ComEX

IEICE Communications Express, Vol.5, No.8, 248–253

A dynamic distributed frequency reuse scheme for OFDMA downlink cellular networks

Mohamed Elwekeil[1,3a)], **Masoud Alghoniemy**[2], **Osamu Muta**[3], **Adel Abdel-Rahman**[1], **Haris Gacanin**[4], **and Hiroshi Furukawa**[5]

[1] *Electronics and Communications Engineering Department, Egypt-Japan University of Science and Technology (E-JUST), Borg El-Arab, Alexandria, Egypt*

[2] *Department of Electrical Engineering, University of Alexandria, Egypt*

[3] *Center for Japan-Egypt Cooperations in Science and Technology, Kyushu University, Fukuoka-shi, Fukuoka, Japan*

[4] *Customer Experience Management Applications and Analytics, Nokia, Antwerp, Belgium*

[5] *Graduate School of Information Science and Electrical Engineering, Kyushu University, Fukuoka-shi, Fukuoka, Japan*

a) *mohamed.elwekeil@ejust.edu.eg*

Abstract: In this paper, a distributed algorithm for dynamic frequency reuse scheme in OFDMA downlink cellular networks is proposed. Each cell is divided into two regions, namely, inner and outer regions. The proposed distributed algorithm is based on minimizing the total interference at all users in each region. Unlike other fractional frequency reuse (FFR) schemes, the main advantage of the proposed algorithm is that it adapts to the network channel conditions. Simulation results show that the proposed algorithm provides better performance than that of FFR, in terms of both total system throughput and average user bit-rate.

Keywords: inter-cell interference coordination, frequency reuse

Classification: Wireless Communication Technologies

References

[1] M. Assaad, "Optimal fractional frequency reuse (FFR) in multicellular OFDMA system," 2008 IEEE 68th Vehicular Technology Conference. VTC 2008-Fall, pp. 1–5, 2008. DOI:10.1109/VETECF.2008.381

[2] T. Novlan, J. G. Andrews, I. Sohn, R. K. Ganti, and A. Ghosh, "Comparison of fractional frequency reuse approaches in the OFDMA cellular downlink," 2010 IEEE Global Telecommunications Conference (GLOBECOM 2010), pp. 1–5, 2010. DOI:10.1109/GLOCOM.2010.5683973

[3] N. U. Hassan and M. Assaad, "Optimal fractional frequency reuse (FFR) and resource allocation in multiuser OFDMA system," International Conference on Information and Communication Technologies, 2009. ICICT'09, pp. 88–92, 2009. DOI:10.1109/ICICT.2009.5267207

DOI: 10.1587/comex.2016XBL0080
Received April 12, 2016
Accepted May 10, 2016
Publicized May 24, 2016
Copyedited August 1, 2016

[4] R. Y. Chang, Z. Tao, J. Zhang, and C. C. J. Kuo, "A graph approach to dynamic fractional frequency reuse (FFR) in multi-cell OFDMA networks," Proc. of IEEE International Conference on Communications (ICC 2009), Dresden, Germany, pp. 1–6, (2009). DOI:10.1109/ICC.2009.5198612

[5] O. G. Aliu, M. Mehta, M. A. Imran, A. Karandikar, and B. Evans, "A new cellular-automata-based fractional frequency reuse scheme," *IEEE Trans. Veh. Technol.*, vol. 64, no. 4, pp. 1535–1547, 2015. DOI:10.1109/TVT.2014.2330601

[6] I. WP5D, "Guidelines for evaluation of radio interface technologies for IMT-Advanced," Document 5D/TEMP/99-E, Tech. Rep., 2008.

1 Introduction

Orthogonal frequency division multiple access (OFDMA) has been widely utilized for cellular network systems such as LTE-Advanced, where orthogonal resource blocks (RBs) in each cell are utilized by users within the cell. However, because of scarcity of available spectrum and to achieve high spectral efficiency, RBs have to be reused by neighboring cells; this causes inter-cell-interference (ICI) which impacts users' data rates. Therefore, ICI coordination (ICIC) in cellular networks is crucial.

