Eng. & Tech. Journal , Vol.32,Part (A), No.2, 2014

Suboptimal Resource Allocation for MIMO-OFDMA Systems

Dr. Salah Awad Aliesawi
Computer College, University of Al-Anbar/Anbar
E-mail: salah_eng1996@yahoo.com

Received on:22/4/2013 & Accepted on:3/10/2013

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 هوتعظيم 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 الشبه الأمثل. أظهرت نتائج المحاكاة لمعدل وصول المعلومات الصحيحة واحتمالية التخريج، المحصلة من برنامج المحاكاة (MATLAB)، كفاءة و دقة النظام المقترح مقارنه 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

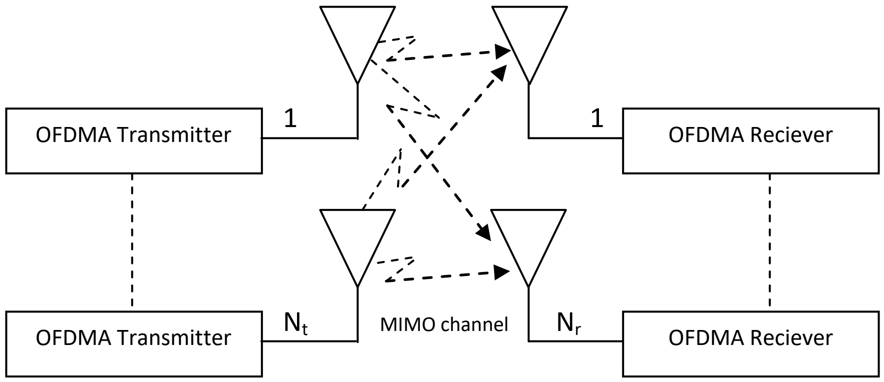
https://doi.org/10.30684/etj.32.2A.14
2412-0758/University of Technology-Iraq, Baghdad, Iraq

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.

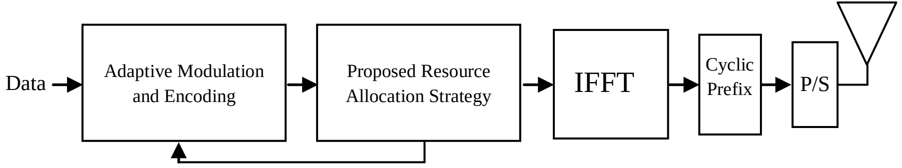
This paper presents a resource allocation (RA) method for a single-cell downlink spatialmultiplexing MIMO-OFDMA systems. The proposed method aims tomaximize the systemthroughput by allocating users, information, represented as bit vectors, and total power overthe considered subcarriers at an assigned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

MIMO-OFDMA System Model

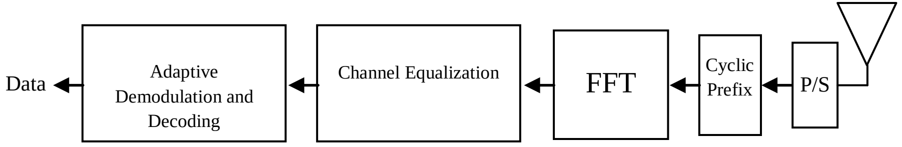
Singular value decomposition (SVD) based single-cell MIMO downlink channel is consideredto transmit a wireless OFDMA signal from an assigned BS to K mobile users [2].The BSis equipped with $N_t$transmit antennas, whilst each user has $N_r$receive antennas, under theassumption of $N_r \geq N_t$. This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



(a) MIMO transmission system



(b) OFDMA Transmitter



(c) OFDMA Receiver

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

Figure (1) illustrates the block diagram of the investigated MIMO-OFDMA system based on theproposed 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 encodedand modulated based on the selected MCS levels, which satisfy the total transmission power andcorresponding channel conditions. The ‘Proposed Resource Allocation Strategy’ block allocatesthe users, power and information bits among the utilized subchannels and selects the suitableMCS for them by implementing the proposed method. It is important to note that the resourceallocation information (RAI) is generated by the ‘Proposed Resource Allocation Strategy’ blockand sent to the receiver of each user using the downlink control signals. A time domain OFDMAsignal 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 residualmultipath channel interference as shown in Figure (1c) [8]. At the output of equalizers, thedecision variables for user *k* are demodulated and decoded according to the known selectedMCS of each subchannel utilizing soft maximum likelihood demodulator and soft-in-hard-outViterbi 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-thsubchannel, is bounded bymin(N_t,N_r), i.e. N_c= min(N_t,N_r) for $k\in\{1, ..,\mathrm{K}\}$users and $b\in\{1, ..,\mathrm{B}\}$ subchannels. Thethroughput of g-th OFDMA block, which includes different transmitted OFDMA frames from$N_t$antennas over $N_c$channels can be formulated as,

