequency reuse is only the suitable solution which will enhance the spectrum efficieny and network capacity at the price of interference [1]. Handling the substantial impact of interference from the neighboring cell is one of the major issue, especially the user located at the cell boundaries [2] in the multicell cellular network. For networks utilizing Orthogonal Frequency Division Multiple Access (OFDMA), inter-cell interference coordination (ICIC) resource allocation strategies have been proposed to balance interference management with spectral enhancement [3]. To get overall best performance in terms of capacity can be possible only by reusing same frequeny in all cells (reuse factor = 1)[4]. Fractional Frequency Reuse (FFR) is an attractinve ICIC technique that falls between full-reuse and conventional frequency reuse techniques with a goal of optimizing cell edge user SINR through interference reduction while maximizing overall spectral efficiency [5, 6]. In literature, most of the work done for hexagonal cell geometry while very little work is done for irregular cell geometry. The network cell geometry has a great impact on defining the best frequency reuse factor [7]. In the irregular cell geometry the number of interfering cells and amount of interference varies from cell to cell [8]. Therefore, cell edges and their user are in different conditions due to edge region size, number of users and their SINR [7]. In the enhancement of FFR-3 scheme for regular cells, sectroing in irregular cell geometry is proposed, which gave better results in comparing to regular or hexagonal cell geometry in terms of capacity and capacity density [9].

The primary challenge in uplink celluar arises from the interdependence between mobile and base station locations, transmit powers, and the resulting interference distribution [2]. In our proposed work which is the further enahancement of [9] in terms of uplink resources allocation and spatial distribution of the cell edge region into multiple regions based on SINR to avoid ICI from users to BSs.

Recently, there have been substantial research works that applies game theory for the analysis of resource allocation in wireless communication networks. This is basically due to the need for distributed mobile networks where mobile user can make independent and rational strategic decision [11]. Resource allocation in terms of capacity enhancement by subcarrier allocation and power allocation has done with cooperative game [12] and non cooperative game [13].

In this paper, we modeled a single tier network with number of uniformly distributed mobile user attached with a base station (BS) in uplink. Each BS builds a coverage based on voronoi tessellation, as shown in Figure.1. Furthermore, the cell edge user further distributed into two spatial region based on SINR threshold. Subchannels are allocated based on the coverage of these levels. Higher the coverage will get more subchannels. We are emphasizing on to reduce the regions to get overall improved system performance. The model is evaluated under noncooperative game theory techniques to enhance average resource allocation by carefully adjust their strategies to avoid interference for and from neighboring cells.

The rest of the paper is divided into following sections: Section II gives the system model and game theoretic model. Section III gives the proposed scheme with problem formulation and solution. Section IV gives the Numerical Result and discussion. Section V concludes the paper with future work.

II. Preliminaries and System Model

A. System Model

The complete network model is shown in Fig. 1. Assume that the subchannels, $\mathcal{N} = \{1, 2, \ldots, N\}$ which consists of N number of orthogonal sub-channels. The channel quality is denoted by $h_i^{(l)}$ from mobile users to BS. The channel quality set for BS $h_i = \{h_i^{(1)}, h_i^{(2)}, h_i^{(3)}, h_i^{(4)}, \ldots . h_i^{(N)}\}$. The distance between transmitter and the receiver, attenuation, random fading effect and antenna gain change the channel quality. Furthermore, the transmit power of a mobile user $i, j \epsilon K$ where i belongs to desired signal and j belongs to interfering signal on a l-th sub-channel to be p_i^l and total transmit power is p_t. The transmit power vector of machines is defined by, $\mathcal{P}_i \triangleq \{p_i^{(1)}, p_i^{(2)}, p_i^{(3)}, p_i^{(4)}, \ldots . p_i^{(N)}\}$ where $\sum_{l \,\epsilon\, N} p_i^{(l)} \leq p_t,\ 0 \leq p_i^{(l)}$.

