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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

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

Information Technology Journal 12 (5): 935-942, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.935.942

A New Interference Alignment Algorithm in the MIMO-OFDM System

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Abstract: As is known to all, the inter-cell interference of the cell-edge users in cellular network is serious which deteriorate the quality of communication to a great extent, so this study formulated a distributed, low system overhead linear precoding to solve this problem. It considered the downlink channel of a cellular broadband wireless system where base stations and users are assumed to have at least two antennas each and are scheduled based on fractional frequency reuse. Then, the study introduced a balancing algorithm which helps the adjacent base stations to simultaneously beamform to its own user while still minimizing the interference on the non-intended user. Finally, in this study, it also analyzed the degree of freedom can be achieved in the cellular network. The simulation results showed that this new scheme can improve the performance of the cell-edge user significantly while causing only a mild degradation in the performance of the in-cell users.

Key words: Interference alignment, balancing algorithm, precoding, zero-forcing equalization

INTRODUCTION

Cells introduced can improve the mobile communication system capacity greatly however, the users located in the cell edge area are tend to suffer severe interference caused by neighboring cells. When multi-cells organize a network in MIMO system, since each antenna is a source of interference, inter-cell interference (ICI) during MIMO cellular system is much more severe than that in single antenna cellular system. The problem that how to eliminate ICI in order to achieve more efficient spectrum usage than current existing communication systems becomes a key issue while designing the next generation networks. At present, there mainly exists two kinds of schemes to solve this problem, one kind is to utilize superior frequency multiplexing scheme such as Fractional Frequency Reuse (FFR), the other is to utilize collaboration processing technology based on multiple base stations (Xie and Lei, 2009).

Fractional Frequency Reuse (FFR) has been adopted by 802.16 m and LTE-A. However, it cannot eliminate ICI completely because the subchannels utilized by the users located in the cell edge area are also utilized by internal users in its neighboring cells (Zhou and Zein, 2008).

Collaboration processing technology based on multiple base stations is to utilize beamforming and precoding technologies and then jointly transmit signals to the mobile stations located in the cell edge area, in order to transform the interference caused by neighboring cells into meaningful signals towards the mobile station. The main idea in interference alignment (Cadambe and Jafar, 2008; Boudreau *et al*., 2009) is to design beamforming vector or precoding matrix in a ingenious manner in order that signals will be transmitted are firstly well aligned on non-intended receivers and simultaneously are distinguished among intended receivers. This strategy can eliminate ICI completely through forced zero beamforming adopted on the receivers. The scheme that interference alignment is utilized in multiple base stations collaboration processing technology is proposed and studied (Suh and Tse, 2008; Tresch and Guillaud, 2009; Sun *et al*., 2010; Nagarajan and Ramamurthi, 2010), in particular, the scheme that interference alignment is utilized in cellular system adopting FFR is studied (Nagarajan and Ramamurthi, 2010).

MMSE detection algorithm is utilized in the receivers in the interference alignment scheme proposed in (Nagarajan and Ramamurthi, 2010). The proposed interference alignment scheme can apply to flat slow fading channel under the circumstance that both transmitters and receivers are static. Further more, it can achieve very high information transmission rate and spectrum efficiency by taking advantage of more antennas in layered space-time code system, for example adopting four or eight antennas.

However, a common problem that interference alignment will impair the performance of users inside the cell even thought improving the performance of users located in the cell edge area is ignored by the proposed interference alignment schemes previously. It is because original beamforming features of base station are weakened causes losses of uses channel gain inside the cell.

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The problem aforementioned can be settled by the algorithm proposed in this paper. Based on the downlink of interference limited cellular systems which use the fractional frequency division multiplexing (FFR) in the Gaussian noise environment, a distributed, low-feedback, linear-precoding technique to completely eliminate the inter-cell interference, is formulated in this paper and then in order to solve the problems existing in the current researches, a balance algorithm to help the interfering Base Station (BS) to simultaneously beamform to its own user while still minimizing the interference on the non-intended user is introduced (Jiang *et al*., 2010).

The study introduced a balancing algorithm which helps the adjacent base stations to simultaneously beamform to its own user while still minimizing the interference on the non-intended user. The finally simulation results showed that this new scheme improve the performance of the cell-edge user significantly while causing only a mild degradation in the performance of the in-cell users.