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

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

Where $(k,b)\in\{0,1\}$is the element value of the user allocation matrix that assigns the user k tothe subchannel$b$[2]. Each row in this matrix represents a user $k\in\{1, ..,\mathrm{K}\}$ and each columnis a subchannel$b\in\{1, ..,B\}$. The term $D_k^{(r)}(b)$denotes the number of data subcarriers ofthe subchannel$b$ assigned to the user k propagated over the spatial channel r. It is importantto note that the this paper considers the subchannels, which include $D_k^{(r)}(b)$ subcarriers foreach one. Therefore, the formulated equation of (1) adopts the total number of subcarriersinvolved in each subchannel instead of subcarriers and then just subchannel summation isrequired. Moreover, $\gamma_k^{(r)}(b)$denotes the related spectral efficiency that can be evaluated interms 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 thethroughput of the investigated system with number of restrictions includes power and userallocation. The arithmetical representation of the proposed method is formulated following theoptimization methods of [12] as,

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

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

subject to:

$$\sum_{k=1}^{K}\sum_{b=1}^{B}\sum_{r=1}^{N_c}\vartheta(k,b)\mu_k^{(r)}(b)\Lambda_{sc_k}^{(r)}(b) = \Lambda_T \quad \cdots (3)$$

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

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

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, $\varLambda_{sc_k}^{(r)}(b) = D_K^{(r)} \varLambda_{s_k}^{(r)}(b)$is the power value of the b-thsubchannel that is assigned to *k*-th user and transmissionover *r*-th channel as a function of the average coded and modulated symbol power, $\varLambda_{s_k}^{(r)}(b)$.Moreover, $\mu_k^{(r)}(b)$adjusts the required power value for each subcarrier within the b-thsubchannel.Its initial value is determined in terms of uniform power distribution as$\mu_k^{(r)}(b) = \frac{\Lambda T}{N_C D_K^{(r)}(b) \varLambda_{s_k}^{(r)}(b)}$.Finally, ΛT is the total transmission power of thecorresponding BS. In contrast, $\varpi_k^{(r)}(b)$can beobtained utilizing the general approximated BER formula [10],

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

where$\hat{\zeta}_k^{(r)}(b)$ is the minimum SNR value of the subcarriers within the b-thsubchannel, while$\propto_{1_k}^{(r)}(b)$and$\propto_{2_k}^{(r)}$ are fitting constants. The minimum SNR value has been chosen to guaranteethe 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],

$$\hat{\zeta}_k^{(r)}(b) = \mu_k^{(r)}(b) \hat{\zeta}_k^{(r)}(b),$$
$$= \mu_k^{(r)}(b) \min[\varLambda_{s_k}^{(r)}(b) \frac{\varrho_{k_{t,r}}^{(b,d)}}{2\sigma^2_{W_{kr}^{(b,d)}}(b)}], \qquad \ldots(7)$$

Where$\sigma^2_{W_{kr}^{(b,d)}}$is the variance value of the related complex AWGN coefficients. In the otherwords, it is evaluated from the AWGN complex coefficients represented mathematically as avector. The term $\left[\varrho_{k_{t,r}}^{(b,d)}\right]_{r \in \{1,\ldots,Nc\}}$ denotes the *r*-th eigenvalue of $[\boldsymbol{H}_{\mathbf{k}}^{(\mathbf{b,d})} \boldsymbol{H}_{\mathbf{k}}^{(\mathbf{b,d})^{\mathbf{H}}}]$ for the *d*-thdata subcarrier within *b*-thsubchannel, where $(.)^H$is the Hermitian transpose operation. Inorder 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 twoalgorithms based on the decomposition method [12]. These algorithms are low complex andobtain 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 resultof the huge searching operations amongst the transmitted subcarriers to obtain the optimalallocation for users, information bits and power. The search operations look at the user allocationand at the same time find out if this allocation can be satisfied in terms of power andinformation 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 andbits distribution, which indeed reduces the search operations to almost half and then reduce thecomputational complexity. The user allocation assignment sub-problem is considered here based on assuming that thedata, 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 subchannelsas $\Lambda_{sc_k}^{(r)}(b) = \frac{\Lambda T}{N_c B}$, where $\mu_k^{(r)}(b) = 1$.The$\mu_k^{(r)}(b) = 1$is assumed to distribute the power equallyover the subchannels. As a result, the power constraint of (3) is removed. Furthermore, theobjective function of (2) is rewritten to be a concave function that satisfies the Hessian matrixconditions [12] by rewriting (6) as,

