Co-channel Interference Mitigation in MIMO-OFDM System

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***Abstract*—OFDMA (orthogonal frequency division multiple access) has emerged as a promising physical layer technology for 4G wireless networks. Along with the requirement for higher system capacity, how to improve cell edge performance to provide better QoS (quality of service) support has become a pressing issue. Considering the channel characteristic in wireless communication, new interference avoidance based algorithms, which consider both time domain and frequency domains, are proposed to mitigate the influence of frequency selective channel on cell edge user in MIMO-OFDM system. Meanwhile, in order to further improve the system spectral efficiency, an algorithm that integrates beamforming is put forward. Simulation results show that the proposed algorithms can improve the throughput of cell edge user effectively as well as the overall system throughput.**

Keywords—OFDMA; interference mitigation; cell edge user performance; beamforming

I. INTRODUNCTION

In wireless cellular communication systems, an issue has been identified and yet to be solved: cell edge users (users having low SINR due to weak signal and strong co-channel interference) suffer from severe inter-cell co-channel interference (CCI) and can only achieve far lower throughput compared with center users (users that experience less CCI and have high SINR). This not only degrades the overall system throughput, but also causes instability issues when supporting Quality of Service (QoS) among different users. Orthogonal Frequency Division Multiplexing (OFDM) has emerged as a strong candidate for 4th generation mobile communication systems because of its high spectral efficiency and robustness against multi-path channels. Based on OFDM, OFDMA networks provide great scheduling flexibility by defining resource unit that consists of multiple sub-carriers (frequency domain) and symbols (time domain). Scheduling in OFDMA systems is facing the pressing issue of how to mitigate inter-cell interference and improve cell edge performances [1,2].

Various interference mitigation methods have been proposed in literature and they can be classified into three categories: interference randomization, interference cancellation and interference coordination.

Inter-cell-interference randomization techniques [3,4] aim at randomizing the interfering signals and thus to allow for interference suppression. These approaches include: interleave division multiple access (IDMA) and frequency hopping (FH). These methods randomize the interference into "White Gauss Noise", which can not reduce interference in nature. Thereby, these approaches can hardly achieve fundamental performance improvement.

Generally, interference cancellation (IC) schemes [5,6] aim at demodulating and canceling interferences through multi-user detection methods at the receiver. However, these approaches suffer from heavy complexity overhead and only limited amount of strong interferences can be cancelled. Typically in cellular networks, the number of non-trivia interferences is well beyond what IC techniques can handle at a reasonable price. Therefore, the effect of interference cancellation alone is not enough to address the CCI issue in cellular networks.

One type of interference coordination techniques[7,8,9,10,11], known as "fractional frequency reuse (FFR)", aims at using orthogonal frequency resources among neighboring cells' edge users to actively mitigate the inter-cell co-channel interference (ICI). Implementation of this approach has very low complexity and the achieved performance gain is promising. Interference coordination has become very important to mitigate ICI in next generation wireless communication networks.

However, FFR has two drawbacks: first, since the cell-edge user can only use part of whole frequency band, it suffers from loss of frequency selectivity gain. Second, spectral efficiency might drop due to larger reuse factor (such as 3) at cell edge, which leads to lower system throughput. Based on these two observations, in this paper we proposed new algorithms to address these issues.

The organization of this paper is as follows: Fractional frequency reuse algorithm is introduced in Section II. Based on the characteristic of wireless channel, new interference avoidance (IA) methods in time domain and/or frequency domains are proposed and analyzed in Section III. In Section IV an IA and beamforming combined technology in MIMO

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system, FFR-RBF algorithm, is proposed. Simulation parameters are given in section V and Section VI presents simulation results and performance analysis. Finally we draw conclusions in Section VII.

II. FRACTIONAL FREQUENCY REUSE

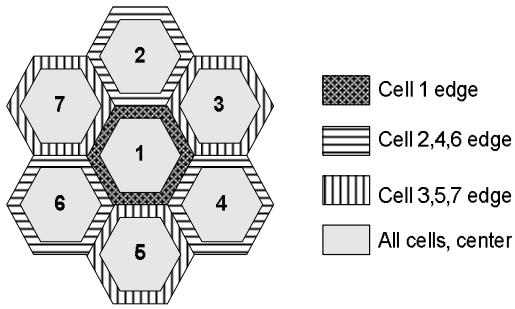

Figure 1. Fractional frequency reuse

As shown in Figure 1, the fundamental idea of FFR is as follows: The whole frequency band is first divided into two groups that serves cell center and edge users respectively in each cell. Sub frequency bands for edge users from neighboring cells are kept orthogonal, hence reuse factor 3. Center users adopt reuse factor 1 since the whole frequency band is made available to cell center. Ensuing this dynamic frequency planning, power loading is employed to lower cell edge CCI. Since center users has better channel SINR compared to cell edge users, less power is needed to achieve the same link performance. Thus, sub-frequency bands for center users will be loaded with less power than those for cell edge users.

