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An efficient approach for sub-carrier allocation in MIMO MC-CDMA systems

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Sub-carrier allocation is an important process that directly affects users data and bit error rates for multi-user multi-carrier systems. The most important feature of the allocation process is to assign the sub-carriers to the active users in proportion to their needs to provide high-speed data transmission and reduce the bit error rates. In this study, an efficient subcarrier allocation algorithm has been proposed based on both capacity and fairness criteria for a MIMO MC-CDMA system, which is preferred as the multiplexing scheme in high data rate communication systems. The proposed algorithm achieves not only better error rate performance but also increases the total data rate compared to other algorithms

K e y w o r d s: MIMO MC-CDMA, subcarrier allocation, fairness, capacity

1 Introduction

Due to the ever-increasing use of high-data-rate multimedia applications, the need for wireless data transmission at high sp has arisen. Data transmission at high speed is possible by using multiplexing methods that allow efficient use of the frequency band assigned to the system. MC-CDMA is an important multiplexing method that provides spectral efficiency due to the orthogonality of the sub-carriers, so that high speed data transmission can be performed. In addition to providing high-speed data transmission of the MC-CDMA, inter-symbol interference and inter-channel interference immunity and multi-user availability are other important advantages of this system [1].

One of the destructive effects to be considered for wireless communication systems is the signal distortions caused by multi path fading effects. The multi path fading effects cause the signals to arrive at the receiver side from many paths, resulting in undesirable changes in the phase and amplitude of the signal. One of the most effective ways to reduce the negative effects of multi path fading on system throughput is to use multi-input multi-output antennas. The use of multiple antenna structures reduces the fading effects that occur in the channel and consequently the bit error rate of the system is minimized, [1,2].

The MIMO MC-CDMA systems are obtained by combining an MC-CDMA system with multiple receiver and transmitter antenna arrays to increase the system capacity and diversity gain over time-varying or frequency selective fading channels. By using MIMO MC-CDMA in communication systems, not only data transmission at high data rate, but also system performance will be remarkably enhanced. However, in these multi-user systems, how to determine the assignment of total number of subcarriers to active users will directly affect the users data speeds and data error rates [3-23]. In this determination process called subcarrier allocation, total number of subcarriers is assigned to the active users in the amount they required.

The sub-carrier allocation process is generally classified based on capacity and fairness criteria. Capacity based sub-carrier allocation scheme aims to maximize system capacity until the user data rate reaches its highest value [3-5]. And the fairness-based allocation process performs the allocation scheme according to the fairness criterion while maintaining the proportional constraints [6-8]. As can be inferred from the studies about allocation process, resource management is an indispensable process for a communication system to achieve greater efficiency with minimum resources. Therefore, for this process various proposals have been presented in recent years. In the study [9], the performance of the max-min algorithm considering the fairness criterion has been examined in OFDM systems. In the study of [10] the Max min-based resource allocation has been performed to provide fairness with regards to energy efficiency for OFDMA systems.

And it has been shown that system performance gains can be obtained by performing less complex resource allocation based on robust max-min operation in cognitive radio systems [11]. In the greedy algorithm, which is another algorithm used for allocation process, the allocation has been performed considering capacity maximization. The study [12] has presented the bit error performance of the allocation process using the greedy algorithm in MC DS-CDMA systems. The proposal of allocation scheme using greedy algorithm has better system capacity compared to water filling algorithm for MIMO-OFDMA sys-

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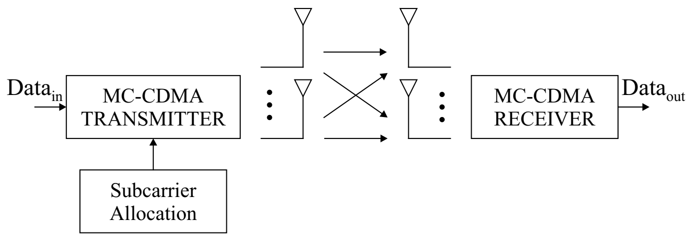

Fig. 1. MIMO MC-CDMA system

tems in [13]. With use of the advantages of both the capacity and fairness criteria, it is possible to achieve the maximum value of the speed obtained from the system while maintaining the fairness between the users. Thus, a fairer allocation process is carried out in the two-stage allocation process in the studies [14-16], which take into account both criteria. The proposed algorithm in [17] has shown better performance than the other algorithms in MC- CDMA system and the bit error rates were reduced, and the users data rate was increased.