Thus, the channel quality to noise plus interference ratio (SINR) at BS on sub-channel l is given as:

$$SINR_i^{(l)} = \frac{p_i^{(l)}, h_i^{(l)}}{n + \sum_{j \in K} h_j^{(l)}, p_j^{(l)}} \tag{1}$$

The data rate of each mobile user to respective BS.

$$r_i = B \log_2(1 + SINR_i^{(l)}) \tag{2}$$

perfect channel state information (CSI) is estimated by dedicated transmitters with static in mobility and channel quality is invariant [14].

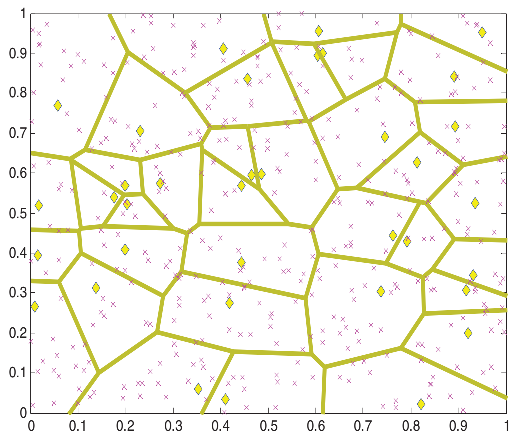

Fig.1. Irregular cells with uniformly distributed mobile users and randomly distributed BS.

B. Game theoretic Model:

In game theory, a game Γ can be defined as triplet, $\Gamma = \{\mathcal{K}, \{S_i\}_{i \in \mathcal{K}}, \{u_i\}_{i \in \mathcal{K}}\}$, where $\mathcal{K}$ is a set of players (mobile users), S_i is a set of all strategies (i.e set of actions based on the parameters taken by the competing players), u_i is the utility function of the competing player; u_i is the scalar quantity, to be maximized based on the strategies or action taken by all players of the game.

Thus, a change in strategy from one player directly affects the strategies of all other player, and initiates a dynamic process, in which each player interatively update its own strategies in response to the strategies of the other players. This process is normally called as a best response dynamics, since in each iteration, given the strategies of the other players, each player responds by choosing the strategy that maximizes its own utility function.

III. Proposed Spatial Resource Allocation Scheme

The proposed spatial resource allocation scheme (SRAS) overcomes the problem of low data rate of cell edge users by limiting the users near to cell boundary to interfere with neighboring cells. The existing network model is shown in Fig. 2 and Fig. 3 illustrates a cell model for the proposed scheme. In this proposed model, the irregular cell area with the precalculated boundaries either cell center or cell edge based on SINR. As SINR is the best measure of the distance between user and he serving BS [15] therefore, we have considered average received SINR to classify the cell center and cell edge users.

Furthermore, these regions are partitioned into multiple spatial L SINR regions as shown in Figure-3. SINR is the only solution to classify them either the region is near to cell centre or cell boundary. Overall improvement in the system data rate is required on which the regions are distributed in multiple regions.

A. Problem Formulation

It is assumed that the total number of subchannels N_T allocated to a cell and the same channels are also allocated to the neighboring cells. Its is known that cell has two major parts [5] such as cell centre region and cell edge region. The realization of these regions are based on average SINR received levels from the number of uplink mobile users Respectively the subchannels allocated to these regions are N_c and N_e as shown in Fig. 2(a).