$$\varpi_k^{*(r)}(b) = \propto_{1_k}^{(r)} (b) \exp\left[\frac{-\vartheta(k,b) \propto_{2_k}^{(r)}(b) \hat{\zeta}_k^{(r)}(b)}{\vartheta(k,b)}\right], \qquad \ldots (8)$$

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

$$\begin{aligned} \Xi[\vartheta(k,b)] = & \sum_{k=1}^{K} \sum_{b=1}^{K} \sum_{r=1}^{N_c} \vartheta(k,b) D_k^{(r)} (b) \gamma_k^{(r)}(b)], \\ & - \sum_{k=1}^{K} \sum_{b=1}^{K} \sum_{r=1}^{N_c} [\vartheta(k,b) D_k^{(r)} (b) \gamma_k^{(r)}(b)\, \varpi_k^{*(r)}(b), \qquad \ldots (9) \\ & - \sum_{b=1}^{B} \eta_k(b) [\sum_{k=1}^{k} \varphi(k,b) - 1], \\ & - \sum_{k=1}^{K} \eta_b(k) [\sum_{m=1}^{M} \varphi(k,b) - 1], \end{aligned}$$

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

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

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 setted with the maximum valueto avoid the choosing of the same channel for two or more users. On the other hand, the userallocation sub-problem is tackled in the fixed domain, i.e.$\vartheta(k,b)\epsilon\{0,1\}$. In this domain, the$b$-thsubchannel 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],

$$\vartheta(k,b) = \mathrm{f(x)} = \begin{cases} 1, & \mathrm{if k} = \mathrm{k_{opt}(b)} = \arg\max\{\eta_b(k)\} \\ 0, & \text{otherwise} \end{cases}, \forall m \epsilon \{1, \ldots M\} \quad \ldots(11)$$

user allocation algorithm is illustrated in Figure (2). All the subchannels of the available users selectthe top level of the MCS options with modulation type of 64-QAM andconvolutional codingrate of 3/4. Then, a zero value is given for $\eta_k(b)$ for all users. After obtaining the performanceof all users among the subchannels using (10), the $\vartheta(k,b)$ value for the k-th user is evaluatedfollowing (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 investigatedproblem, is solved here. After obtaining the optimal user allocation as mentioned in the previoussection, the optimal power allocation is achieved by solving the underlying problem usingLagrange multiplier as [12],

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

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

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

Figure (3) explains the proposed bit and power allocation algorithm. In this algorithm, all the underlyingsubchannels are valued with the highest MCS option. The next step is the evaluationof 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 statusof all subchannels. Otherwise, the selected MCS option of the subchannels with low SNR valuesis 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.