In this study, an efficient subcarrier allocation process is performed in MIMO MC-CDMA systems with different antenna structures by using an algorithm that takes into consideration both of capacity and fairness criterion.

2 Multi-input multi-output multicarrier code division multiplexing system

The simplified block diagram of a multi-user MIMO MC-CDMA with U users and N_x transmitter antennas at base station (BS) and N_y receiver antennas in a downlink channel is shown in Fig.1.

For this system, the BS allocates the subcarriers to u-th user according to a specific criterion and informs them that they have been assigned. The parameter υ with values 1 or 0 specifies whether subcarrier (s) will be allocated to user u

$$u_{\mathrm{u,s}} = \begin{cases} 1, & u = \operatorname{argmax}\{\lambda^1_{s,\max}, \ldots, \lambda^U_{s,\max}\} \\ 0, & \text{else} \end{cases}, \qquad (1)$$

where λ^U_s is the s-th subcarriers's signal to noise ratio for user u. It is necessary to minimize total power value P_{tot} to optimize the system

$$P_{\mathrm{tot}} = \sum_{s=1}^{S}\sum_{u=1}^{U} \upsilon_{u,s}\, P_{u,s}, \qquad (2)$$

where, $P_{u,s}$ is the power that is assigned to u-th user's s-th subcarrier.

Minimum total transmit power for subcarriers can be obtained by maximizing the received SNR. Beamforming is best with regards to maximizing the received SNR. Based on this result, first beamforming vector a_s and weighted combining vector b_s are achieved, [18,19]. $a_s = [a_{s,1}\ldots a_{s,N_x}]^\top$ is the beamforming vector N_x for s-th subcarrier and $b_s = [b_{s,1}\ldots b_{s,1}]^\top$ is the combining vector for s-th subcarrier.

Let H_s define the channel response of u-th at the s-th subcarrier of $N_y \times N_x$ matrix. In that case the received data at s-th subcarrier is,

$$r_s = H_s a_s x_s + n\upsilon_s, \qquad (3)$$

where, x_s is a transmitted signal for s-th subcarrier and n is the noise vector, [20]. To achieve the optimum weighted combining vector, we obtain

$$b_s = \left(H_s a_s\right)^{\mathrm{H}}, \qquad (4)$$

where the notation "H" is Hermitian transpose. Combined received signal can be obtained, when received signal and weighted combining vector are multiplied as

$$b_s r_s = \left(H_s a_s\right)^{\mathrm{H}} H_s a_s x_s + \left(H_s a_s\right)^{\mathrm{H}} n\upsilon_s. \qquad (5)$$

The SNR at receiver output can be expressed as,

$$r_{SN} = \frac{E\{|\left(H_s\right)^{\mathrm{H}}\left(a_s\right)^{\mathrm{H}} H_s a_s x_s|^2\}}{E\{|\left(H_s\right)^{\mathrm{H}}\left(a_s\right)^{\mathrm{H}} n w_s|^2\}} = \frac{E}{N_0} H_s^{\mathrm{H}} H_s a_s, \qquad (6)$$

where E, $H_s^{\mathrm{H}} H_s$ represent expectation and hermite matrix, respectively. Eigen decomposition of the Hermite matrix is

$$H_s^{\mathrm{H}} H_s = M_s D_s M_s^{\mathrm{H}}. \qquad (7)$$

Here M_s is unitary matrix and D_s is diagonal matrix.

The subcarriers can be assigned to the user who has the maximum received SNR. This user's maximum eigenvalue $\lambda_{s,\max}$ is larger than any other users.

