http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 9 (7): 1490-1494, 2010
ISSN 1812-5638

Dynamic Inter-cell Interference Cancellation for Uplink in Multi-cell OFDMA Systems

Weilin Jiang, Zhongzhao Zhang, Yubin Xu and Linan Sun
Communication Research Center of Harbin Institute of Technology, Harbin, 150080, China

Abstract: In this study, we consider the joint application of adaptive Soft Frequency Reuse (SFR) and Maximum Ratio Combining (MRC) to dynamic Inter-Cell Interference (ICI) cancellation. The ICI is the dominant factor in system performance degradation for uplink in multi-cell Orthogonal Frequency Division Multiple Access (OFDMA) systems. This study firstly investigates the problem of ICI for uplink. Then dynamic ICI cancellation for uplink in OFDMA systems is proposed. When loading is small, low complexity and practical adaptive soft frequency reuse is adopted. As users in the boundary grow larger, MRC is applied to improve edge user performance, which can also cancel ICI by reducing user transmission power. Analysis results show the proposed scheme can provide better reuse efficiency over the adaptive SFR and also can mitigate ICI significantly. Simulation results indicate that the ergodic capacity proposed scheme increases larger 14.5% than not using MRC for E_s/N_0 around 10 dB. Higher spectral efficiency is achieved for large number of users in multi-cell environments, especially for users at the cell boundary.

Key words: Ergodic capacity, maximum ratio combining, soft frequency reuse, diversity, cell boundary

INTRODUCTION

Recent study in wireless systems has focused on broadband service systems. Orthogonal Frequency Division Multiple Access (OFDMA) has become the most promising multiple access technology for 3GPP Long Term Evolution (LTE) and Worldwide interoperability for microwave access (WiMAX), not only for its inherent ability to combat Inter-Symbol Interference (ISI) resulting from frequency selective fading, but also for the flexibility it offers in radio resource allocations as each subcarrier can be modulated adaptively to exploit frequency-domain diversity and achieve high system throughput (Sampath *et al*., 2002). Despite those efforts, there are still a lot of limiting factors to the system capacity in wireless cellular system. In particular, Inter-Cell Interference (ICI) becomes a major source of performance degradation of SINR for uplink transmission at the cell edge region.

Soft Frequency Reuse (SFR) techniques have been proposed for OFDMA systems to mitigate ICI (Xuehong *et al*., 2008; Doppler *et al*., 2009). The SFR is also called interference coordination, which can improve the performance of cell edge effectively and easy to realize. However, such mechanisms limit the utilization of the available frequency spectrum, which determined by Frequency Reuse Factor (FRF) (Boudreau *et al*., 2009). Hence, the FRF of one or near one is desirable for OFDMA systems. Recently, some promising flexible SFR based on interference levels, as well as scheduling users with a given subband based on Channel State Information (CSI) fed back from the mobiles have been proposed such as Boudreau *et al*. (2009) and Kim and Seong (2008). However, if the loading factor is greater than 1/3, ICI will increase with loading, especially for the users in the boundary. At present the ICI cancellation in OFDMA multi-cell mostly is considered for downlink, very little literatures deal with uplink, while without considering the edge and low power users. Macroscopic diversity algorithm for uplink OFDMA systems is proposed to mitigate the effect of ICI (Sungjun *et al*., 2007). However, this scheme also uses macroscopic diversity even the loading is not greater, the complexity of whole system will be increased.

Maximum Ratio Combining (MRC) which is one of the diversity techniques used to combine the multi-path fading signal provides diversity gain and has a greater performance for improving SNR in OFDM systems (Bo-Seok *et al*., 2006). Single mobile signal will be assigned to multiple base stations. The Base Stations (BS) can collect signal energy for using MRC techniques (Sungjun *et al*., 2007). In order to reduce the information exchange between BSs for MRC, in this study, only boundary co-channel interference users will be combined for MRC, information exchange between BSs will be reduced. Thus, compared to the conventional system with a universal MRC, system complexity of the proposed scheme will be greatly decreased.