$$N_T = N_c + N_e \tag{3}$$

Furthermore, sectoring further distributes the cell edge region into three parts as shown in Fig. 2(b) and respectively the resource allocated to these regions are,

$$N_e \geq N_{e_1} + N_{e_2} + N_{e_3} \tag{4}$$

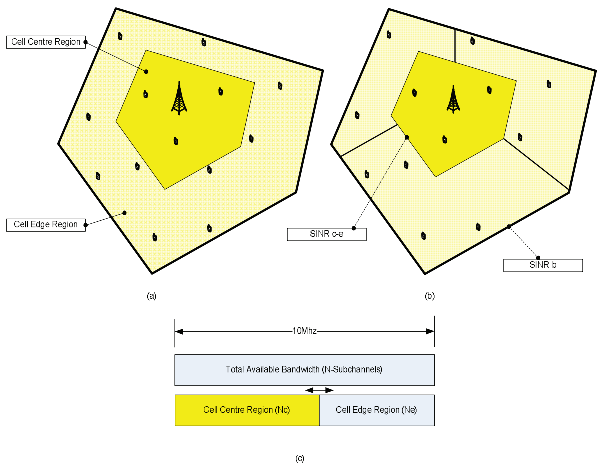

Fig.2. (a) Irregular cell with cell edge and cell centre region (b) Sectoring (c) bandwidth distribution.

In our proposed model as shown in Fig. 3(a), each sector further distributed into two dynamic regions based on users and their SINR. This new spatial boundary situated in between cell centre boundary and cell edge boundary where the SINR threshold values for these boundaries are $SINR_{c\text{-}e}$ and $SINR_b$ respectively. The SINR threshold level of the new spatial boundary is $SINR_a$. The allocated subchannels for these two new regions in each sectors are shown in Eq. 5-7

$$N_{e_1} \geq N_{e_{1a}} + N_{e_{1b}} \tag{5}$$

$$N_{e_2} \geq N_{e_{2a}} + N_{e_{2b}} \tag{6}$$

$$N_{e_3} \geq N_{e_{3a}} + N_{e_{3b}} \tag{7}$$

For all cell edge sectors and their spatial distributed region, the subchannel allocated as per their SINR threshold level, where

$$N_{e_a} \propto SINR_a \tag{8}$$

and

$$N_{e_b} \propto SINR_b \tag{9}$$

If both threshold levels are the same

$$SINR_a = SINR_b$$

then the subchannels of the two regions merged to a single region

$$N_{e_a} + N_{e_b} = N_{e_1} = N_{e_2} = N_{e3} \tag{8}$$

The achievable data rate in this region near to cell boundary based on the number of users and available subchannels.

$$r_{ie_b} = \sum\nolimits_{l\,\in\mathcal{N}} \frac{BW}{N_{e_b}} \log_2(1 + \frac{h_{ie}^{(l)} p_i^{(l)}}{n + \sum_{j\epsilon K} h_j^{(l)} p_j^{(l)}}) \tag{9}$$

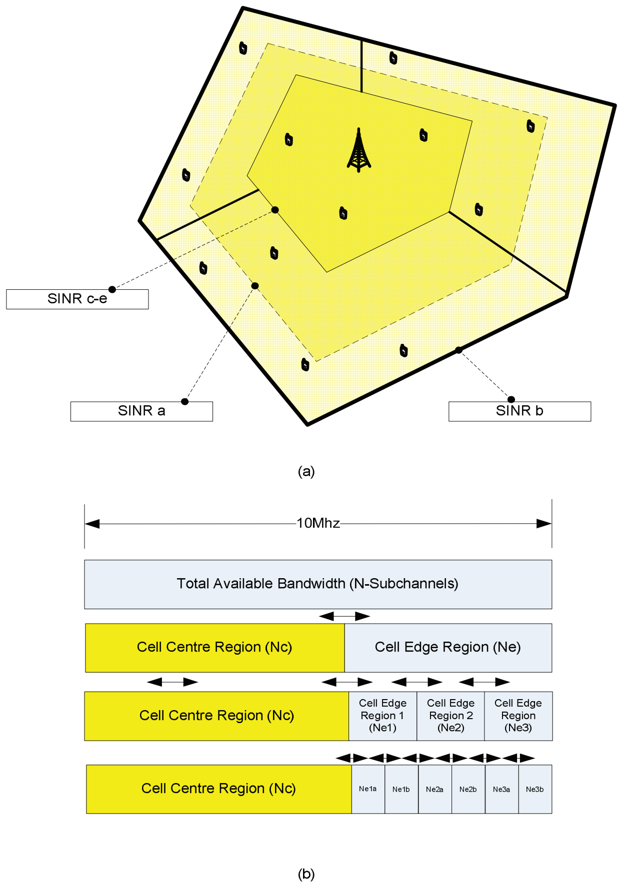

Fig.3. (a) Proposed model with Spatial distributed regions (b) bandwidth distribution for each region.