Optimal beaming vector and weighted vector are

$$a_s = u_(u, s, \max), \qquad (8)$$

$$b_s = \left(H_s \alpha_s\right)^{\mathrm{H}} = \left(H_{u,s} u_{u,s,\max}\right)^{\mathrm{H}}, \qquad (9)$$

where, $u_{s,\max}$ represents an eigen vector. We can write the transmitted symbol of s-th subcarrier as

$$t_s = \sum_{i=1}^{U} \alpha_{i,s} H_{i,s} a_s x_{i,s} = H_{u,s} u_{u,s,\max} x_{u,s}. \qquad (10)$$

Then maximum received SNR of the s-th subcarrier can be written as

$$\left(r_{SN}\right)_{s,\max} = \frac{E_s \lambda^u_{s,\max}}{N_0}, \qquad (11)$$

3 Subcarrier allocation algorithm

The proposed allocation process is performed in 2 steps. These steps are shown in flow diagram in Fig. 2.

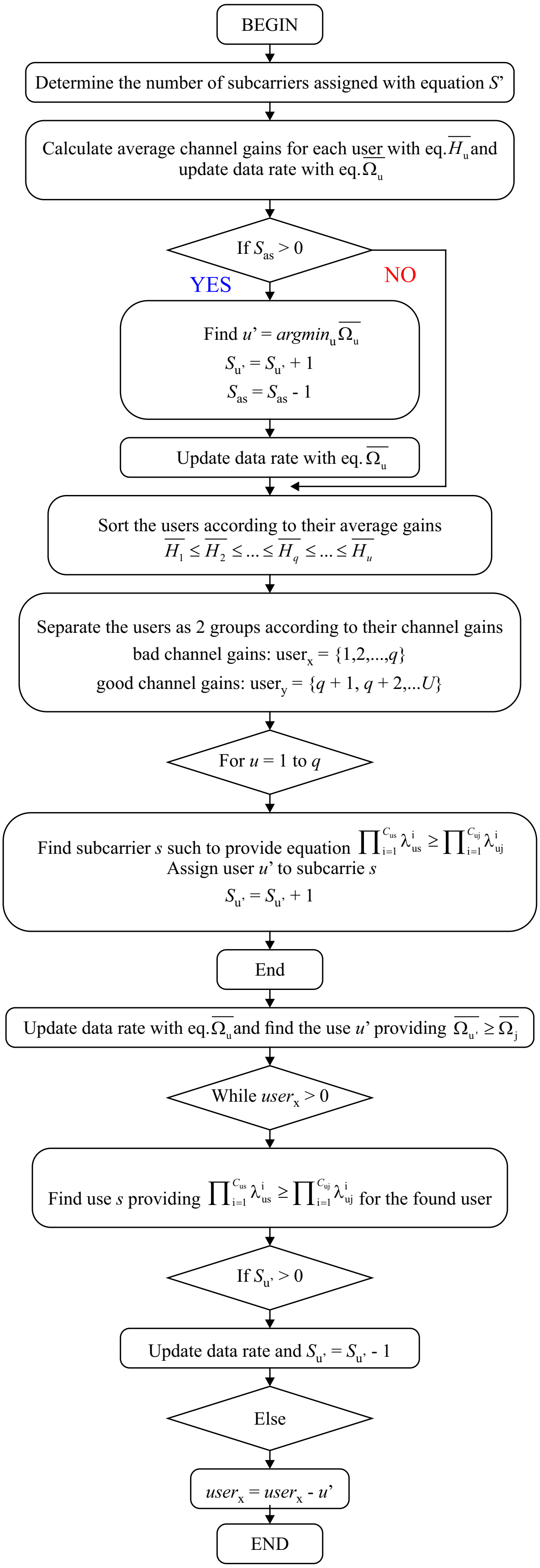

Fig. 2. Flow diagram of the proposed algorithm

At the start of the step 1, the number of subcarriers that will be assigned to the user is determined. The total number of subcarrier S_T is divided to user's plus 1, the number of subcarriers to be assigned per user

$$S' = \text{floor}(\frac{S_T}{u+1}), \quad u = \{1, 2, \dots, U\}, \tag{12}$$

and the number of subcarriers be unassigned

$$S_{as} = S' + remainer. \tag{13}$$

We need to know the rates of users to distribute unassigned subcarriers to users. For each user, the average channel gains are calculated as

$$\overline{H_u} = \frac{1}{S} \sum_{s=1}^{S} \text{sum}(H_{us}), \quad \forall_u, \tag{14}$$

where H_{us} is the channel gain of u-th user at s-th subcarrier.

