

Suboptimal Resource Allocation for MIMO-OFDMA Systems

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ABSTRACT

In this paper, a pragmatic resource allocation algorithm for single-cell downlink multi input-multi-output (MIMO) based orthogonal frequency division multiple access(OFDMA) systems is proposed. The objective of this method is to maximize the average system throughput as a function of bit error rate and (BER) spectral efficiency by allocating the users, transmission power and information bits across the utilized subchannels. The resulting throughput maximization problem has been decoupled into two sub-problems to reduce the computational complexity, however, at the expense of performance a sub-optimal solution is obtained. The simulation results of the throughput and outage probability, obtained using MATLAB simulator, show the efficiency and accuracy of the proposed system in comparison with the other approaches.

Keywords: Multi Input-Multi-Output, Orthogonal Frequency Division Multiple Access.

توزيع المصادر شبه الأمثل في أنظمة MIMO-OFDMA

الخلاصة

في هذا البحث، تم اقتراح خوارزمية واقعية لتخصيص الموارد لأنظمة الخلية الواحدة والمعتمدة على تقنية متعدد المدخلات والمخرجات (MIMO) لمقسم الترددات المتعامدة ذات الوصول المتعددة. الهدف من هذه الخوارزمية هو تعظيم معدل وصول المعلومات الصحيحة والتي يتم وصفه كدالة لنسبة المعلومات الخاطئة (BER) والكفاءة الطيفية من خلال تخصيص المستخدمين، توزيع القدرة الكهربائية وتوزيع المعلومات على القنوات الفرعية المستخدمة. تم تقسيم مشكلة زيادة معدل المعلومات الصحيحة إلى عدة مشاكل لتقليل التعقيد وكلفة الحل ولكن على حساب الأداء لكي يعطي الحل شبه الأمثل. أظهرت نتائج المحاكاة لمعدل وصول المعلومات الصحيحة واحتمالية التخريخ، المحصلة من برنامج المحاكاة (MATLAB)، كفاءة و دقة النظام المقترح مقارنة بالأنظمة الأخرى.

INTRODUCTION

Multi-Input-Multi-Output (MIMO) and Orthogonal Frequency Multiple Access (OFDMA) technologies represent efficient candidates for wireless transmission multiuser systems, which are considered by many modern system standards [1]. Recently, MIMO-OFDMA technologies have been combined with adaptive modulation and coding (AMC) in addition to resource

allocation methods in order to achieve an efficient transmission systems that can exploit the change over the underlying channels, called channel diversity, for different users. Numerous publications focus on transmission techniques based on combining AMC and resource allocation methods with MIMO-OFDMA systems. In [2] and [3], a performance comparison in terms of total capacity for MIMO-OFDMA and MIMO-multicarrier (MC)-coded division multiple access (CDMA) systems was presented. In [4], a resource allocation method aimed to minimize the required transmission power for each user in MIMO-OFDMA systems was provided. In [5], an adaptive algorithm was proposed constructed to maximize the spectral efficiency in terms of bit error rate (BER) constraint based on selected active eigenmodes, power assigning and modulation order, while in [6], a sub-optimal resource allocation technique for MIMO-OFDMA system was investigated.

This paper presents a resource allocation (RA) method for a single-cell downlink spatial multiplexing MIMO-OFDMA systems. The proposed method aims to maximize the system throughput by allocating users, information, represented as bit vectors, and total power over the considered subcarriers at an assigned base station (BS). The throughput of the investigated systems can be written as a function of the number of transmitted bits per seconds, called spectral efficiency and BER for distinct modulation and coding schemes (MCS) involved within the same transmitted OFDMA frame. This is to provide the underlying system with more flexibility in terms of MCS selection. The throughput maximization problem is divided into two sub-problems, which are solved using different algorithms based on a decomposition method. The aim was to reduce the cost complexity and the required long time search among the subcarriers to allocate the given sources. It is important to note that there are ten MCS selections used in the AMC technique. These ten options start from the lowest one, which is no transmission, while the other nine options include 64-quadrature amplitude modulation (QAM), 16-QAM and quadrature phase shift keying (QPSK) combined with the convolutional coding rates of 1/2, 2/3 and 3/4.