As mentioned in the previous section, FFR has its intrinsic drawback of limited frequency selective gain and lower overall spectral efficiency due to large reuse factor at the cell edge. In following sections we propose new algorithms to address these issues.

III. FTR/FTFR

Wireless channels are characterized with two types of fading: frequency selective fading and time selective fading.

Frequency selectivity leads to diversified channel responses at different OFDM frequency sub-carriers. With FFR applied, since cell-edge user can only use part of total bandwidth, frequency selective gain is limited for cell edge users. In worst case, edge users may be suffer from deep fading at the allocated sub-bands, hence poor throughput. To give edge users the advantage of fully explored frequency selective gain, we proposed a new method: fractional time reuse (FTR).

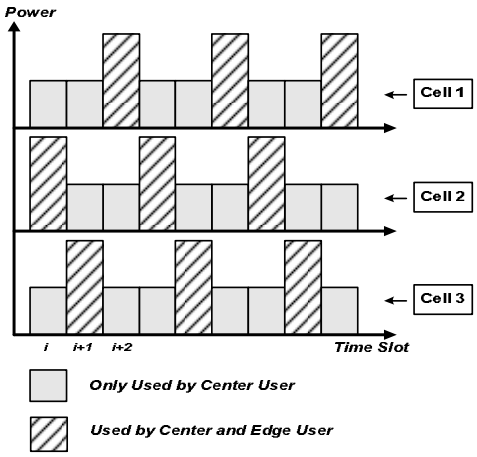

Figure 2. Fractional time reuse

As seen in Figure 2, edge users' receiving happens orthogonally in time domain. Among the 3 neighboring cells at each given time slot, only one of them is serving cell edge users, while the other 2 devote all their resources to cell center users with relatively lower transmit power to reduce their caused CCI to other cells. For example, in Figure 2 during the ith time slot only cell 2 is serving both edge and center users, while cell 1 and 3 only serves their center users. The system scheduler will schedule edge users ahead of centers users in a greedy way (choose the best one for edge users among all available resource units) to benefit edge users with better performance.

Besides the frequency selective gain for edge users, the proposed FTR algorithm has another advantages of allowing cell edge users to go into sleep mode (defined in IEEE 802.16e) 2/3 of the time while only center users are to be served. This will greatly facilitate power saving for subscriber stations.

It has been noticed that compared with the original FFR algorithm FTR intrinsically introduces more delay. For services that are sensitive to delay, we propose a second interference coordination method: fractional time and frequency reuse (FTFR) method.

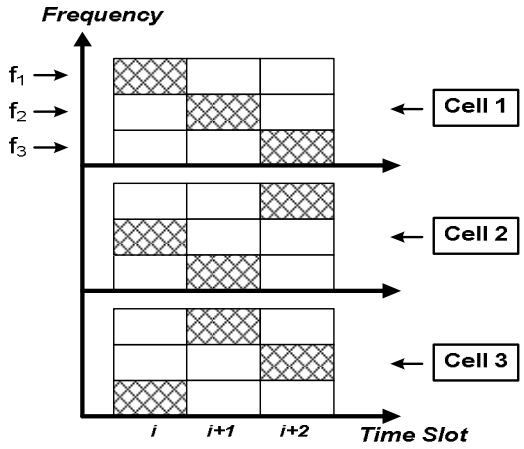

Figure 3. Fractional time and frequency reuse

FTFR algorithm is shown in Figure 3. Resource units

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marked in grid are frequency sub-bands reserved for edge users. Basically this sub-band will be dynamically adjusted from frame to frame for each cell, while maintaining the "edge resource orthogonally" among the 3 neighboring cells. Compared with FFR, FTFR avoids deep fading for edge users. FTFR allows cell-edge user with frequency selective gain without introducing more packet delay. It will perform better especially when the channel fluctuates greatly at time domain.

IV. FFR-RBF

Through FTR and FTFR, CCI is minimized for cell edge users. In order to further enhance the system and cell edge performance, an FFR and beamforming combined algorithm is proposed in this paper.

In a multi-cell MIMO system, the received signal of Kth user is shown by Equation (1):

$$Y^k = H^k \times X + \sum_{i=1}^{n} H_{ifi}^k \times X_{ifi} + N \qquad (1)$$

In Equation (1), Y^k is the received signal vector of the Kth user, X is the transmitted signal, H^k is the channel between the user and the serving BS, and its dimension is $N_{rx} \times N_{tx}$. N_{tx} and N_{rx} are BS transmit antenna number and receiver antenna number of the Kth user respectively. The subscript "if" denotes interference signal. N denotes white Gauss noise with covariance is $\phi_N = \sigma^2 I$.