SYSTEM MODEL

In this study, it consider an interference-limited cellular systems, where one User-Equipment (UE) is active at any given time in any cell. Each UE not only receives the signal transmitted by the Base Station (BS) located in its own cell but also receives the inter-cell interference signals transmitted by the neighboring cells.

FFR is a resource-scheduling concept that lies in between reuse 1 and reuse 3. In the case of reuse 3, the available spectrum is divided into a number of sub-channels (discrete or continuous chunks) and allocated to a group of cells which is called a cluster. This allocation is done in such a way that adjacent cells from the same cluster do not operate with the same set of sub-channels. Furthermore, two cells that operate with the same set of sub-channels are geographically well separated. As a result, the interference seen by a user becomes extremely small, irrespective of the position of the user within the cell. However, this arrangement is under-efficient, as only a fraction of the allocated bandwidth can be utilized within each cell. Reuse-1 systems are spectrally more efficient because the whole allocated bandwidth can be utilized within each cell. However, as users move closer to the cell boundary, the interference that they experience increases rapidly. Reuse 1 and reuse 3 are the two extreme situations of spectrum allocation, whereas FFR inherits the properties of both these techniques.

In the case of FFR, users are classified as in-cell or cell-edge users, according to their Signal-to-Interference Ratio (SIR). The in-cell users experience high SIR and are located well within the cell, also they are served with the whole available spectrum. (the users inside of the dotted line hexagon of Fig. 1). The cell-edge users are characterized by low SIR and located closer to the cell boundary, they are served with only one third of the total spectrum in each cell (the users outside the dotted line hexagon but inside the solid line hexagon, as shown in Fig. 1). It is ensured that adjacent cells do not use the same set of sub-channels to serve their cell-edge users. However, FFR does not completely avoid interference among adjacent cells because the set of sub-channels used by a cell-edge user are used by in-cell users from the adjacent cells. However, with FFR-based scheduling, only the cell-edge user who suffer serious interference while that suffered by the in-cell users will be lesser because they are located well within the cell.

The system model considered in this study is an interference-limited cellular system; the interference seen

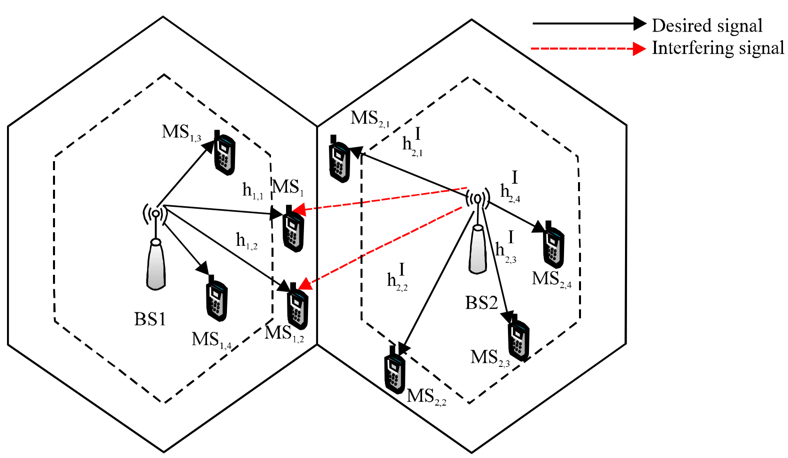

Fig. 1: The multiuser MIMO broadcast channel under inter-cell interference

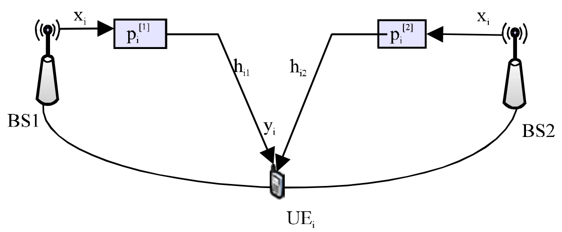

Fig. 2: The local precoding scheme

by a UE is generally within different power levels and are classified as dominant or weak interferers. The dominant interferers would be at par with the desired signal, so their Channel State Information (CSI) can be reliably estimated through a training sequence. However, the weaker interferers are collectively modeled as colored Gaussian noise. The system model as shown in Fig. 1, it assume that there exists M-1 dominant interferers, with all co-channel users equipped with $N_R \geq 2$ antennas. The BSs are considered to be equipped with $N_T \geq 2$ antennas (Wang *et al.*, 2010a, b).