MIMO-OFDMA System Model

Singular value decomposition (SVD) based single-cell MIMO downlink channel is considered to transmit a wireless OFDMA signal from an assigned BS to K mobile users [2]. The BS is equipped with N_t transmit antennas, whilst each user has N_r receive antennas, under the assumption of $N_t \geq N_r$. This assumption has been considered to guarantee the full scattering MIMO channel. The transmitted OFDMA frames are divided into B subchannels, which include equal number of subcarriers. Additionally, it is assumed that each user has been assigned to a subchannel, thus, the number of used subchannels is equal to the number of users. The considered channel between the BS and k -th user for a subcarrier at b -th subchannel is denoted $\mathbf{H}_k \in \mathbf{C}^{N_t \times N_r}$, where $b = 1, \dots, B$, $k = 1, \dots, K$ are the index of utilized subchannels and users respectively. In this paper, it is assumed that the Channel State Information (CSI) is perfectly known at the transceivers of both BS and mobile users. In addition, different profiles of mobile international telecommunication union (ITU) channels are considered to generate i.i.d time varying MIMO multipath fading channels that simulate the physical location of each user [7].

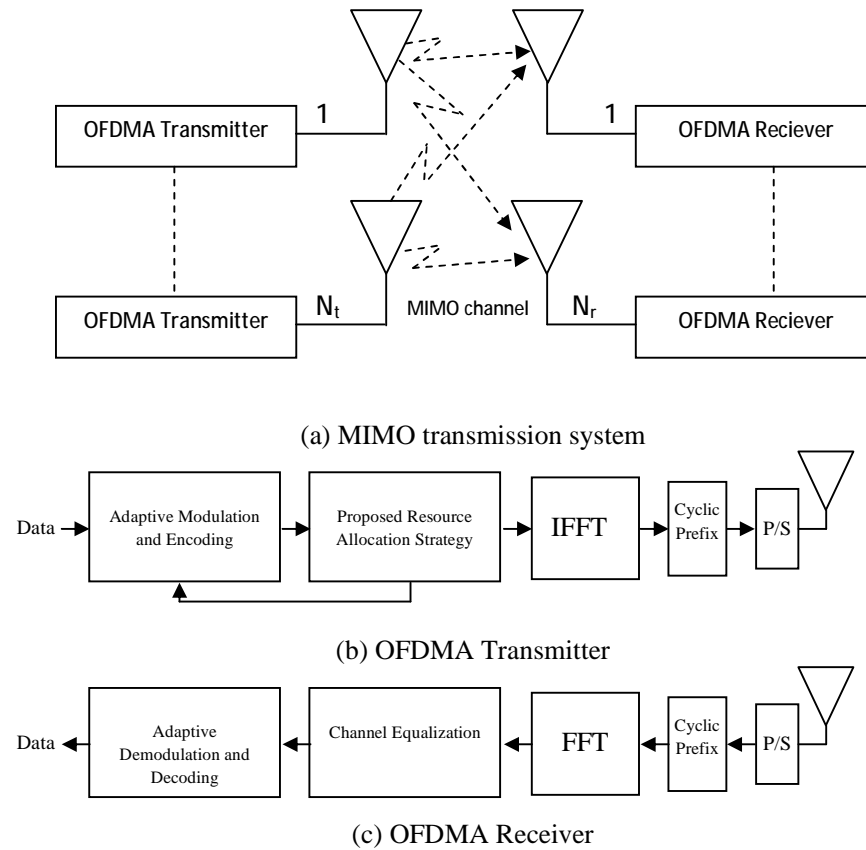


Figure (1) Block diagram of the proposed MIMO-OFDMA system.

Figure (1) illustrates the block diagram of the investigated MIMO-OFDMA system based on the proposed RA strategy. Figure (1a) explains the MIMO-OFDMA system in general. From Figure (1b), the transmitter groups the data of all users in B subchannels and these groups are encoded and modulated based on the selected MCS levels, which satisfy the total transmission power and corresponding channel conditions. The ‘Proposed Resource Allocation Strategy’ block allocates the users, power and information bits among the utilized subchannels and selects the suitable MCS for them by implementing the proposed method. It is important to note that the resource allocation information (RAI) is generated by the ‘Proposed Resource Allocation Strategy’ block and sent to the receiver of each user using the downlink control signals. A time domain OFDMA signal is generated via the Inverse Fast Fourier Transform (IFFT) block and by appending acyclic prefix (CP).