Beamforming comes from adaptive antenna technology. It seeks an improved SINR performance by forming an ideal signal through weighted combination of all the signals in each array element. From the directional graph point of view, this equals to forming a beam in spatial direction.

Taking transmit beamforming in BS, the received signal of the Kth user is changed to Equation (2):

$$Y^k = H_E^k \times X + \sum_{i=1}^{n} H_{Eifi}^k \times X_{ifi} + N \qquad (2)$$

In Equation (2), H_E^k is the equivalent channel between the Kth user and serving BS, the detailed definition of H_E^k is as Equation (3):

$$H_E^k = H^k \times V_{BF}^K \qquad (3)$$

In Equation (3), V_{BF}^K is the beam vector BS adopts when transmitting to the Kth user.

By setting different amplitudes and phases in each antenna element for each base station, the received signal can be controlled in the main lobe on the directional graph, while the inter-cell interference can be adjusted to the side lobe or null on the directional graph. Then the signal to interference and noise (SINR) on the receiver can be boosted largely and the received signal quality can be improved accordingly.

In general, beamforming can be classified into two types: coherent beamforming (CBF) and random beamforming (RBF). CBF has more potential gain, while it requires CSI (Channel state information) at the base station in order to choose beamforming vectors that best fit user's channels.

With only CQI(Channel quality index), BS could use random beamforming[12] to improve system throughput. Beamforming vectors are chosen randomly at the transmitter side. Users are scheduled based on their CQI feedback for the current beamforming vector. As the number of users increases, it is more likely to find a channel that best suits the beam vector. Thus, the system can explore user diversity gain. Besides, since interference from other cell becomes directional instead of omni-directional, RBF enjoys extra potential gain from reduced CCI.

The motivation of combining FFR-RBF is to further enhance both overall system and edge user performance. On top of the original FFR algorithm, a random beamforming vector will be used at base station for data transmission.

V. SIMULATION ASSUMPTIONS

The simulation environment consists of 19 cells. The system network layout is shown in Figure 4.

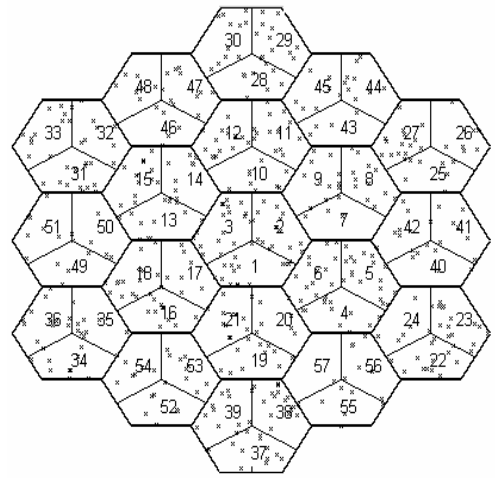

Figure 4. Simulation network layout

Detailed simulation parameters are listed in Table 1, Table 2 and Table 3.

TABLE I. Network Parameters

Cell Num	19
Sector/Cell	3
Cell Radius	577m
Carrier Frequency	2GHz
Reuse Factor	1x3x1
Cell Load	100%

TABLE II. System Model

Channel Model	GSM TU 3km
Path loss	128.1+37.6*log(d)
Shadow Fading	8dB
Max BS tx power	43dBm
Antenna Pattern	sector antenna
BS tx Gain	18dB
BS tx Num	2
SS rx Gain	0dB
SS rx Num	2

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Detection	MMSE
Scheduling	Proportional Fair
Noise Figure	8dB
AMC	QPSK (R = 1/4, 1/2, 3/4), 16QAM (R = 1/2, 5/8, 3/4), 64QAM (R = 5/8, 3/4)

TABLE III. OFDMA Parameters

System Bandwidth	10MHz
FFT	1024
Data Sub-carrier	600
CP length	1/8
Frame Duration	10ms
Sub-channel/Frame	24
Minimum Resource Block	25 Sub-carrier* 7Symbol

VI. SIMULATION RESULTS

The performance comparison among FFR, FTR and FTFR is listed in Table 4 and Table 5.