As shown in the Fig. 2, the symbol vector received by UE i is:

$$y_i^{[j]} = \sqrt{\rho h_{ij} \rho_i^{[j]} x_i^{[j]}} + \sum_{\bar{j} \leq M, \bar{j} \neq j} \sqrt{\rho} g_{i\bar{j}} h_{ij} \rho_i^{[\bar{j}]} x_i^{[\bar{j}]} + n_i \qquad i=1,...K, j=1,...,M \tag{1}$$

where, $h_{ij} \in C^{NR \times NT}$ is the $N_R \times N_T$ channel matrix between UE_i and BS_j with the channel coefficients coming from a circularly symmetric complex Gaussian distribution with zero mean and unit variance. $P_i^{[j]}$ is precoding matrix. $x_i^{[j]} \in C^{d_i^{[j]} \times N_T}$ is the transmitted symbol with average power constraint $E(X_i^{[j]} X_i^{[j]*}) = 1$ and $d_i^{[j]} \leq \min(N_T, N_R)$ represents the degree of freedom of user i in cell j. $n_i \in C^{N_R \times 1}$ denotes additive white complex Gaussian noise at UE_i, with zero mean and variance σ^2.$g_{ij} = (d_{ij}/d_{jj})^{-\alpha}$ is the distance-dependent path-loss gain between the jth BS and the ith UE, where, d_{ij} is the distance from the edge UE in the ith cell to the jth BS, d_{ij} s the distance between two adjacent BSs, α is the propagation exponent. Therefore, $g_{i\bar{j}}$ represents the distance-dependent path-loss gain between the $\bar{j}$th BS and the ith UE in cell j^0.

THE PERFORMANCE ANALYSIS OF INTERFERENCE ALIGNMENT IN GENERAL CELLULAR NETWORK

In the general cellular network, the interference suppression matrix $u_i^{[j]}$ is chosen in such a way that the signal $\hat{y}_i^{[j]}$ lies in the $d_i^{[j]}$-dimensional subspace with the least interference:

$$\hat{y}_i^{[j]} = u_i^{[j]\dagger} y_i^{[j]} \tag{2}$$

Assuming that user 1 is located at the cell-edge, if it meets:

$$\text{rank}(u_i^{[j]\dagger} h_{ij} P_i^{[j]}) = d_i^{[j]} \tag{3}$$

$$\sqrt{\rho} u_i^{[j]\dagger} g_{i\bar{j}} h_i^{[\bar{j}]} p_i^{[\bar{j}]} = 0, \quad \bar{j} \leq M, \bar{j} \neq j \tag{4}$$

Then the interference received by users 1 who is located at the cell-edge in the cellular systems will be completely eliminate.

In order to accomplish this, the receivers of cell-edge users are assumed to know the interference covariance matrix (including the AWGN):

$$Q = \sum_{\bar{j} \leq M, \bar{j} \neq j}^{M} \sqrt{\rho} h_{i\bar{j}} P_t^{[\bar{j}]} p_t^{[\bar{j}]\dagger} h_{t\bar{j}}^{\dagger} + I_N \tag{5}$$

So that, the interference suppression matrix $u_i^{[j]}$ is chosen as the $d_i^{[j]}$ eigenvectors corresponding to the smallest $d_i^{[j]}$ eigenvalues of Q^i and each interference $BS_{\bar{j}}$, $\bar{j} \leq M, \bar{j} \neq j$ must use precoder $P_i^{[j]}$ given by:

$$P_i^{[j]} \in \text{null space } [u_i^{[j]\dagger} g_{i\bar{j}} h_i^{[\bar{j}]}) \quad \bar{j} \leq M, \bar{j} \neq j \tag{6}$$

The term null space used in Eq. 6 is defined, for any matrix A, as the set of all vectors x such that Ax = 0. Therefore, the precoders determined using Eq. 6 ensure that all the interfering signals lie in a particular subspace at the cell-edge UE.