In this study, we focus on the dynamic ICI cancellation in the uplink of multi-cell OFDMA systems to improve system performance. The SFR or MRC adopted

Corresponding Author: Weilin Jiang, Communication Research Center of Harbin Institute of Technology, Harbin, 150080, China

in different loading of cell to improve boundary user performance is proposed. The proposed scheme guarantees higher spectral efficiency and fairness, especially for users at the cell edge.

SYSTEM DESCRIPTION

A hexagonal uplink multi-cell OFDMA cellular system is considered in this study. Each cell is served by a BS located at the center of the cell. Each user is classified as either in the cell center or the cell edge. The boundary that separates the cell center and edge can be distance or signal strength. We assume that the users are uniformly distributed over the service area within each cell. We also assume that channel gain is constant in each time slot but changes with slots.

It is well known that wireless systems should exploit multi-user diversity to share the radio resources among users. However, the decision about which terminal is allowed to transmit is difficult. That is because the user with good channel condition may be a strong interference user. Signal to Interference and Noise Ratio (SINR) is more accurate measure than SNR in interference limited cellular systems. CSI is periodically provided by the users who listen to broadcast signals from BSs. Therefore, the users can estimate the signal strength from each BS. The received SINR for user k in the cell n can be written as:

$$SINR_{k,n} = \frac{p_{k,n} h_{k,n}^2}{I_k + \sigma^2} \qquad (1)$$

where, $h_{k,n}$ and $p_{k,n}$ denote the channel gain and power for user k in cell n, respectively. I_k implies interference caused by the set of users using same frequency in the other cell. Given the Additive White Gaussian Noise (AWGN), σ^2 is the noise power, which is assumed to be same for all the user k. Hence, ICI has a strong effect for system throughput. It should be taken into account.

Based on the above analysis, we focus on ICI mitigation which is implemented by SFR when loading is less than 2/3. While loading is greater than 2/3, MRC is adopted.

PERFORMANCE ANALYSIS

Here, we present dynamic ICI cancellation scheme for uplink in multi-cell OFDMA systems, which is divided into two steps: the first step is to cancel ICI by SFR effectively when loading is small because it is practicable and valid; the second step is MRC in the boundary to low power in order to mitigate ICI.

Soft frequency reuse: The entire frequency spectrum is divides into three spectrum segments. Firstly, the total frequencies are divided into three parts $\{f_1, f_2, f_3\}$. The three neighboring cells use different parts when the loading is not large, that is, each user uses one third of the separated radio channels from among all available channels, such as the cell 1 using frequency in order of $\{f_1, f_2, f_3\}$, the cell 2 in order of $\{f_2, f_3, f_1\}$ and the cell 3 in order of $\{f_3, f_1, f_2\}$, which guarantees that the spectrum reuse factor is 1. When loading increases in a cell, the newly arrived user can randomly choose other two parts. On the basis of this, interference of each cell will be randomized, so that SFR effectively reduce the ICI when the loading is small.

When the loading mounts up in all cells, neighboring cells will use the same frequency so that ICI gradually increases. That is, collision is possible if nearby cells use the same frequency band. Take two cells for example, the probability of collision of neighboring cells using the same subcarriers is calculated. Let the number of total available subcarrier in cell 1 is m_1, the number of total available subcarrier in cell 2 is m_2, selecting subcarriers in each cell relative to another cell are independent. The number of collisions can not be larger than the smaller number of allocated subcarriers in the two cells and that, if $m_1+m_2>M$, the number of collisions is always $s>m_1+m_2-M$, that is $s = [\max(0, m_1+m_2-M): \min(m_1, m_2)]$, the probability of s collisions in two cells is equal to:

$$P(s) = \binom{m_1}{s}\binom{M-m_1}{m_2-s} \bigg/ \binom{M}{m_2}$$

(Elayoubi *et al*., 2006). Thus, SFR can be reduced to conventional OFDMA systems as users increases to a certain degree.

Maximum ratio combining: When the loading exceeds 1/3, collision is possible if nearby cells use the same frequency band. Therefore, mitigating ICI is critical for improving service quality, especially users at the cell boundary. Thus, when the loading exceeds 2/3, further improvements in SINR can be achieved by MRC for the boundary users, as illustrated in Fig. 1a. The ICI is no longer interference signal but a desirable signal to the other cell. We can reduce user power to avoid ICI in the boundary as illustrated in Fig. 1b. This is demonstrated by the simulations.