TABLE IV. Average cell-edge data rate/user (kbps)

User Num	10	15	20	25	30	35	40
FFR	1340	896	672	602	468	430	391
FTR	1390	924	702	621	490	439	409
FTFR	1380	910	683	607	471	432	395

TABLE V. Average cell-edge packet delay (ms)

User Num	10	15	20	25	30	35	40
FFR	9.10	11.08	12.10	12.68	13.08	13.39	13.59
FTR	9.37	11.30	12.21	12.81	13.19	13.47	13.66
FTFR	9.12	11.09	12.11	12.67	13.09	13.39	13.58

Table 4 and Table 5 show average cell-edge data rates per user and packet delay against the number of user per sector in different methods respectively. Identification of cell-edge user is based on their large scale fading such as path loss and shadow fading. Users with worst 20% fading are identified as cell-edge users.

From Table 4, it can be seen that FTR achieves the highest average data rate for cell edge users because it explores frequency selective gain. Meanwhile, from Table 5 we can see that since the packet of cell-edge user can only be sent in special time, the packet delay is slightly longer. And with the increase of user number per sector, more and more users will contend resource to send data, so the average delay of cell-edge users is larger. As for FTFR, since it considers both packet delay of cell-edge user and frequency selective channel, the whole performance of FTFR is the best.

To further improve the system spectral efficiency, FFR-RBF (Random beamforming) algorithm is proposed in this paper. Continuous Mode, which uses continuous sub-carrier allocation method, is considered as a baseline of the performance comparison. We compare the improvement of FFR, RBF and FFR-RBF algorithms.

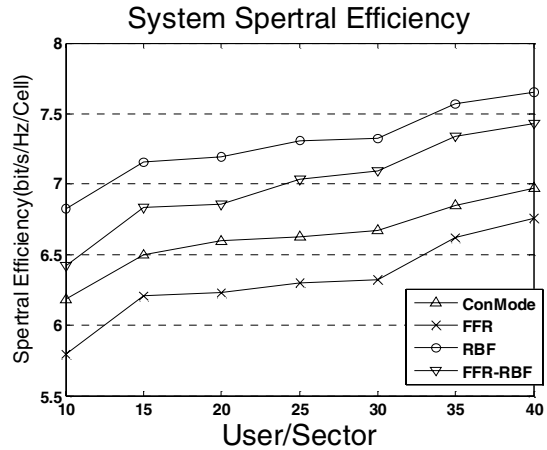

Figure 5. System spectral efficiency

Figure 5 shows the system spectral efficiency in each algorithm. From the figure it can be seen that as the number of users/sector grows larger, the system spectral efficiency increases, too. This extra gain comes from the enhanced user diversity. Comparing with the "continuous mode," FFR has a lower spectral efficiency as expected since it adopts higher reuse factor at cell edge. With RBF mechanism integrated, the system spectral efficiency is improved greatly. In FFR-RBF, its spectral efficiency is also higher than the "continuous mode" as it benefits from extra gain from RBF.

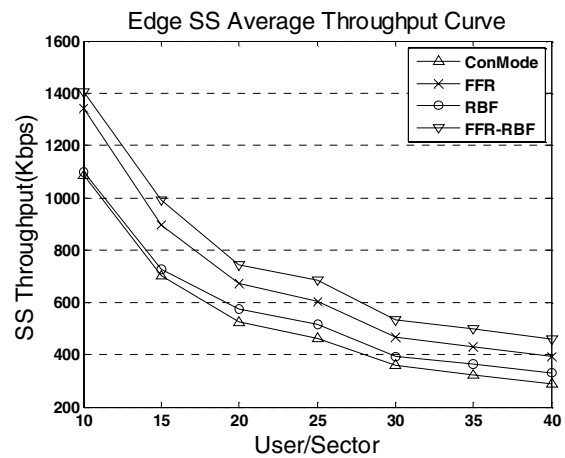

Figure 6. Average cell-edge data rate/user

Figure 6 shows the average cell-edge data rate in different algorithms. The figure shows that since Continuous Mode does not reserve resources for edge users, it achieves the worst average cell-edge data rate. In FFR, resources are reserved for edge user to improved cell edge data rate. As for RBF, since it can only enhance some users' SINR, while can not meet the channel state of most of the users, the improvement on edge user is not as obvious as FFR. In FFR-RBF, which combines the merit of both FFR and RBF, the improvement on cell-edge users' data rate is the best.

VII.CONCLUSION

In the next generation mobile communication system, inter-cell interference has become the major obstacle to

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achieve high spectral efficiency. Two (FTR/FTFR) algorithms are proposed in this paper to improve the system spectral efficiency and cell edge performance compared with FFR. Furthermore, an enhanced algorithm, which combines FFR and RBF, is proposed to improve the overall system spectral efficiency. Simulation results show that FFR-RBF can enhance the cell-edge data rate while keeping high spectral efficiency. As the next step, how to combine interference coordination with other interference cancellation technologies to mitigate inter-cell interference is a promising research direction.

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