Moreover, the precoder determined by (6) ensures zero interference after ZF equalization, irrespective of the power in the interfering signals. To illustrate this condition, consider a cell-edge UE that suffers dominant interference from two BSs at 0 dB and -3 dB with respect to the desired signal. The background interference and thermal noise are at -6 dB with respect to the desired signal. The interfering BSs are assumed to serve in-cell users (FFR-based scheduling) whose total interference is assumed to be at -6 dB, with respect to its desired signal. The BSs and UEs are assumed to have two antennas each. Path-loss is considered and we choose the path-loss transmission exponent $\alpha = 3$.

Figure 3 and 4 show the Bit Error Rate (BER) performance of the cell-edge and the in-cell UEs, respectively obtained by the use of the proposed precoding scheme.

According to Fig. 3, significant performance improvement is observed for the cell-edge UE . Because that use of the precoder determined by Eq. 6, the inter

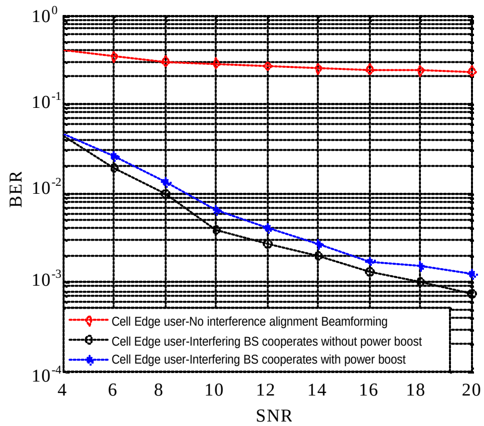

Fig. 3: The bit error rate (BER) performance of 2×2 MIMO channel of cell-edge users

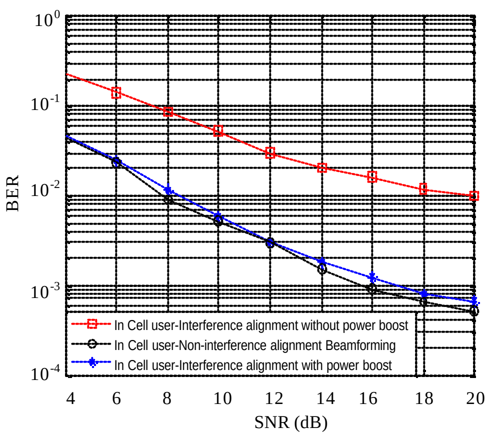

Fig. 4: The bit error rate (BER) performance of 2×2 MIMO channel of in-cell users

ference received by users 1 who is located at the cell-edge in the cellular systems can be aligned well, make them lie the same specific subspace and through ZF equalization, all the interference can be eliminated easily, so the SIR of cell-edge users is improved obviously thus, the performance of cell-edge users are upgraded greatly. But according to Fig. 4, the use of Eq. 6 by the interfering BSs degrades the performance of the in-cell UEs because the interfering BS does not beamform to its own in-cell UE, resulting in the loss in array gain to the in-cell UE. This degradation in performance can be overcome if the interfering BS increases its transmit power. Let us assume that information of the loss in array gain is available at the interfering BS. With this information, the interfering BS can increases its transmit power to restore the performance of the in-cell UE. As is known to all, increasing power will lead to a high interference suffered by the cell-edge UE. However, it can be observed in Fig. 3 that the proposed precoding scheme ensures that the interfering signals are aligned well such that there is zero interference after ZF equalization, irrespective of their strength.

THE NEW BALANCE ALGORITHM

Previous derivation and simulation results indicate that, the use of the optimal precoder in Eq. 6 by the interfering BSs brings the remarkably enhanced in the BER performance of cell-edge users. At the same time it also leads to a large degradation in the BER performance of the in-cell UE being served by the interfering BS. As Fig. 1 shows, the transmit beam of interference BS2 which have already aligned the in-cell users of itself, e.g. the beam direction of $MS_{2,3}$, $MS_{2,4}$, because the use of precoder determined by Eq. 6, they does not beamform to its own in-cell UE, resulting in the loss in array gain $h^1_{2,3}$, $h^1_{2,4}$.