FFR is one of the most effective schemes for ICIC, where the cell is divided into two regions, namely, the inner-region where frequency reuse one is utilized, i.e., all inner-regions of all cells use the same frequency resources, and the outer-region where higher frequency reuse is adopted, i.e., outer-regions of neighboring cells cannot use same frequency resources [1]. The results in [1] show that the optimal radius of the inner-region is about 0.63 of the cell radius. The authors in [2] evaluated the two major forms of FFR schemes, namely, strict-FFR, where users in inner-region do not share any RBs with outer-region users; and Soft-frequency-reuse (SFR), where inner-region and outer-region users can share RBs. They concluded that strict-FFR exhibits better performance than SFR in terms of overall network throughput and cell outer-region users signal-to-interference-plus-noise power ratio (SINR). In [3], an attempt to determine optimal FFR is proposed where the objective is to minimize the total power subject to minimum rate constraints. Both [1] and [3] declare that the optimal frequency reuse factor for outer-region is three (FFR-3). However, FFR is a static scheme which does not consider the varying nature of both wireless channel and traffic load. Moreover, FFR overstates the interest in cell outer-region users' performance at the price of the corresponding cell inner-region users' performance.

There are some dynamic FFR schemes proposed in the literature, e.g., [4] and [5]. In [4], the authors proposed a graph approach for dynamic FFR in OFDMA networks; however, their algorithm cannot outperform strict-FFR in equal cell-load scenario. The authors in [5] presented a dynamic distributed FFR scheme by employing cellular automata. While their proposed algorithm has better performance than the SFR, it failed in providing significant improvement over strict-FFR.

The contribution of this paper lies in presenting a distributed algorithm for dynamic frequency reuse for the downlink of OFDMA cellular systems, exploiting

DOI: 10.1587/comex.2016XBL0080
Received April 12, 2016
Accepted May 10, 2016
Publicized May 24, 2016
Copyedited August 1, 2016

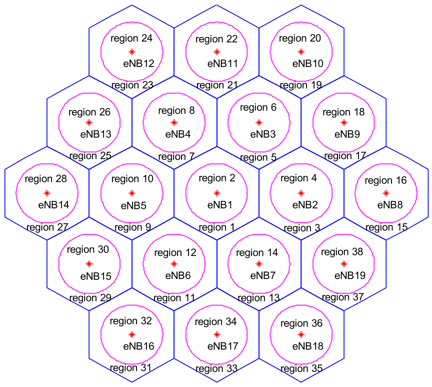


Fig. 1. Dividing each cell into 2 regions: An example of 19 cells.

the varying nature of the wireless channel; where every evolved NodeB (eNB) selects sub-bands that minimize the total interference for both cell inner- and outer-regions without restricting any sub-band to the inner-region. To the best of our knowledge, the above points have not been taken into consideration in either conventional or dynamic FFR schemes [1, 2, 3, 4, 5]. In this paper, we concentrate on the equal cell-load scenario, where other algorithms in the literature failed to provide any significant throughput improvement compared to strict-FFR-3 [1, 2, 3, 4, 5]. The proposed algorithm provides better performance compared to strict-FFR-3 in terms of average user bit-rate and total system throughput even in equal cell-load scenarios.

2 The proposed dynamic distributed algorithm

We consider the downlink of an OFDMA cellular system. The proposed algorithm depends on minimizing the total interference of all users in every region in the network. By reducing total interference in any region, users' data rates improve. Particularly, consider a cellular system that consists of L cells, where each cell is divided into inner- and outer-region as shown in Fig. 1. Thus, the total number of regions is $M = 2L$. Without loss of generality, we adopt LTE definition of resource block (RB) which consists of 12 sub-carriers. Moreover, we assume that the available resources are divided into four sub-bands, $SB \in \{1, 2, 3, 4\}$, i.e., every sub-band consists of a number of RBs. All users in region i share the RBs of SB_i. In contrast to classical FFR, the proposed algorithm does not restrict any of the sub-bands to the inner-regions. Our target is to dynamically assign a sub-band to each region in the network such that total interference in each region is minimized. In this context, we define co-channel interference factor, ρ_{ij}, between region i and region j as an indicator whether there is mutual interference among regions i and j, namely,

$$\rho_{ij} = \begin{cases} 1, & if\ SB_i = SB_j \\ 0, & otherwise \end{cases}, \tag{1}$$

where SB_i and SB_j are sub-bands assigned to regions i and j, respectively.

Suppose that the total transmit power of every eNB is Pt. We assume that every eNB fully utilizes the available power to achieve the maximum possible cell data rate. Moreover, for the sake of fairness, we assume that every user occupies only

DOI: 10.1587/comex.2016XBL0080
Received April 12, 2016
Accepted May 10, 2016
Publicized May 24, 2016
Copyedited August 1, 2016

one RB at a time and the eNB distributes its power equally to all users in the corresponding cell. We assume that all cells are equally loaded by the same number of users. If number of users per cell is N_u, the power transmitted for every user in this cell equals $\frac{Pt}{N_u}$. Thus, the power transmitted by the serving eNB of a cell to a user in region j, either inner or outer, that belongs to this cell is $Pt_j = \frac{Pt}{N_u}$. Total interference I_{ij} received by all users of region i from eNB serving region j is given by

$$I_{ij} = \rho_{ij} \sum_{k=1}^{K_i} Pr_{ijk}, \tag{2}$$

where K_i is number of users in region i and Pr_{ijk}, is the received power by kth user in region i from eNB that serves region j.