The rate of u-th user is

$$\overline{\Omega_u} = \frac{S_u}{S} \log_2\big(1 + \frac{\overline{H_u}\,\overline{P_u}}{S_0}\big), \tag{15}$$

where S_u is the number of u-th user's subcarrier and $\overline{P_u}$ is average power.

If S_{as} is not zero, the user with the minimum rate according to the updated data rates is found. While subcarriers amount to be assigned to that user is increased by one, S_{as} is decreased by one. This process is repeated until S_{as} value is 0. As a result of this, and subcarriers amount which will be allocated to each user is specified. At the second step, the users are sorted from small to large according to their channel gain. For this process, firstly the number of users is divided by 2. Its first half is called bad channel gains group and the other half is called as good channel gains group. At first, assignment is made to bad channel gains group. For this operation, a subcarrier with maximum eigen value is found and it is assigned to the first user and the number of subcarriers to be allocated to that user is reduced by one. Again, a subcarrier with maximum eigen value is found and it is allocated to the second user and the number of subcarriers to be allocated to that user is reduced by one. This method continues till the last user in the bad channel gains group. At the end of assignment, the rates of users in the bad channel gains group are updated. In result of the update, the user with minimum rate is found, and the subcarrier with the maximum eigen value between the unassigned subcarriers is found and it is assigned to that user. The number of subcarriers to be allocated to the active user is reduced by one. This state continues until the specified number of subcarriers are assigned to the all the users in the bad channel gains group. When the assignment is finished, the same operations are performed for users in the good channel gains group and the allocation operation is completed.