Although, increasing the transmit power may solve the problem, additional feedback with regard to the loss in array gain from the in-cell UEs is a big system overhead. Responding to these defects, one alternative approach is to let the interfering BS to seek a compromise between the two precoder requests (the beamforming precoder from its in-cell UE and the interference-aligning precoder from the cell-edge UE) that it gets, instead of increasing its transmit power. In this section, it put forward a simple balance algorithm for the interfering BS to ensure that the interference suffered by the cell-edge UE is kept as low as possible while allowing only a minor degradation in performance for its own in-cell UE. The algorithm does not require centralized precoder and the perfect channel state information. Because in the cellular network based on FER scheduling, all the co-channel users will not suffer severe interference (Cao *et al*., 2011).

To derive the balancing algorithm, consider the system model in 3 and 4 again. The cell-edge UE would expect the precoder of the interfering BS to meet Eq. 6, so that can completely eliminate the inter-cell interference, i.e.:

$$\sqrt{\rho} u_1^{[j]\dagger} g_{i\bar{j}} h_1^{[\bar{j}]} p_1^{[\bar{j}]} = 0, \quad \bar{j} \le M, \bar{j} \ne j$$

Assume that:

$$A^{[\bar{j}]} = g_{i\bar{j}} (u_i^{[j]\dagger} h_1^{[\bar{j}]})^H$$

Therefore:

$$\left(A^{[\bar{j}]}\right)^H P_1^{[\bar{j}]} = 0 \quad \bar{j} \le M, \bar{j} \ne j \tag{7}$$

Meanwhile, the in-cell UE being served by the interfering BS would expect its precoder $p_1^{[\bar{j}]}$ can well match to its link, to maximize the array gain. Let this beamforming vector be denoted by $(p_1^{[\bar{j}]})^{[bf]}$. Let the basis for the left null space of $(p_1^{[\bar{j}]})^{[bf]}$ be denoted by the columns of the matrix $B^{[\bar{j}]}$. Therefore, the UE being served by the interfering BS would expect $p_1^{[\bar{j}]}$ to meet:

$$\left(B^{[\bar{j}]}\right)^H P_1^{[\bar{j}]} = 0 \tag{8}$$

In conclusion, the optimal choice of $p_1^{[\bar{j}]}$ by the interfering BS should meet both 7 and 8 simultaneously. Therefore, $p_1^{[\bar{j}]}$ should meet:

$$\left(T^{[\bar{j}]}\right)^H P_1^{[\bar{j}]} = \underline{O}\ \bar{j} \le M, \bar{j} \ne j \tag{9}$$

Where:

$$T^{[\bar{j}]} = \begin{bmatrix} \left(A^{[\bar{j}]}\right)^H \\ \left(B^{[\bar{j}]}\right)^H \end{bmatrix}$$

Equation 7-9 show that $T^{[\bar{j}]}$ is a square matrix of size $N_T \times N_T$ and is completely dependent on the channel. Because the channel coefficient is random and produced by a continuous distribution, $T^{[\bar{j}]}$ is likely to be a full rank matrix. Therefore, the only choice to $p_1^{[\bar{j}]}$ satisfies 9 will be $P_1^{[\bar{j}]} = \underline{0}$ which is not of interest. In such cases, the optimal solution will be the one that minimizes $\left\|(T^{[\bar{j}]})^H P_1^{[\bar{j}]}\right\|$ subject to the constraint $\left\|P_1^{[\bar{j}]}\right\| = 1$. Therefore, the optimal precoder for both the UEs is given by the unit-norm eigenvector which corresponds to the minimum given value of $\|(T^{[\bar{j}]})\left\|(T^{[\bar{j}]})^H P_1^{[\bar{j}]}\right\|$. Let λ_{min} and v_{min} denote the minimum eigenvalue and the corresponding eigenvector of $\left\|(T^{[\bar{j}]})^H P_1^{[\bar{j}]}\right\|$. Hence, the optimal precoding vector is given by:

$$P^{[\bar{j}]}_{opt} = v_{min} \tag{10}$$

It could be observed in Eq. 10 that, even if $T^{[\bar{j}]}$ is rank deficient, the optimal solution would lead to zero interference at the cell-edge UE while maximizing the array gain to the UE being served by the interfering BS. This is because $(T^{[\bar{j}]})^H T^{[\bar{j}]}$ is positive semidefinite and when $T^{[\bar{j}]}$ is rank deficient, $(T^{[\bar{j}]})^H T^{[\bar{j}]}$ will have at least one zero eigenvalue.