In the proposed algorithm, every eNB autonomously tries to select sub-bands for its inner and outer regions by solving the following model so as to minimize each region interference:

$$\min_{SB_i} I_i = \sum_{j=1, j \neq i}^{M} I_{ij} \tag{3.1}$$

$$s.t\ I_{ij} = \rho_{ij} \sum_{k=1}^{K_i} Pr_{ijk}, \tag{3.2}$$

$$\rho_{ij} = \begin{cases} 1, & if\ \ SB_i = SB_j \\ 0, & otherwise \end{cases}, \tag{3.3}$$

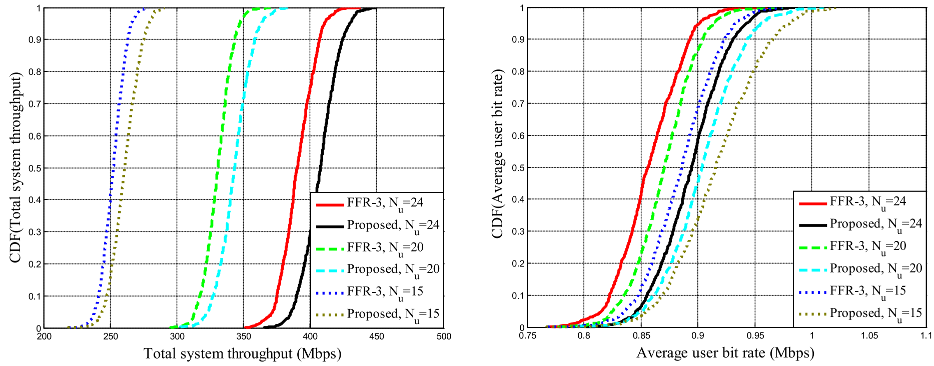
$$SB_i \in \{1, 2, 3, 4\} \tag{3.4}$$

Equation (3.1) minimizes the total interference encountered by users of region i from all neighboring regions $j \neq i$. Equation (3.2) defines the interference received by users of region i from the eNB that serves region j; where the co-channel interference factor, ρ_{ij}, is given by equation (3.3). We assume that interfering signals from different eNBs can be distinguished based on their cell-identifications. For every region i, every user k should, periodically or upon request, report Pr_{ijk} received from eNBs serving all neighboring regions $j \neq i$ to the corresponding eNB; which should implement the aforementioned dynamic sub-band selection algorithm to select the sub-band that minimizes the interference seen by users in this region, i, from neighboring regions.

3 Numerical results

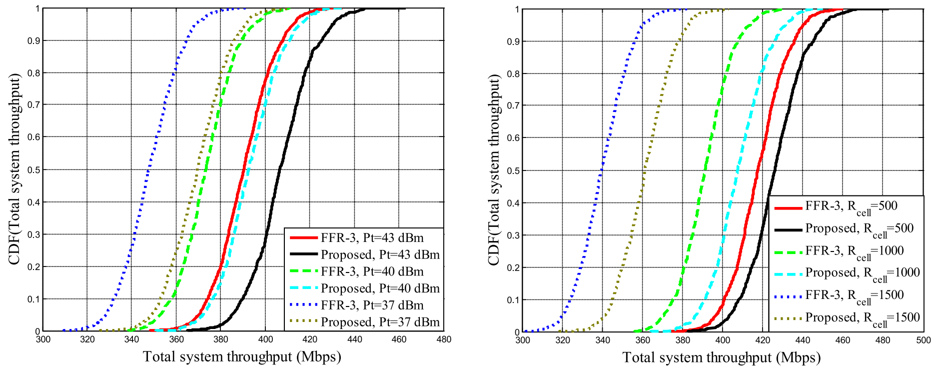
In this section, we compare the proposed algorithm with FFR-3. Consider LTE system of bandwidth 10 MHz, that consists of 50 RBs and each RB has 180 KHz bandwidth. We assume Urban Macro non-line-of-sight (NLOS) path loss model with 20 m street width, 20 m average building height, 25 m eNB height, 1.5 m user terminal height and 2 GHz frequency [6]. Using the aforementioned parameters, the NLOS path loss model [6] can be expressed as $PL(d) = 19.57 + 39.09 log(d) + \chi$; where χ is the log-normal shadow fading with 6 dB standard deviation. Thus, Pr_{ijk} is computed as $Pr_{ijk} = \frac{Pt_j}{PL(d_{ijk})}$, where $PL(d_{ijk})$ is the path loss, that includes shadow fading, from eNB of region j to kth user in region i; and d_{ijk} is the distance from