Zero forcing (ZF) equalization is performed at the receiver prior detection to cancel residual multipath channel interference as shown in Figure (1c) [8]. At the output of equalizers, the decision variables for user k are demodulated and decoded according to the known selected MCS of each subchannel utilizing soft maximum likelihood demodulator and soft-in-hard-out Viterbi decoder [8], [9]. In a rich

scattering environment based on the eigenmode transmission, the number of spatial channels, N_c , for each subcarrier in b -th subchannel, is bounded by $\min(N_b, N_r)$, i.e. $N_c = \min(N_b, N_r)$ for $k \in \{1, \dots, K\}$ users and $b \in \{1, \dots, B\}$ subchannels. The throughput of g -th OFDMA block, which includes different transmitted OFDMA frames from N_t antennas over N_c channels can be formulated as,

$$\psi_g = \sum_{k=1}^K \sum_{b=1}^B \sum_{r=1}^{N_c} \vartheta(k, b) D_k^{(r)}(b) \gamma_k^{(r)}(b) \quad \dots (1)$$

$$-\varpi_k^{(r)}(b) \sum_{k=1}^K \sum_{b=1}^B \sum_{r=1}^{N_c} \vartheta(k, b) D_k^{(r)}(b) \gamma_k^{(r)}(b),$$

Where $(k, b) \in \{0, 1\}$ is the element value of the user allocation matrix that assigns the user k to the subchannel b [2]. Each row in this matrix represents a user $k \in \{1, \dots, K\}$ and each column is a subchannel $b \in \{1, \dots, B\}$. The term $D_k^{(r)}(b)$ denotes the number of data subcarriers of the subchannel b assigned to the user k propagated over the spatial channel r . It is important to note that this paper considers the subchannels, which include $D_k^{(r)}(b)$ subcarriers for each one. Therefore, the formulated equation of (1) adopts the total number of subcarriers involved in each subchannel instead of subcarriers and then just subchannel summation is required. Moreover, $\gamma_k^{(r)}(b)$ denotes the related spectral efficiency that can be evaluated in terms of selected convolutional coding rate, $\rho_k^{(r)}(b)$, and modulation order, $M_k^{(r)}(b)$, as $\gamma_k^{(r)}(b) = \rho_k^{(r)}(b) \log_2[M_k^{(r)}(b)]$. Furthermore, $\varpi_k^{(r)}(b)$ is the related bit error rate (BER).

THE PROPOSED RA METHOD

As mentioned earlier, the presented resource allocation method is aimed to maximize the throughput of the investigated system with number of restrictions includes power and user allocation. The arithmetical representation of the proposed method is formulated following the optimization methods of [12] as,

$$\underset{\vartheta(k,b)}{\text{Maximize}} \psi_g = \sum_{k=1}^K \sum_{b=1}^B \sum_{r=1}^{N_c} \vartheta(k, b) D_k^{(r)}(b) \gamma_k^{(r)}(b), \quad \dots (2)$$

$$-\varpi_k^{(r)}(b) \sum_{k=1}^K \sum_{b=1}^B \sum_{r=1}^{N_c} \vartheta(k, b) D_k^{(r)}(b) \gamma_k^{(r)}(b),$$

subject to:

$$\sum_{k=1}^K \sum_{b=1}^B \sum_{r=1}^{N_c} \vartheta(k, b) \mu_k^{(r)}(b) A_{sc_k}^{(r)}(b) = A_T \quad \dots (3)$$

$$\sum_{k=1}^K \vartheta(k, b) = 1, \quad b = 1, \dots, B, \quad \dots (4)$$

$$\sum_{b=1}^B \vartheta(k, b) = 1, \quad k = 1, \dots, K, \quad \dots(5)$$

where (3) is the power constraints, while (4) and (5) denote the fairness user allocation constraints, which guarantee the allocation of one user per subchannel. Additionally, $A_{sc_k}^{(r)}(b) = D_K^{(r)} A_{s_k}^{(r)}(b)$ is the power value of the b -th subchannel that is assigned to k -th user and transmission over r -th channel as a function of the average coded and modulated symbol power, $A_{s_k}^{(r)}(b)$. Moreover, $\mu_k^{(r)}(b)$ adjusts the required power value for each subcarrier within the b -th subchannel. Its initial value is determined in terms of uniform power distribution as $\mu_k^{(r)}(b) = \frac{\Delta T}{N_c D_K^{(r)}(b) A_{s_k}^{(r)}(b)}$. Finally, ΔT is the total transmission power of the corresponding BS. In contrast, $\varpi_k^{(r)}(b)$ can be obtained utilizing the general approximated BER formula [10],

$$\varpi_k^{(r)}(b) = \alpha_{1_k}^{(r)}(b) \exp \left[-\alpha_{2_k}^{(r)}(b) \hat{\zeta}_k^{(r)}(b) \right], \quad \dots(6)$$