THE ANALYSIS OF DoF OF MULTI-CELL CELLULAR NETWORK

"Degrees of freedom" is an important capacity approximation in networks literature. To give a simple intuition of degrees of freedom of a network , it is worthy to note that:

- The degrees of freedom of a network may be interpreted as the number of resolvable signal space dimensions
- A network has d degrees of freedom if and only if the sum capacity of the network can be expressed as d log (SNR)+o (log (SNR)), where:

$$d = \lim_{SNR \to \infty} \frac{C_\Sigma(SNR)}{\log(SNR)}$$

- It is a capacity approximation that is accurate in high SNR regime

From section 2, it is assumed that, $\bar{\underline{d}} \le \min(N_T, N_R)$ represents the degree of freedom of user i in cell j.N_T and N_R is the number of transmitting antenna and receiving antenna, respectively. DoF provides the first-order approximation of the capacity in the high SNR regime and can be regarded as the number of independent streams in the system, thus in terms of DoF it suffices to apply the simple zero-forcing decoding at the receivers to extract all the available degrees of freedom.

The two-cell network can be effectively modeled as consisting of two interfering multiple access channels (IMAC) or interfering broadcast channels (IBC). Due to the duality of the DoF results for the uplink channel and the downlink channel when linear interference alignment schemes are utilized (Sun *et al*., 2010).

Figure 5 illustrates the scenario of two interfering multiple access channels, where there are two cells, each having K users who only communicate to their intended BS. All the users are of single antenna while the BSs are equipped with N_T antennas. Assume there are $d_1^{[\bar{j}]}$ parallel independent sub-channels in the system which might result from the symbol extensions of the channel in the time domain or from the sub-channels in the frequency domain.

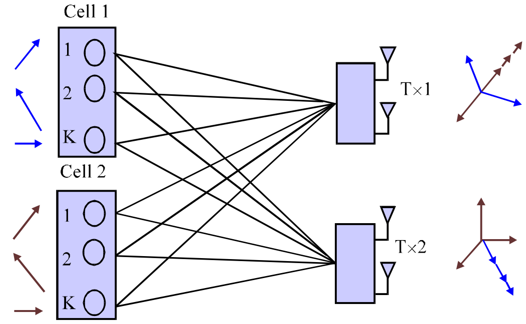

Fig. 5: Two interfering multiple access channels with N_T antennas at each base station (BS)

In the work of (Cadambe and Jafar, 2008; Sun *et al*., 2012) on the K-user interference channel, it is proved that half of the interference-free DoF can be asymptotically achieved by exploiting the interference alignment idea. Based on the interfering MAC channel model, it's can be demonstrated that the performance can still be further upgraded by taking advantage of the interference alignment technique-actually, nearly interference-free DoF can be achieved.

For the considered network, the case of single-antenna BS has been addressed by Sun *et al.* (2012), where the DoF is shown to be K/(K+1) (K is the number of users per cell). The model considered in this study is equipped with N_T antennas, its DoF will be discussed soon.

Lemma 1 (Spencer *et al.*, 2004): For a multiple access channel with K distributed transmitters (with n_K antennas at transmitter k) and a receiver of n_R antennas, its degree of freedom is given by:

$$DOF_{MAC} = \sum_{k=1}^{K} d_k = \min(\sum_{k=1}^{K} n_k\ n_{R)} \tag{11}$$

Theorem 1: For the two-cell cellular network with N_T antennas at the BSs and time- or frequency-varying channel coefficients, the DoF per cell is:

$$\sum_{k=1}^{K} d_k^{[1]} = \frac{KN_T}{K+N_T} \quad K \geq N_T \tag{12}$$

$$\sum_{k=1}^{K} d_k^{[1]} = \min\left(K, \frac{N_T}{2}\right) \quad K < N_T \tag{13}$$

For the specific proof of this theorem, please reference (Sun *et al.*, 2012).