The details of process of dynamic ICI cancellation based on SFR and MRC are as follows:

Each BS would begin in SFR of 1/3 and maintain a record of throughput levels, coverage or interference levels through use of Channel Quality Indicator (CQI) and

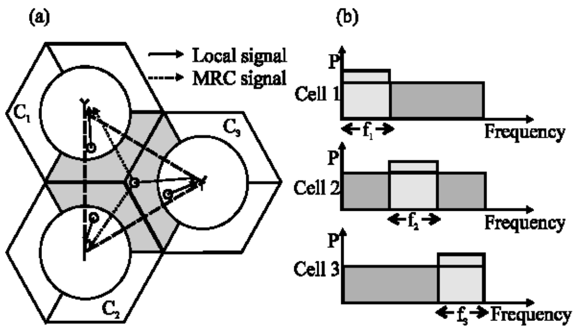

Fig. 1: MRC after loading exceeding 2/3

feedback information from the mobiles it is serving. If a BS detects the interference for the number of users at the cell boundary exceeds a certain threshold, then the scheduler directs BS start up MRC mechanism and sends a message to neighboring BSs to receive signals of users at the boundary of cell to combine.

Therefore, ICI is effective utilization by the MRC when the loading exceeding 2/3, we can lower users power to further reduce ICI, thus communication quality of users at the boundary of cell is improved even edge users are very large.

The signals received from the diversity antennas must be combined to form a decision variable. But if using MRC in overall OFDMA systems, weighting coefficients which are calculated in the transmitter using channel state information fed back from the receiver are need to know by receiver and transmitter. To decrease information feedback, MRC is applied to users in the cell boundary.

Three-cell OFDMA system for uplink is considered in performance analysis. The BSs can receive the user signal to combine useful signal by MRC. It is assumed that there are three antennas to receive. The transmitted equivalent baseband signal is defined as:

$$x = [x_1, x_2, x_3]^T = \sqrt{2P} \cdot w \cdot s \tag{2}$$

where, P and s denote average power and transmitting signal. Since, the sum of L Rayleigh random variables is a chi-square random variable with 2L degrees of freedom (Lee *et al*., 1999). Degrees of freedom for transmitting average power are 2. $w = [w_1,w_2,w_3]$ is the weighted vector, accordingly, SIMO(single-input multiple-output) channel is given by $h = [h_1,h_2,h_3]^T$, the received signal is in the form of:

$$y = w\left(\sqrt{2P}sh^T + n\right) \tag{3}$$

$n = [n_1,n_2,n_3]^T$, n_i is additive white Gaussian noise with mean zero and variance $2N_0/T_s$, where, N_0 is single band power spectrum density, T_s is symbol duration.

$$\begin{aligned} SNR &= \frac{\left\|\sqrt{2P}swh\right\|^2}{\|wn\|^2} = \frac{2PE\|s\|^2\|wh\|^2}{wnn^H w^H} \\ &= \frac{E\|s\|^2 PT_s\|wh\|^2}{N_0 ww^H} = \frac{E\|s\|^2 E_s\|wh\|^2}{N_0 ww^H} \end{aligned} \tag{4}$$

where, $E_s = PT_s$ is energy of a symbol. MRC is to maximize SNR of the received signal. While, $w = h^H$, capacity is written as:

$$C(h) = \log_2\left(1 + \frac{E_s}{N_0}\|h\|^2\right) \tag{5}$$

Due to the process of MRC, ICI at the boundary is transformed desirable signal. ICI is only from users which use the same channel in adjacent cell center, because of path loss, it becomes much smaller. Therefore, this scheme improves the system performance, especially for users at the boundary.