where $\hat{\zeta}_k^{(r)}(b)$ is the minimum SNR value of the subcarriers within the b -th subchannel, while $\alpha_{1_k}^{(r)}(b)$ and $\alpha_{2_k}^{(r)}$ are fitting constants. The minimum SNR value has been chosen to guarantee the safe selection of the MCS and then increasing the efficiency of the proposed system. Furthermore, $\varpi_k^{(r)}(b)$ is evaluated as described in [11]. Furthermore, $\hat{\zeta}_k^{(r)}(b)$ can be evaluated as [11],

$$\begin{aligned} \hat{\zeta}_k^{(r)}(b) &= \mu_k^{(r)}(b) \zeta_k^{(r)}(b), \\ &= \mu_k^{(r)}(b) \min \left[A_{s_k}^{(r)}(b) \frac{\varrho_{k_t, r}^{(b, d)}}{2\sigma_{W_{kr}}^{(b, d)}(b)} \right], \quad \dots(7) \end{aligned}$$

Where $\sigma_{W_{kr}}^{(b, d)}$ is the variance value of the related complex AWGN coefficients. In the other words, it is evaluated from the AWGN complex coefficients represented mathematically as a vector. The term $\left[\varrho_{k_t, r}^{(b, d)} \right]_{r \in \{1, \dots, N_c\}}$ denotes the r -th eigenvalue of $[\mathbf{H}_k^{(b, d)} \mathbf{H}_k^{(b, d)H}]$ for the d -th data subcarrier within b -th subchannel, where $(.)^H$ is the Hermitian transpose operation. In order to achieve a practical solution to the investigated complex problem expressed in (2)-(5), the problem is divided into two sub-problems. Each sub-problem is solved by proposing two algorithms based on the decomposition method [12]. These algorithms are low complex and obtain a sub-optimal solution due to the decoupling.

THE ASSIGNMENT OF USER

As highlighted above, the resource allocation problem has been divided into two sub-problems. This is to reduce the computational complexity. The computational complexity is the result of the huge searching operations amongst the transmitted subcarriers to obtain the optimal allocation for users, information bits and power. The search operations look at the user allocation and at the same time

find out if this allocation can be satisfied in terms of power and information bits. Therefore, these operations run many times to achieve the optimal allocation. On the other hand, the proposed method separates the allocation of users on the power and bits distribution, which indeed reduces the search operations to almost half and then reduce the computational complexity. The user allocation assignment sub-problem is considered here based on assuming that the data, represented in binary bits, are allocated to the top level of the MCS options. Additionally, the transmission power of the base station is divided equally over the underlying B subchannels as $A_{sc_k}^{(r)}(b) = \frac{\Lambda T}{N_c B}$, where $\mu_k^{(r)}(b) = 1$. The $\mu_k^{(r)}(b) = 1$ is assumed to distribute the power equally over the subchannels. As a result, the power constraint of (3) is removed. Furthermore, the objective function of (2) is rewritten to be a concave function that satisfies the Hessian matrix conditions [12] by rewriting (6) as,

$$\omega_k^{*(r)}(b) = \alpha_{1k}^{(r)}(b) \exp \left[\frac{-\vartheta(k,b) \alpha_{2k}^{(r)}(b) \zeta_k^{(r)}(b)}{\vartheta(k,b)} \right], \quad \dots (8)$$

The user allocation sub-problem can be solved using the Lagrange optimization method. The Lagrange function is written as [12],

$$\begin{aligned} \Xi[\vartheta(k,b)] &= \sum_{k=1}^K \sum_{b=1}^K \sum_{r=1}^{N_c} \vartheta(k,b) D_k^{(r)}(b) \gamma_k^{(r)}(b), \\ &- \sum_{k=1}^K \sum_{b=1}^K \sum_{r=1}^{N_c} [\vartheta(k,b) D_k^{(r)}(b) \gamma_k^{(r)}(b) \omega_k^{*(r)}(b), \quad \dots (9) \\ &- \sum_{b=1}^K \eta_k(b) \left[\sum_{k=1}^K \varphi(k,b) - 1 \right], \\ &- \sum_{k=1}^K \eta_b(k) \left[\sum_{m=1}^M \varphi(k,b) - 1 \right], \end{aligned}$$