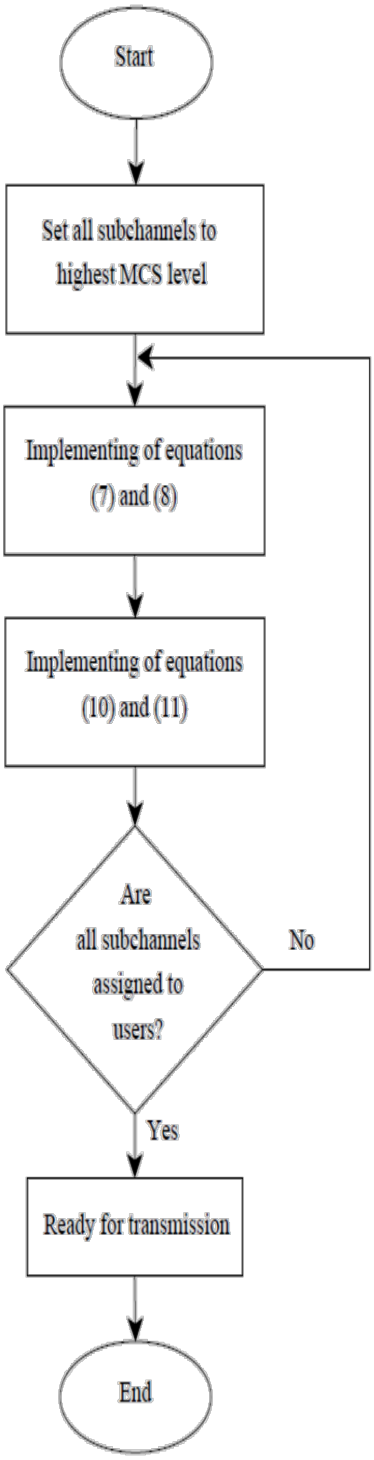


Figure (2) Flow chart of the proposed user allocation algorithm.

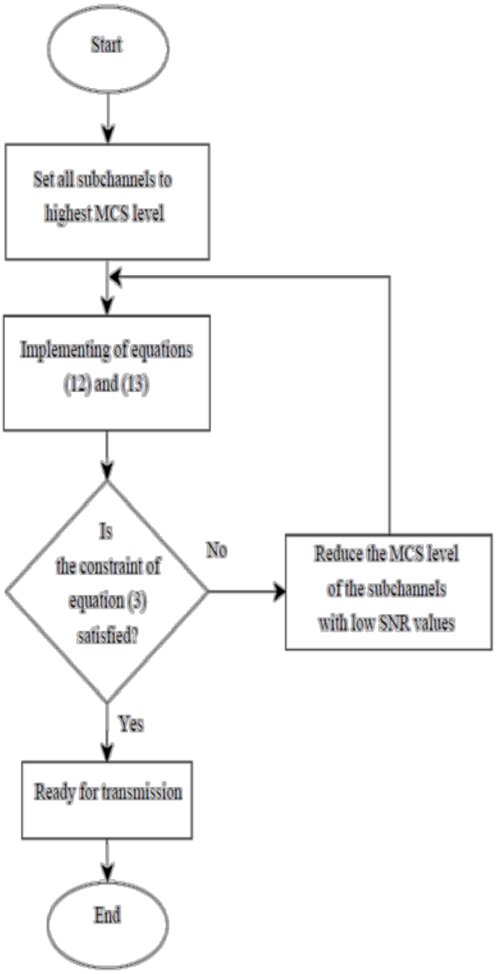


Figure (3) Flow chart of the proposed bit and power allocation algorithm.

SIMULATION RESULTS

In this section, the performance results of the investigated MIMO-OFDMA system based on theproposed RA method and conventional strategies are presented. The proposed MIMO-OFDMAsystem considers the following parameters based on WiMAX technology [1]. The number ofsubcarriers for each transmitted OFDMA frame is the same number of FFT points, which isN_{FFT}=2048. These subcarriers are divided into D_T=1440 data subcarriers, PI_T=240 pilotsubcarriers and G_T=368 guard subcarriers. Furthermore, mobile ITU channels are adopted togenerate the MIMO multiuser environment with distinct mobility speed and channel conditionsfor each user. The number of users, k=15, transmit antennas of $N_t \in \{1,2,3,4\}$and receiveantennas of $N_t \in \{1,2,3,4,5\}$are considered. The presented results are plotted against theaverage SNR values of all users, ζ_{av}, and versus the average SNR of g-th transmitted OFDMAblock, $\zeta_{avq} = E\{\vartheta(k,b)\acute{\zeta}_k^{(t)}(b)\}$with$\zeta_{av} = \frac{1}{N_g}\sum_{q=0}^{N_{fr}-1}\zeta_{avq}$, where $N_{fr} = 1000$is the number oftransmitted OFDMA blocks. In the paper, a MATLAB software simulator has been consideredto design the simulation model. In addition, the adopted numbers of the above variables havebeen chosen to exam the proposed system over different conditions.In the results, three systems are adopted. Firstly, a MIMO-OFDMA-conventional bit andpower allocation (CBPA) system that adopts the conventional bit and power allocation algorithmof [13], where this algorithm has been developed to work with MIMO systems based oncombining 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 powerand bit allocation algorithms of the RA method. Finally, a MIMO-OFDMA-bit, power anduser allocation (BPUA) system, considers the whole RA method.