B. Proposed Game theoretic

1) Subchannel allocation for data rate maximization:

Each mobile user is distributed like to maximize its data rate (utility), assuming for the moment, that the transmit powers are arbitrary and fixed. In particular, each mobile user may transmit on the available subchannels based on the region in with a fixed power. We are going to discuss, each mobile user only transmits on its chosen subchannels and transmit power on the remaining subchannels will be zero. We formulate a game theoretic framework for this system in order to provide a clear representation of interaction among players. Strategic noncooperative game for noncooperative mobile users in the network is given as:

Elements of the game Γ, are given as:

- $\mathcal{K} = \{1, 2, \ldots., K\}$ is a set of mobile user as players.
- A set of actions, denoted by S_i is action space for all machines $i \in \mathcal{K}$. Where the joint strategy profile, $\prod_{i=1}^{\mathcal{K}} S_{\mathcal{K}}$.
- Payoff/utility functions for mobile user, denoted by $u_i: S_{\mathcal{K}} \rightarrow R$, corresponding to their actions

The mobile user selected actions, $s_i = (a_i, p_i) \in S_i$ is a composite strategy consisting:

where, $s_i \neq s_i'$ and $s_{-i} = \{s_1, s_2, s_3, \ldots, s_{i-1}, s_{i+1}, \ldots s_{\mathcal{K}}\}$

1. Sub-channel assignment matrix.
2. $a_i = \{a_i^{(1)}, a_i^{(2)}, \ldots a_i^{(N)}\}$, where $a_i^{(l)} \in \{0,1\} \forall \mathcal{N}$.
3. Power allocation vector, $\mathcal{P}_i \triangleq \{p_i^{(1)}, p_i^{(2)}, \ldots p_i^{(N)}\}$, where $p_i^l = \{0, P_t\}$.

The utility of every mobile user under different cell region choosing action s_i can be given as,

$$u_i(s_i, s_{-i}) = \sum_{l \in \mathcal{N}} \frac{BW}{N s_i} \log_2 \left(1 + \frac{a_i^{(l)} h_i^{(l)} p_i^{(l)}}{n + \sum_{j \epsilon K} g_j^{(l)} p_j^{(l)}}\right) \quad (10)$$

Hence, as every player would selfishly maximize its own utility while we desire maximal social utility, the problem can be formulated as follow:

$$max \quad u_i(s_i, s_{-i}) \quad , \forall i \in \mathcal{K} \quad (12)$$

subject to

$$\sum_{n \in N} p_i^{(n)} \leq P_{max}$$

$$p_i^{(n)} \geq 0, \forall i \in K, l \in N$$

2) Definition: (Nash Equilibrium).

For the game Γ, the action profile $s = \{s_1, s_2, s_3, \ldots, s_K\}$ is an Nash Equilibrium for all players $i \in K$ if and only if,

$$u_i(s_i, s_{-i}) \geq u_i(s_i', s_{-i}), \forall\ i\ \in \mathcal{K} \quad (13)$$

The above definition indicates that no mobile user can improve utility by a unilateral deviation from current actions. This implies that all other mobile user's actions do not change at NE thus convergence is achieved.

IV. Results and Discussion

We evaluate the performance of our proposed scheme by allocating a number of subchannels. In the result Fig. 4 displays the social welfare during convergence. It shows that as the number of player increase in the cell edge region which is closer to the cell edge boundry, social welfare (utility) slowly degraded and overall performance of the each player. However, an increasing number of shared subchannels, it exhibits no apparent distinction in terms of degradation magnitude as the number of players increase. The result is evaluated for $N = 32, 48, 64$ *and* 80.