where $\eta_k(b)$ and $\eta_b(k)$ denote the Lagrange multipliers, that are used for achieving the optimal solution. After applying the Lagrange multiplier method to solve the expressed Lagrange function, the optimal value of the Lagrange multiplier $\eta_b(k)$ is evaluated as,

$$\eta_b(k) = \sum_{r=1}^{N_c} D_k^{(r)}(b) \gamma_k^{(r)}(b) - \sum_{r=1}^{N_c} D_k^{(r)}(b) \gamma_k^{(r)}(b) \left\{ \alpha_{1k}^{(r)}(b) \times \exp \left[-\alpha_{2k}^{(r)}(b) \zeta_k^{(r)}(b) \right] \right\} - \eta_k(b), \quad \dots (10)$$

additionally, $\eta_b(k)$, referred to as *user allocation value*, has been set to zero when the user k has not been assigned to the subchannel b at this point. It is set with the maximum value to avoid the choosing of the same channel for two or more users. On the other hand, the user allocation sub-problem is tackled in the fixed domain,

i.e. $\vartheta(k, b) \in \{0, 1\}$. In this domain, the b -th subchannel is allocated to the k -th user with maximum $\eta_k(b)$ value, $k_{opt}^{(r)}(b)$. The $\vartheta(k, b)$ values are evaluated as [12],

$$\vartheta(k, b) = f(\mathbf{x}) = \begin{cases} 1, & \text{if } k = \mathbf{k}_{opt}(\mathbf{b}) = \arg \max \{ \eta_b(k) \}, \forall m \in \{1, \dots, M\} \\ 0, & \text{otherwise} \end{cases} \quad \dots(11)$$

user allocation algorithm is illustrated in Figure (2). All the subchannels of the available users select the top level of the MCS options with modulation type of 64-QAM and convolutional coding rate of 3/4. Then, a zero value is given for $\eta_k(b)$ for all users. After obtaining the performance of all users among the subchannels using (10), the $\vartheta(k, b)$ value for the k -th user is evaluated following (11). In addition, the $\eta_k(b)$ value for the selected user is maximized.

THE ASSIGNMENT OF POWER AND BIT

The bit and power assignment sub-problem, which is the second division of the investigated problem, is solved here. After obtaining the optimal user allocation as mentioned in the previous section, the optimal power allocation is achieved by solving the underlying problem using Lagrange multiplier as [12],

$$\mu_k^{(r)}(b) = \frac{\ln[\vartheta(k, b) D_k^{(r)}(b) \gamma_k^{(r)}(b) \alpha_{1k}^{(r)}(b) \alpha_{2k}^{(r)}(b) \zeta_k^{(r)}(b)] - \ln(\Omega) - \ln[\vartheta(k, b) \Lambda_{sc_k}^{(r)}(b)]}{\alpha_{2k}^{(r)}(b) \zeta_k^{(r)}(b)}, \quad \dots (12)$$

Where Ω denotes the Lagrange multiplier that can help to obtain the desired power values for the subchannels. In order to find $\ln(\Omega)$, (12) is substituted in (3) to obtain,

$$\ln(\Omega) = \frac{\sum_{k=1}^K \sum_{b=1}^B \sum_{r=1}^{N_c} \left[\frac{\ln[\vartheta(k, b) \Pi_{A_r}(k, b) \alpha_{1k}^{(r)}(b) \alpha_{2k}^{(r)}(b) \zeta_k^{(r)}(b)] \vartheta(k, m) \Lambda_{sc_k}^{(r)}(b) - \ln[\vartheta(k, m) \Lambda_{sc_k}^{(r)}(b)] \vartheta(k, m) \Lambda_{sc_k}^{(r)}(b)}{\alpha_{2k}^{(r)}(b) \zeta_k^{(r)}(b)} \right] - \Lambda_T}{\sum_{k=1}^K \sum_{b=1}^B \sum_{r=1}^{N_c} \left[\frac{\vartheta(k, m) \Lambda_{sc_k}^{(r)}(b)}{\alpha_{2k}^{(r)}(b) \zeta_k^{(r)}(b)} \right]}, \quad \dots (13)$$

Figure (3) explains the proposed bit and power allocation algorithm. In this algorithm, all the underlying subchannels are valued with the highest MCS option. The next step is the evaluation of the SNR values for the subchannels over distinct spatial channels. Subsequently, the $\mu_k^{(r)}(b)$ values for the subchannels based on (12) are computed and the power constraints expressed in (3) is verified. Based on the satisfactory of this constraint, the system checks the serving status of all subchannels. Otherwise, the selected MCS option of the subchannels with low SNR values is reduced sequentially until either the lowest MCS option is reached (no transmission) or the constraint of (3) is satisfied. The subcarriers of the subchannels that select no transmission option are distributed over other subchannels.