RESULTS

Here, the analysis of the proposed dynamic ICI cancellation scheme based on SFR-MRC is validated by numerical results. Assume the users in the boundary exceed 2/3. The triangle oriented shape is considered as illustrated in Fig. 1a, the radius of cell is 1km. Each BS has one omnidirectional antenna, channel gain from user k to the nth BS can be denoted:

$$h_{k,n}=d_{k,n}^{-a}.10^{-\frac{e_{k,n}}{10}}.?_{k,n}$$

where, $d_{k,n}$ is the distance in km of the k user and the nth BS. α is the pathloss exponent, $\alpha = 3.5$ in the simulation. $10^{-\varepsilon_{k,n}/10}$ denotes the log-normal shadow loss, $\varepsilon_{k,n} \sim \mathcal{N}(0,\sigma^2)$, standard deviation of lognormal shadowing is 8 dB. $\varsigma_{k,n}$ represents the Rayleigh fading loss from the user k to the nth BS. To obtain the average values, we have simulated 1×10^5 independent trials.

To best evaluate the performance of the proposed scheme, we compare it with all cell MRC, 0.6 R and 0.7 R neighboring users MRC. Figure 2 is the simulation of Cumulative Distribution Function (CDF) of the frequency efficiency for different scheme under E_s/N_0 = 10 dB. As expected the proposed scheme is better than without using MRC. This can be seen that the CDF of

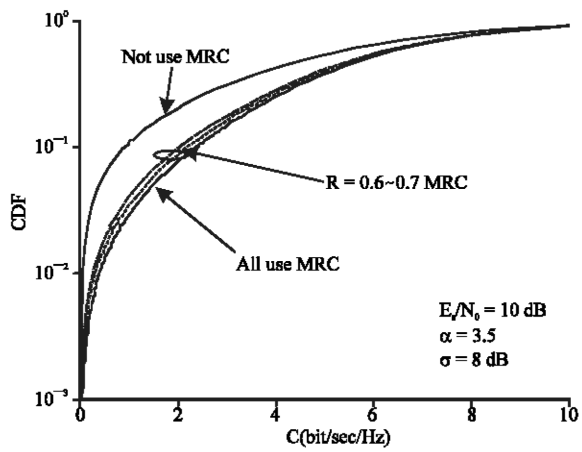

Fig. 2: CDF of system frequency efficiency

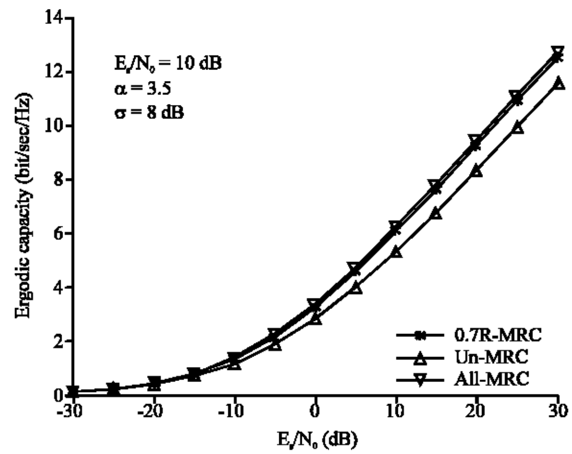

Fig. 3: Ergodic capacity versus E_s/N_0

the 0.6R-MRC is steeper than the one corresponding to the without MRC (Un-MRC). It would have approached nearer all using MRC if boundary is close to center, meanwhile, too much closing center will result in the complexity of system.

Figure 3 is the ergodic capacity in the three neighboring cell for E_s/N_0 ranging from -30 to 30dB. We can see the ergodic capacity for all the methods increases almost linearly with E_s/N_0. The ergodic capacity proposed scheme increases larger 14.5% than not using MRC for E_s/N_0 around 10 dB. The proposed scheme also improves cell-edge user throughput. The propose 0.7R-MRC is close to all cell MRC (All-MRC). Therefore, we can lower users power as illustrate in Fig. 1b to further reduce ICI on the condition of the service quality.