Next, we made a closer look at the individual utility of each player in a game. As shown in Fig. 5, the individual data rates are compared with one of the known Nash Equilibrium (NE). This NE is where all of the player transmitted on every allocated subchannel of the cell edge region. This is infact an NE because no player has the incentive to unilaterly deviate from this allocation[16]. It is observed in the result that some of players do not mind on reducing their data rate during the iteration.

Overall network performance is shown in Fig. 6, in which our proposed scheme totally outperforms soft frequency reuse (SFR) and partially outperforms FFR-3 scheme in terms of achievable data rate.

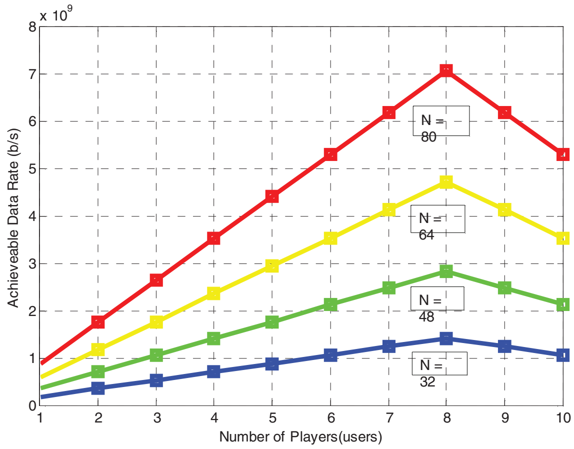

Fig.4. Sum rate for multiple players and different subchannels

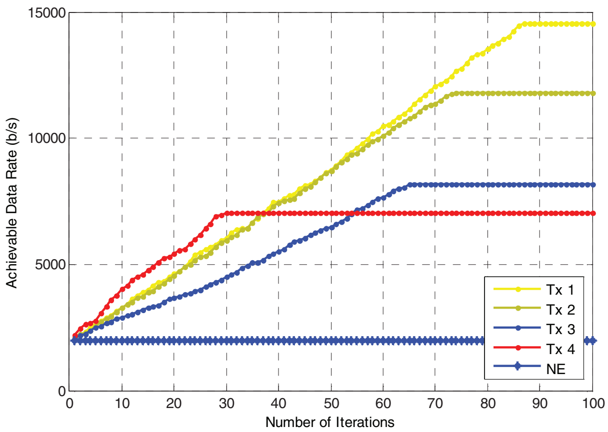

Fig.5. Individual data rate for players and NE.

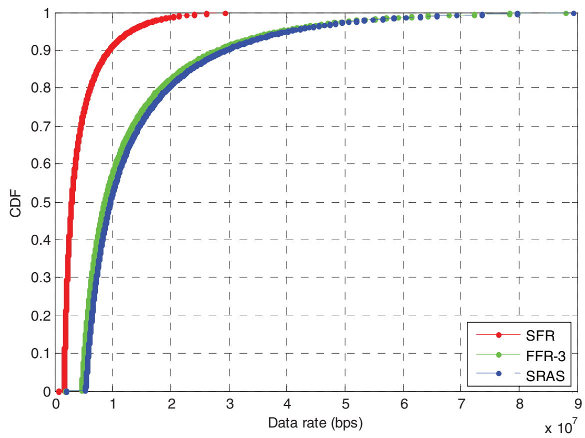

Fig.6. Data rate comparison of proposed scheme with FFR-3 and SFR.

V. Conclusion and Future Work

Our proposed scheme helps to enhance average data rate of the user by distribute them into multiple spatial regions based on SINR. This technique helps to reduce the interference for the user located at the cell edge. Interference from the neighboring cell will be affected only the limited portion of the cell edge region instead of full region and overall system performance enhanced. This scheme can be further enhanced by power controlling strategies of each user. This scheme can extend for heterogeneous network by changing SINR threshold value of different region to avoid intercell and itracell interference.