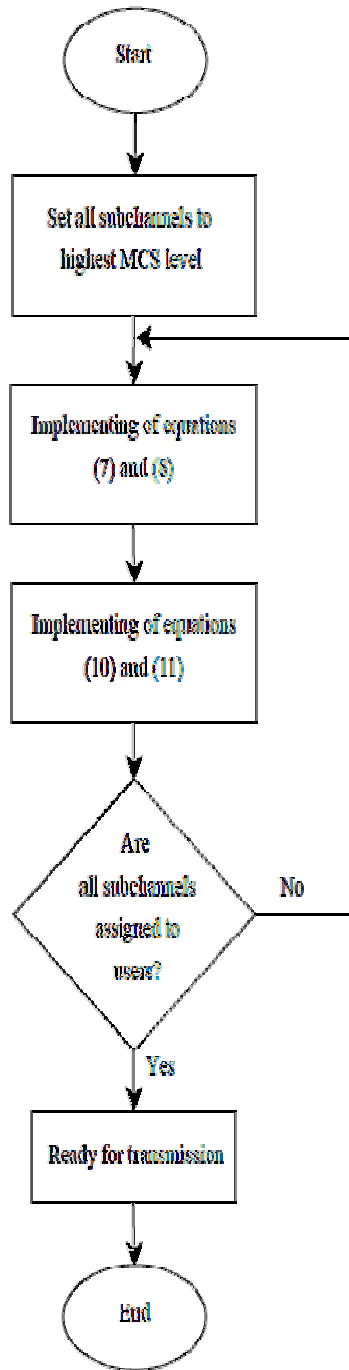


Figure (2) Flow chart of the proposed user allocation algorithm.

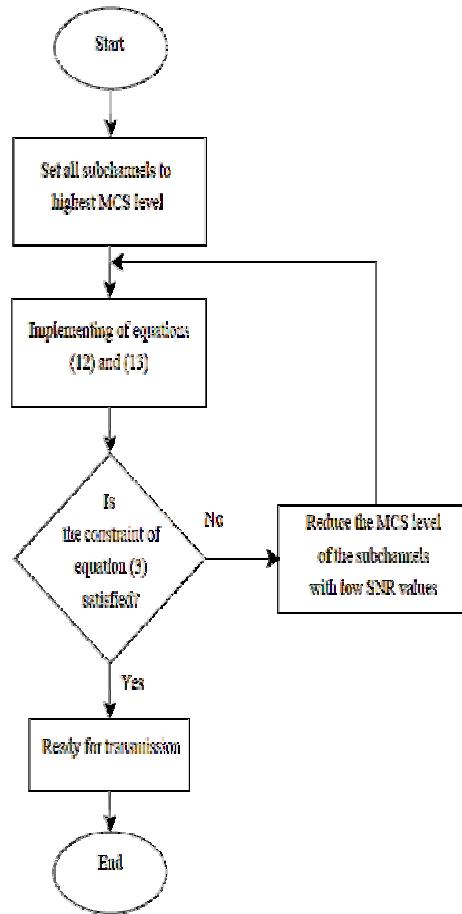


Figure (3) Flow chart of the proposed bit and power allocation algorithm.

SIMULATION RESULTS

In this section, the performance results of the investigated MIMO-OFDMA system based on the proposed RA method and conventional strategies are presented. The proposed MIMO-OFDMA system considers the following parameters based on WiMAX technology [1]. The number of subcarriers for each transmitted OFDMA frame is the same number of FFT points, which is $N_{FFT}=2048$. These subcarriers are divided into $D_T=1440$ data subcarriers, $PI_T=240$ pilot subcarriers and $G_T=368$ guard subcarriers. Furthermore, mobile ITU channels are adopted to generate the MIMO multiuser environment with distinct mobility speed and channel conditions for each user. The number of users, $k=15$, transmit antennas of $N_t \in \{1,2,3,4\}$ and receive antennas of $N_r \in \{1,2,3,4,5\}$ are considered. The presented results are plotted against the average SNR values of all users, ζ_{av} , and versus the average SNR of g -th transmitted OFDMA block, $\zeta_{avq} = E\{\vartheta(k,b)\zeta_k^{(t)}(b)\}$ with $\zeta_{av} = \frac{1}{N_g} \sum_{q=0}^{N_{fr}-1} \zeta_{avq}$, where $N_{fr} = 1000$ is the number of transmitted OFDMA blocks. In the paper, a MATLAB software simulator has