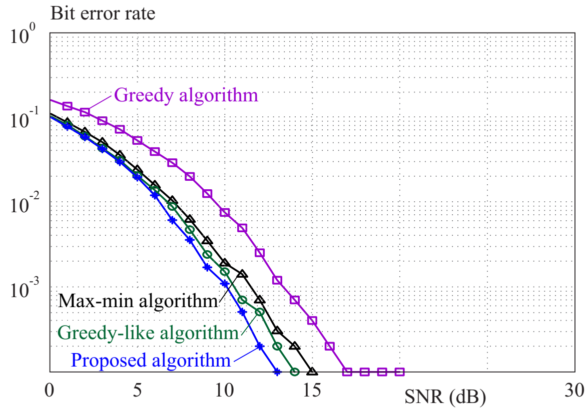

Fig. 3. BER of algorithms for first user in 2×2 MIMO MC-CDMA systems

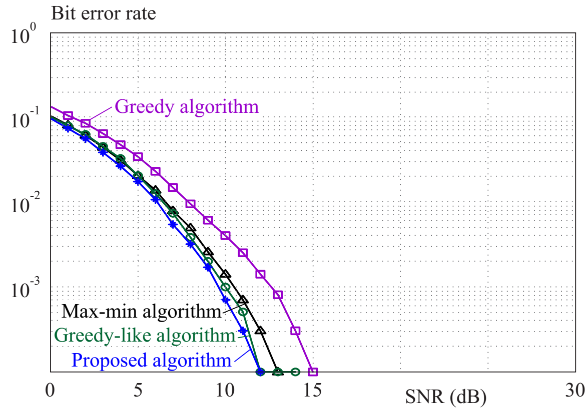

Fig. 4. BER of algorithms for first user in 3×3 MIMO MC-CDMA systems

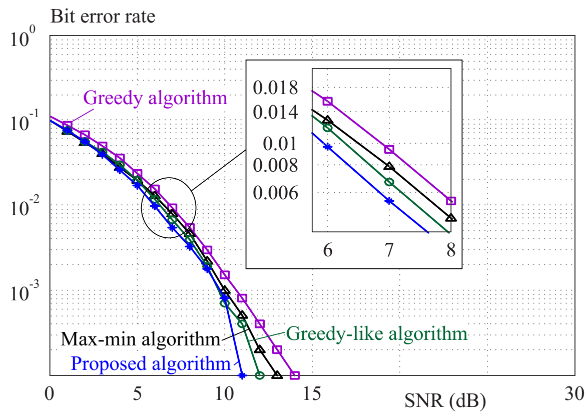

Fig. 5. BER of algorithms for first user in 4×4 MIMO MC-CDMA systems

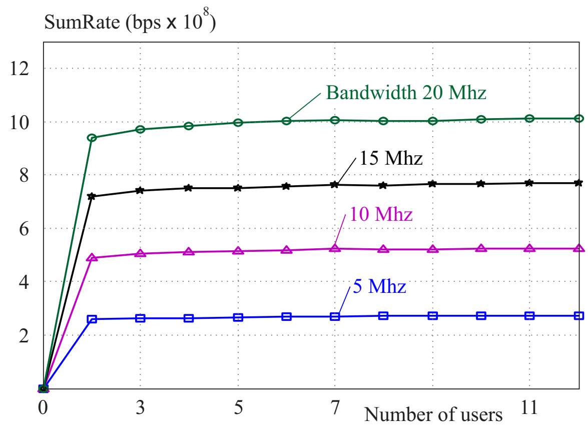

Fig. 6. Sum rate of the proposal for various bandwidths

4 Simulation results

Simulations have been carried out for a 4 users MIMO MC-CDMA with 256 subcarriers and different amounts of transceiver antennas to compare the proposal with the other algorithms with regards to bit error rate and total data rate. And the modulation scheme has chosen as BPSK over Rayleigh fading channel with 1 MHz bandwidth. The performance of the proposed algorithm for the 2×2 MIMO MC-CDMA system has been analyzed through the variation of the BER versus the SNR in Fig. 3, where we observe that the BER of the proposal is better than others. Although the proposed algorithm has the best BER value among the simulated algorithms, greedy algorithm has the worst BER value. The BER values of the proposed algorithm are further reduced at increasing SNR. For example, at 5 dB SNR, the BER distinction between the proposal and greedy algorithm is about 10^{-1} and this difference is reach to more than 10^{-1} value. Moreover, at 10^{-2} BER, SNR gain of the proposed algorithm is 1 dB better than the Greedy-like algorithm, which has the closest performance to the proposal. At $10-3$ BER, the proposed algorithm has 2 dB more than max-min and 3.5 dB more than greedy algorithm.

The second comparison of the algorithm is done for 3x3 MIMO MC-CDMA system in Fig. 4. According to the Fig. 4, increasing the number of transceiver antennas has further improved the BER values of the system. When we examine the performances of the algorithms, we can see that the proposed algorithm has the least error values as in the 2x2 system. Such that at 10$^{(}$-3) BER, the SNR gain of the proposed algorithm is 1 dB than Greedy-Like 2 dB than Max-Min and 4 dB than Greedy algorithm.

Figure 5 contains the results obtained for 4×4 MIMO MC-CDMA system. As we can infer from this, although the performance of the algorithms is close to each other, the performance of the proposed algorithm remains higher than others. As shown in the magnified graphs, the BER value of the proposed algorithm is 0.0056, Greedy-Like is 0.0068, max-min is 0.008 and Greedy is 0.0096 at 7 dB SNR. In the case of increasing SNR values, these BER values are further increased. In addition, the SNR gain of the proposed algorithm improves even more with the decreasing BER value, as compared to the values where the BER values are higher.

The Sum rate versus users performance evaluation of the proposed algorithm in the system with various bandwidths has been presented in Fig. 6. As clearly be inferred from Fig. 6, the data rate of the users will also increase in the event of increase in bandwidth. For example, the total speed of the system with 12 users in 5 MHz bandwidth is approximately 2.67 $\times$108 bps, whereas the total speed is 5.34 x108 bps in 10 MHz bandwidth. In case of bandwidth is 20 MHz, the sum data rate is more than 10×108 bps.

5 Conclusion

In this work, it is proposed to use an efficient algorithm for subcarrier allocation in the MIMO MC-CDMA system that is used for high-speed data transmission. The main difference of this algorithm compared to the other algorithms is that it makes the allocation process more efficient by considering both capacity maximization and fairness. Simulation results also demonstrate that the proposal has significant performance improvements both in bit error rates and in the total speed values of the system. It can be said that this proposal can be used for subcarrier allocation not only in MIMO MC-CDMA system but also in other high-speed communication systems due to it is both flexible and easy to use and its good performance in bit-rate and data speed.

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