From the formula 12 and 13 it can be seen:

- When K is larger than N_T, the DoF grows monotonically with N_T which is a manifestation of the multiplexing gain that N_T antennas could potentially provide
- From formula 13 it is shown that the DoF is also an increasing function of the number of users K which means that the multi-user gain also exists for the interfering MAC model in the case of multiple- antenna BSs, as reported for the single-antenna scenario in study of Nagarajan and Ramamurthi (2010). Specifically, when K is large, the DoF per cell is very close to N_T which is exactly the interference-free DoF. When $K\rightarrow\infty$, N_T,/(K+N_T)$\rightarrow N_T$, this is consistent with the DoF of interference-free cellular network-fi
- Though, Theorem 1 considers only the situation of single-antenna users and two cells, it is not too difficult to generalize the techniques and results based on the scenarios of multiple-antenna users and arbitrary number of cells, whose results can be found by Sun *et al.* (2012)

THE SIMULATION RESULTS AND PERFORMANCE ANALYSIS

Here, both system simulation results are provided for the performance of the proposed precoding scheme and the balancing algorithm. It have assumed that the BSs and users both employ two transmit antennas. FFR-based scheduling, as described in Section II, has also been assumed. The cell-edge UE sees two dominant interferers at 0 dB and -3 dB (on the average) with respect to its desired signal. The background interference has been assumed to be at -6 dB with respect to the desired signal. This condition leads to an SIR of approximately -2.5 dB. The in-cell UEs have been assumed to see two interferers at -6 dB and -9 dB with respect to their desired signals, leading to an SIR of 1.25 dB. The path-loss propagation exponent α = 3. The BSs have been assumed to employ single-stream transmission to both the in-cell and the cell-edge UEs. However, the in-cell UE with a higher SIR is served with QPSK modulation. A rate-1/2 error-correcting turbo code is assumed (Gazda *et al*., 2012; Guo *et al*., 2010).

The UE of the cell-edge user is assumed to have complete CSI of its desired BS and the two dominant interfering BSs. It also has perfect knowledge of the covariance of the weaker background interference plus noise. When the cell-edge UE feeds their CSI back to its serving BS, the backhaul network is assumed to be error free and latency free. The in-cell UEs have complete CSI of their serving BSs.

Figure 6 shows the performance of the proposed scheme for the 2×2 MIMO channel. The number of coded blocks in error (BLER) is plotted against the signal-to-noise ratio (SNR). As shown in Fig. 6, there is considerable improvement in the link performance of the cell-edge UE, whereas there is only a modest degradation in the link performance of the in-cell UE.

Figure 7 shows the BLER performance of the proposed scheme for the 4×2 MIMO channel. As in the 2×2 case, Fig. 5 shows that there is considerable improvement in the link performance of the cell-edge user. Moreover, the degradation in the link performance of the in-cell user is further minimized due to the availability of more dimensions when solving Eq. 9, as well as the large array gain given by four transmit antennas.

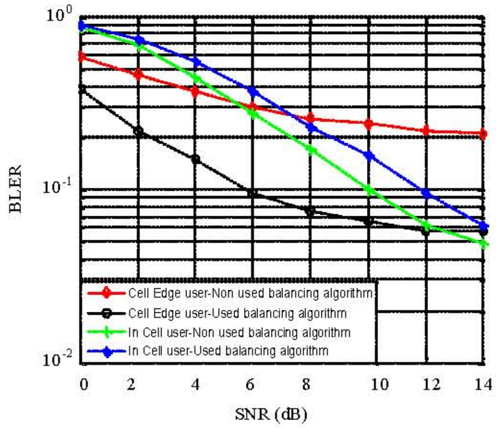

Fig. 6: 2×2 MIMO-block error rate (BLER) performance of the proposed balancing algorithm