The average throughput performance of the MIMO-OFDMA-CBPA, MIMO-OFDMA-BPAand MIMO-OFDMA-BPUA systems for different number of N_t= $N_r$is compared in Fig. 4.The achieved average system throughputs for N_{fr}transmitted OFDMA frame are computedin 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}=20MHz is the total channel bandwidth. From Figure (4), it is evident thatthe MIMO-OFDMA-BPUA system outperforms the other investigated MIMO schemes for allconsidered number of equal transmit and receive antennas. In addition, the MIMO-OFDMA-BPAsystem throughput is improved in comparison with the MIMO-OFDMA-CBPA scheme.

The upper-bound throughput shown in the Figure represents the maximum expected value thatour proposed method aimed to reach. This value can be evaluated as ψ_{UB}=$N_t\gamma_{max}BW_D$, whereγ_{max}=$\rho_{max}\log_2[M_{max}]$=(3/4)×(6) is the maximum spectral efficiency of each subcarrier and$BW_D=1440\times\frac{20\times10^6}{2048}$. It can be noted that our proposed method performance over mediumand high SNR values approaches the upper throughput bound closer than other comparedapproaches. The improvement in the performance of the MIMO-OFDMA-BPUA scheme overother systems isachieved by exploiting the user and multiplexing diversity of the MIMO channel.Additionally, the employed user allocation algorithm assigns each subchannel to a user thatachieves the maximum performance among other users rather than utilizing a sequential userallocation.The outage probability as a function of the average system throughput and the upperthroughput bound for the investigated MIMO-OFDMA-BPUA system based on different N_t=$N_r$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 systemachieves the lowest outage probability for N_t=N_r=4 in comparison with the otherschemes. The highest outage probability is recorded for the proposed MIMO-OFDMA-BPUAwith N_t=N_r=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.

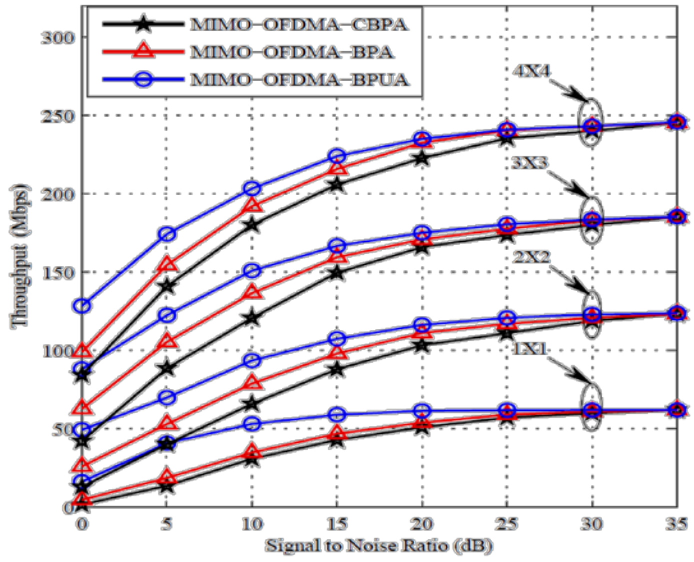


Figure (4) Average system throughput of the MIMO-OFDMA systems.

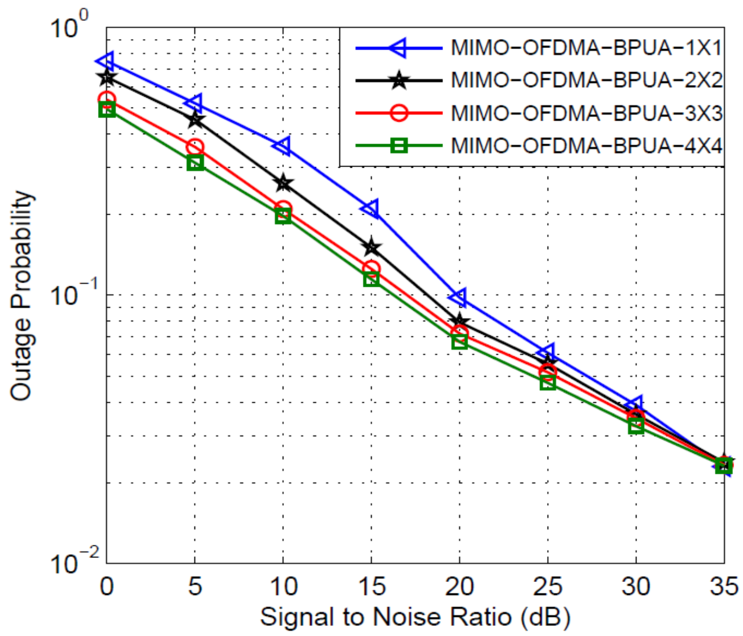


Figure (5) Outage probability of the MIMO-OFDMA-BPUA system for different N_t=N_r.