been considered to design the simulation model. In addition, the adopted numbers of the above variables have been chosen to examine the proposed system over different conditions. In the results, three systems are adopted. Firstly, a MIMO-OFDMA-conventional bit and power allocation (CBPA) system that adopts the conventional bit and power allocation algorithm of [13], where this algorithm has been developed to work with MIMO systems based on combining coding rate of 3/4 with QPSK, 16-QAM and 64-QAM modulation types. Secondly, MIMO-OFDMA-bit and power allocation (BPA) system, which adopts the proposed power and bit allocation algorithms of the RA method. Finally, a MIMO-OFDMA-bit, power and user allocation (BPUA) system, which considers the whole RA method.

The average throughput performance of the MIMO-OFDMA-CBPA, MIMO-OFDMA-BPA and MIMO-OFDMA-BPUA systems for different number of $N_r = N_t$ is compared in Fig. 4. The achieved average system throughputs for N_r transmitted OFDMA frame are computed in terms of the data subcarriers bandwidth, BW_D , as $\psi_{av} = \frac{BW_D}{D_T} \frac{1}{N_{fr}} \sum_{g=1}^{N_{fr}} \psi_g$ where $BW_D = D_T \frac{BW_{sys}}{N_{FFT}}$ and $BW_{sys} = 20\text{MHz}$ is the total channel bandwidth. From Figure (4), it is evident that the MIMO-OFDMA-BPUA system outperforms the other investigated MIMO schemes for all considered number of equal transmit and receive antennas. In addition, the MIMO-OFDMA-BPA system throughput is improved in comparison with the MIMO-OFDMA-CBPA scheme.

The upper-bound throughput shown in the Figure represents the maximum expected value that our proposed method aimed to reach. This value can be evaluated as $\psi_{UB} = N_r \gamma_{max} BW_D$, where $\gamma_{max} = \rho_{max} \log_2[M_{max}] = (3/4) \times (6)$ is the maximum spectral efficiency of each subcarrier and $BW_D = 1440 \times \frac{20 \times 10^6}{2048}$. It can be noted that our proposed method performance over medium and high SNR values approaches the upper throughput bound closer than other compared approaches. The improvement in the performance of the MIMO-OFDMA-BPUA scheme over other systems is achieved by exploiting the user and multiplexing diversity of the MIMO channel. Additionally, the employed user allocation algorithm assigns each subchannel to a user that achieves the maximum performance among other users rather than utilizing a sequential user allocation. The outage probability as a function of the average system throughput and the upper throughput bound for the investigated MIMO-OFDMA-BPUA system based on different $N_r = N_t$ is compared in Figure (5). The throughput outage probability is evaluated as $P_{out} = 1 - \frac{\psi_{av}}{\psi_{UB}}$. This figure demonstrates that the proposed RA method of the MIMO-OFDMA-BPUA system achieves the lowest outage probability for $N_r = N_t = 4$ in comparison with the other schemes. The highest outage probability is recorded for the proposed MIMO-OFDMA-BPUA with $N_r = N_t = 1$ or in other name Single-Input-Single-Output (SISO). As expected, the system performance in terms of throughput is enhanced with the increasing in the number of antennas. It is also evident that the throughput outage probability of the considered systems converges to the same value at high SNR.

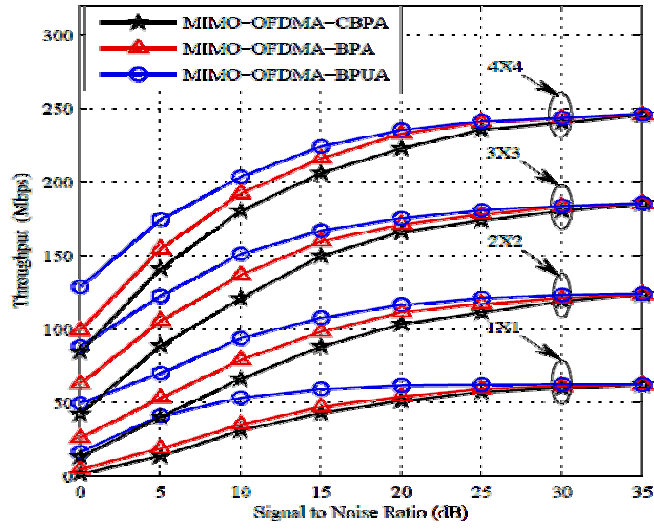


Figure (4) Average system throughput of the MIMO-OFDMA systems.