Compared with adaptive SFR, the proposed scheme guarantees that the spectrum reuse factor is 1 and ICI can efficiently cancel. Through the results in Fig. 2, we can see the CDF of the 0.6R-MRC is steeper than the one corresponding to the without MRC. From the results in Fig. 3, the ergodic capacity proposed scheme increases larger 14.5% than not using MRC for E_s/N_0 around 10 dB. It means that we can obtain higher spectral efficiency. The major contribution of this paper is that we joint the SFR and MRC schemes for uplink in multi-cell OFDMA systems to dynamic cancel ICI, especially for users in the edge of cell. Moreover, the proposed scheme can also reduce users power further mitigate ICI on the premise of ensuring service quality. Meanwhile, the proposed scheme is easier to implement. The ICI is decreased by SFR when the loading is small. When the number of subbands of conflict reaches a certain threshold in the cell edge, MRC start to work. Therefore, the proposed scheme combines the merits of SFR and MRC scheme and it can provide better performance. However, information between adjacent BSs will be exchanged in the process of MRC, which brings a certain complexity. Combing threshold can be set up flexibly, which can get the tradeoff between performance and complexity.

CONCLUSION

In this study, we proposed dynamic ICI cancellation scheme for uplink in the multi-cell OFDMA system. We firstly apply SFR to mitigate ICI when loading is low, because of its practical and low complexity, while the loading of cell exceeds 2/3, the ICI level will gradually increase. MRC in the boundary is then adopted to improve SNR of the users in the edge of cell, which avoid overall cell to combine to reduce complexity. Besides spatial diversity, the proposed scheme can also reduce ICI by lowering power. Simulation results show that the proposed scheme provides the higher spectral efficiency than the only adaptive SFR, while improving system performance, especially users at the boundary.

ACKNOWLEDGMENT

This study is supposed by the National Basic Research Program (also called 973 Program) of China under Grant No. 2007CB310601 and Major Science-Technology Project of Next Generation Wireless Mobile Communication Network of China: 2009ZX03004-001.

REFERENCES

Bo-Seok, S., C. Seong-Gon and C. Jae-Sang, 2006. Maximum ratio combining for OFDM systems with cochannel interference. IEEE Trans. Consumer Electronics, 52: 87-91.

Boudreau, G., J. Panicker, G. Ning, C. Rui, W. Neng and S. Vrzic, 2009. Interference coordination and cancellation for 4G networks. IEEE Commun. Magazine, 47: 74-81.

Doppler, K., C. Wijting and K. Valkealahti, 2009. Interference aware scheduling for soft frequency reuse. Proceedings of the IEEE Vehicular Technology Conference, April 2009, IEEE, Washington, DC., pp: 1-5.

Elayoubi, S.E., B. Fourestie and X. Auffret, 2006. On the capacity of OFDMA 802.16 systems. Proceedings of the IEEE International Conference Communications, June 2006, IEEE, France, pp: 1760-1765.

Kim, T.K. and K.H. Seong, 2008. An incremental frequency reuse scheme for an OFDMA cellular system and its performance. Proceedings of the Vehicular Technology Conference, May 11-14, Ajou University, Suwon, pp: 1504-1508.

Lee, D., G.J. Saulnier, Y. Zhong and M.J. Medley, 1999. Antenna diversity for an OFDM system in a fading channel. Proceedings of the IEEE Military Communications Conference MILCOM, Oct. 31-Nov. 3, Atlantic City, New Jersey, pp: 1104-1109.

Sampath, H., S. Talwar, J. Tellado, V. Erceg and A. Paulraj, 2002. A fourth-generation MIMO-OFDM broadband wireless system: design performance and field trial results. Commun. Magazine IEEE, 40: 143-149.

Sungjun, H., L. Sanghoon and G. Gil, 2007. Flexible channel allocation with macroscopic diversity for uplink OFDMA systems [C]. Proceedings of the IEEE 18th International Symposium Personal, Indoor and Mobile Radio Communications, Sept. 3-7, Athens, Greece, pp: 1-5.

Xuehong, M., A. Maaref and K.H. Teo, 2008. Adaptive soft frequency reuse for inter-cell interference coordination in SC-FDMA based 3GPP LTE uplinks. Proceedings of the IEEE Global Telecommunications Conference, Dec. 2008, Mitsubishi Electric Research Laboratories, Sevilla, Spain, pp: 1-8.