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References

[1] H. ElSawy, E. Hossain, and M. Haenggi, "Stochastic geometry for modeling, analysis, and design of multi-tier and cognitive cellular wireless networks: A survey," *Communications Surveys & Tutorials, IEEE,* vol. 15, pp. 996-1019, 2013.

[2] T. D. Novlan and J. G. Andrews, "Analytical evaluation of uplink fractional frequency reuse," *Communications, IEEE Transactions on,* vol. 61, pp. 2098-2108, 2013.

[3] G. Boudreau, J. Panicker, N. Guo, R. Chang, N. Wang, and S. Vrzic, "Interference coordination and cancellation for 4G networks," *Communications Magazine, IEEE,* vol. 47, pp. 74-81, 2009.

[4] L. Chen and D. Yuan, "Generalizing and optimizing fractional frequency reuse in broadband cellular radio access networks," *EURASIP Journal on Wireless Communications and Networking,* vol. 2012, pp. 1-15, 2012.

[5] N. Saquib, E. Hossain, and D. I. Kim, "Fractional frequency reuse for interference management in LTE-Advanced HetNets," *Wireless Communications, IEEE,* vol. 20, pp. 113-122, 2013.

[6] N. Saquib, E. Hossain, L. B. Le, and D. I. Kim, "Interference management in OFDMA femtocell networks: Issues and approaches," *Wireless Communications, IEEE,* vol. 19, pp. 86-95, 2012.

[7] D. G. Gonzalez, M. Garcia-Lozano, S. Ruiz Boque, and D. S. Lee, "Optimization of soft frequency reuse for irregular LTE macrocellular networks," *Wireless Communications, IEEE Transactions on,* vol. 12, pp. 2410-2423, 2013.

[8] L. Chen and D. Yuan, "Soft frequency reuse in large networks with irregular cell pattern: How much gain to expect?," in *Personal, Indoor and Mobile Radio Communications, 2009 IEEE 20th International Symposium on*, 2009, pp. 1467-1471.

[9] R. Ullah, N. Fisal, H. Safdar, W. Maqbool, and Z. Khalid, "Interference management for irregular cell geometry heterogeneous networks," in *Communications (MICC), 2013 IEEE Malaysia International Conference on*, 2013, pp. 523-527.

[10] H. Jang, S. Kim, K. Ko, J. Cha, and D. Sung, "Spatial Group Based Random Access for M2M Communications."

[11] S. M. Alavi and C. Zhou, "Resource allocation scheme for orthogonal frequency division multiple access networks based on cooperative game theory," *International Journal of Communication Systems,* 2012.

[12] H. Safdar, N. Fisal, R. Ullah, W. Maqbool, and Z. Khalid, "Resource allocation for uplink M2M communication in multi-tier network," in *Communications (MICC), 2013 IEEE Malaysia International Conference on*, 2013, pp. 538-543.

[13] S. Buzzi, G. Colavolpe, D. Saturnino, and A. Zappone, "Potential games for energy-efficient power control and subcarrier allocation in uplink multicell OFDMA systems," *Selected Topics in Signal Processing, IEEE Journal of,* vol. 6, pp. 89-103, 2012.

[14] K. Lee, O. Jo, and D.-H. Cho, "Cooperative resource allocation for guaranteeing intercell fairness in femtocell networks," *Communications Letters, IEEE,* vol. 15, pp. 214-216, 2011.

[15] J. G. Andrews, F. Baccelli, and R. K. Ganti, "A tractable approach to coverage and rate in cellular networks," *Communications, IEEE Transactions on,* vol. 59, pp. 3122-3134, 2011.

[16] L. Rose, S. M. Perlaza, and M. Debbah, "On the Nash equilibria in decentralized parallel interference channels," in *Communications Workshops (ICC), 2011 IEEE International Conference on*, 2011, pp. 1-6.