DOI: 10.1587/comex.2016XBL0080
Received April 12, 2016
Accepted May 10, 2016
Publicized May 24, 2016
Copyedited August 1, 2016



(a) CDF(Total system throughput) (b) CDF(Average user bit-rate)

Fig. 2. CDF curves of both, (a) total system throughput and (b) average user bit-rate, for both proposed and FFR-3 schemes for different number of users per cell, $Pt = 43$ dBm and $R_{cell} = 1000$ m.



(a) Effect of eNB transmit power, $R_{cell} = 1000$ and $N_u = 24$ (b) Effect of cell radius, $Pt = 43dBm$ and $N_u = 24$

Fig. 3. CDF curves of total system throughput of both proposed and FFR-3 schemes for studying the effect of both, (a) eNB transmit power and (b) cell radius.

eNB of region j to kth user in region i. The noise power spectral density is -174 dBm/Hz. We consider 19-cell-model shown in Fig. 1, where every eNB has omni-directional antenna. Users are uniformly distributed within each cell. The radius of the inner-region assumes its FFR optimal value which is 0.63 of the cell radius [1]. In both proposed and FFR-3 schemes, we allow users in inner- and outer-regions of the same cell to borrow free RBs from each other. The impact of number of users in each cell, N_u, eNB total transmit power, Pt, and cell radius, R_{cell}, on both the proposed and FFR-3 schemes are investigated. The total throughput and the average user bit-rate for both the proposed and FFR-3 schemes are evaluated over 1000 iterations using cumulative density function (CDF) curves. The proposed algorithm converges within two seconds for all regions of a network consisting of 19 cells when simulated with a 1.7 GHz processor.

Fig. 2 shows the impact of N_u on both the proposed and FFR-3 schemes. Specifically, Fig. 2(a) illustrates CDF curves of the total system throughput for both the proposed and FFR-3 schemes at various number of users per cell. Increasing Nu leads to an increase in the total system throughput for both schemes. At certain value of N_u, the total system throughput of the proposed distributed algorithm is

DOI: 10.1587/comex.2016XBL0080
Received April 12, 2016
Accepted May 10, 2016
Publicized May 24, 2016
Copyedited August 1, 2016

better than that of FFR-3. Furthermore, Fig. 2(b) shows CDF of the average user bit-rate for both schemes at various values of Nu; where, by increasing number of users, the average user bit-rate is reduced in both schemes. At certain N_u, the proposed algorithm outperforms FFR-3 scheme in terms of average user bit-rate. Moreover, the average user bit-rate for proposed algorithm with $N_u = 24$ is better than that of FFR-3 with $N_u = 15$; i.e., even with an increase in number of users by about 60%, the proposed algorithm can still provide better average user bit-rate compared to FFR-3.

Fig. 3 depicts the effect of both eNB total transmit power, Pt, and the cell radius, R_{cell}, on both the proposed and FFR-3 schemes. Fig. 3(a) shows the effect of Pt; where the total system throughput improves with increasing Pt for both schemes. At a certain value of Pt, the proposed algorithm achieves better total system throughput compared to FFR-3. Moreover, the total system throughput of the proposed algorithm is comparable to that of FFR-3 that have twice power consumption, e.g., CDF curve of the proposed algorithm at $Pt = 40$ dBm is close to that of FFR-3 at $Pt = 43$ dBm. The effect of R_{cell} is depicted in Fig. 3(b); where the total system throughput always increases with reducing R_{cell}. At the same R_{cell}, the proposed algorithm provides higher total system throughput compared to FFR-3.

4 Conclusion

A distributed dynamic frequency reuse algorithm based on minimizing the total interference encountered by all users in each region has been proposed for the downlink of OFDMA cellular systems. Simulation results indicate the effectiveness of the proposed algorithm compared with FFR-3.

DOI: 10.1587/comex.2016XBL0080
Received April 12, 2016
Accepted May 10, 2016
Publicized May 24, 2016
Copyedited August 1, 2016