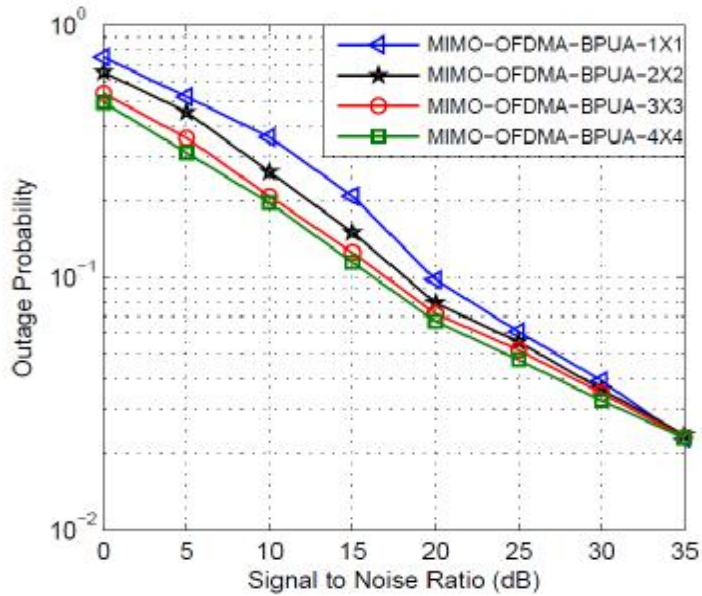


Figure (5) Outage probability of the MIMO-OFDMA-BPUA system for different $N_t=N_r$.

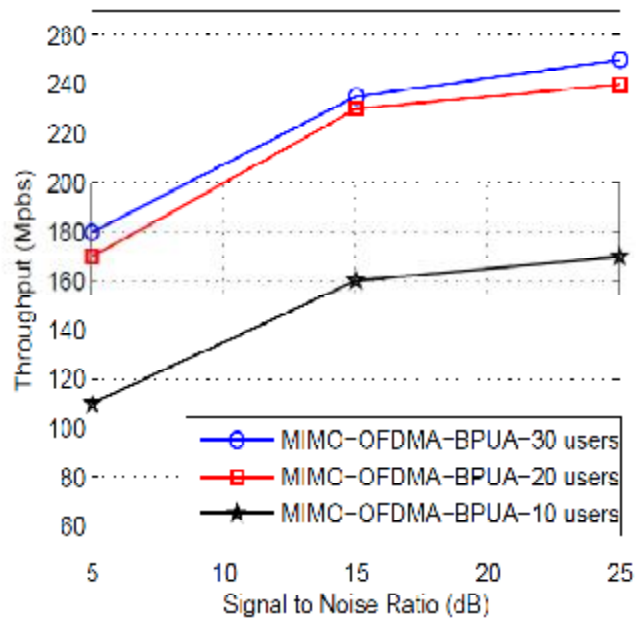


Figure (6) Throughput of the $N_t=N_r=2$ based MIMO-OFDMA-BPUA system for different user numbers.

Figure (6) illustrates the effect of increasing the number of users on the throughput performance of the proposed MIMO-OFDMA-BPUA system. It is clearly shown that the throughput performance is increased with the increasing in the number of users and for high SNR levels. This is due to the high channel diversity provided by the users, which allow the system to select higher MCS levels. In addition, the enhancement in the performance with the SNR values has been explained well in the discussion of Figure (2).

CONCLUSIONS

In order to maximize the average throughput of the investigated MIMO-OFDMA system as a function of BER and spectral efficiency, a new resource allocation method has been proposed. This method includes two algorithms that tackle the user and bit, as well as the power allocation sub-problems, respectively. In order to reduce the mathematical complexity, the throughput maximization problem is divided into two sub-problems to obtain a practical solution. The proposed resource allocation method assigns the resources across the considered subchannels based on the related SNR value of the adopted spatial channels, in which the relevant power constraints and channel conditions are satisfied. The simulation results show that the proposed RA method outperforms the other investigated approaches.

$$\mathbf{k} = \begin{cases} \mathbf{k}_{\text{opt}}(\mathbf{b}) = \arg \max \{\eta_b(k)\} & \text{if } k = 1 \\ 0 & \text{otherwise} \end{cases}$$

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