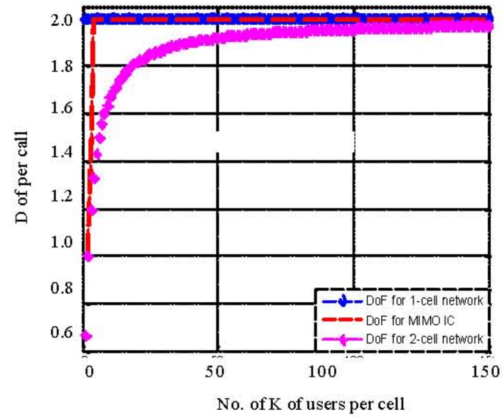

Fig. 8: DoF in the case of Base station Equipped $N_T = 2$ antennas

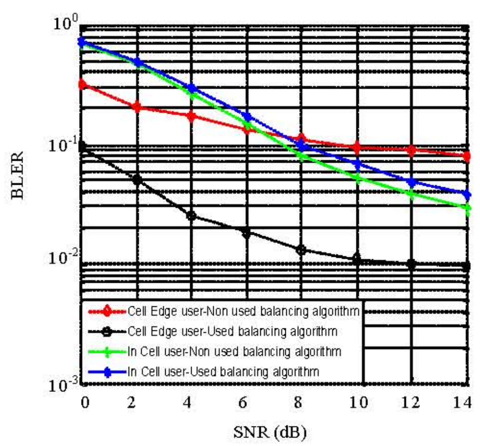

Fig. 7: 4×2 MIMO-block error rate (BLER) performance of the proposed balancing algorithm

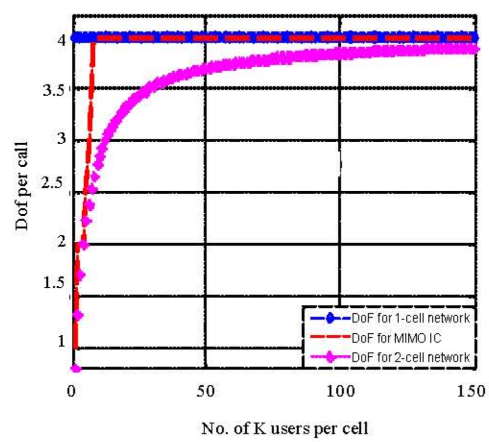

Fig. 9: DoF in the case of Base station Equipped $N_T = 4$ antennas

To achieve better understanding of this result, it would like to compare it with two other well-studied channel models: one is the single-cell model which is free of any interference; the other is the MIMO interference channel model which can be regarded as a scenario in which perfect cooperation is possible among all the K users in each cell such that the K users can be effectively treated as a virtual user with K antennas.

From Lemma 1, we know that the DoF of a cell with K single-antenna users and an N_T-antennas BS equals min (N_T, K). And for the MIMO interference channel with K antennas at each transmitter and N_T-antennas at each BS, the DoF per cell is by the result of Sun *et al*. (2010):

$$\min\left(N_T, K, \frac{\max(N_T, K)}{2}\right)$$

From Fig. 8 and 9, it can be observed that both the effect of muti-user gain (i.e., more users lead to larger DoF and the effect of multi-antenna gain ($N_T = 2$ vs. $N_T = 4$) exist. Comparing between our 2-cell cellular network model and the 1-cell model, it can see that as the number of users increases, the DoF of the former approaches that of the latter which corresponds to an interference-free scenario. Moreover, the comparison between our model and the MIMO interference channel shows that disallowing the perfect cooperation among the users in a cell does incur some DoF loss which however, prone to vanish as the number of users increases. Specifically, the DoF loss of the cellular network as compared with the MIMO interference channel equals:

$$N_T\text{-}(K\,N_T/K+N_T) = N_T^2/(K+N_T)$$

which means that the interference would ruin the potential multiplexing gain of multiple antennas inevitably. That is, through delicate design of interference alignment scheme, it is indeed possible to retain most, in some cases even all, of the multiplexing gain which justifies and encourages the deployment of multiple antennas at the base stations in the future wireless networks (Andrews *et al*., 2007).

CONCLUSION

This study presents a distributed, low system overhead, linear-precoding technique to completely eliminate inter-cell interference of cell-edge users in the presence of colored Gaussian noise. This precoder is based only on locally available Channel-State Information (CSI) at the receiver. At the same time, aiming at the problems existing in the current research that the use of the above precoding, the interfering BS does not beamform to its own in-cell UE, resulting in the loss in array gain to the in-cell UE, it present a balancing algorithm that helps the interfering Base Station (BS) to simultaneously beamform to its own user while still minimizing the interference on the non-intended user. Finally, the degrees of freedom of the two cell cellular network is analyzed. Simulation results show that the proposed scheme considerably improves the performance of the cell-edge users while causing only a mild degradation in the performance of the in-cell users, thereby leading to an increase in the overall system throughput. In the future, the deployment of multiple antennas at the base stations in the wireless networks can be considered.

ACKNOWLEDGMENT

This research work is financially supported by Natural Science Foundation Project of CQ CSTC (cstc2012jjA40046).

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