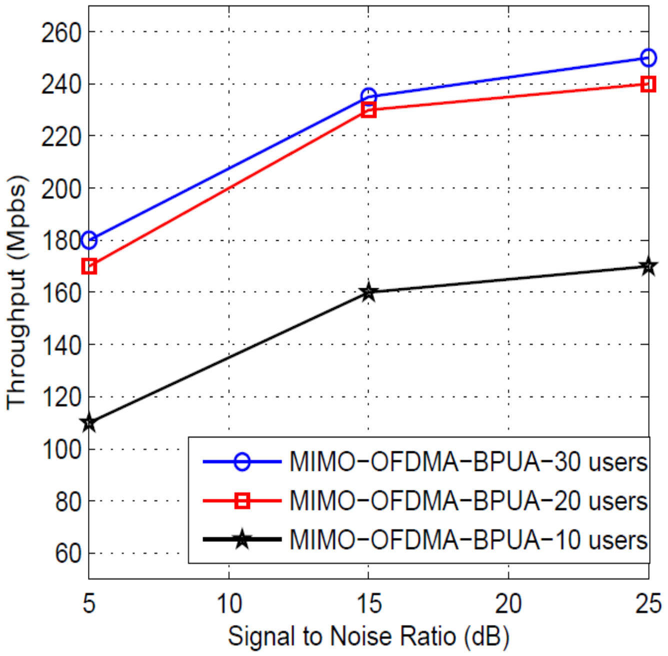


Figure (6) Throughput of the N_t=N_r=2 based MIMO-OFDMA-BPUA system for different user numbers.

Figure (6) illustrates the effect of increasing the number of users on the throughput performanceof the proposedMIMO-OFDMA-BPUA system. It is clearly shown that the throughput performanceis increased with the increasing in the number of users and for high SNR levels. This isdue 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 hasbeen explained well in the discussion of Figure (2).

CONCLUSIONS

In order to maximize the average throughput of the investigated MIMO-OFDMA system asa 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 thepower allocation sub-problems, respectively. In order to reduce the mathematical complexity,the throughput maximization problem is divided into two sub-problems to obtain a practicalsolution. The proposed resource allocation method assigns the resources across the consideredsubchannels based on the related SNR value of the adopted spatial channels, in which the relevantpower constraints and channel conditions are satisfied. The simulation results show thatthe proposed RA method outperforms the other investigated approaches.

$$\begin{matrix} 1, & \mathrm{ifk} = \mathrm{k_{opt}(b)} = \arg\max\{\eta_b(k) \\ 0, & \mathrm{otherwise} \end{matrix}$$

REFERENCES

[1]. Nuaymi, L. *WiMAX Technology for Broadband Wireless Access*, John Willey and Sons, Ltd,England, 2007.

[2]. Chan,E. Lo, P. V. Lau, R. Cheng, K. Letaief, R. Murch and W. Mow, “Adaptive resourcesallocation and capacity comparison of downlink multiuser MIMO-MC-CDMA and MIMOOFDMA,”*IEEE Trans. Wireless Commun.*, vol. 6, n0. 3, pp. 1083-1093, Mar. 2007.

[3]. Chan, P. E. Lo, V. Lau, R. Cheng, K. Letaief, R. Murch and W. Mow, “Performancecomparison of downlink multiuser MIMO-OFDMA and MIMO-MC-CDMA with transmitside information-multi-cell analysis,” *IEEE Trans. Wireless Commun.*, vol. 6, n0. 6, pp.2193-2203, Jun. 2007.

[4]. Liang, W. Ho and Y. “Optimal resource allocation for multiuser MIMO-OFDM systemswith user rate constraints,” *IEEE Trans. Vehicul. Techn.*, vol.58, no.3, pp. 1190-1203, Mar.2009.

[5]. Sun, L. E. Au and M. McKay, “Adaptive MIMO multichannel beamforming with co-channelinterference and noise: algorithm and performance analysis,” *IEEE Trans. Vehicul. Techn.*,vol.8, no.8, pp. 4368-4379, Oct. 2009.

[6]. Maciel and A. Klein, T. “On the performance, complexity, and fairness of suboptimal resourceallocation for multiuser MIMO-OFDMA systems,” *IEEE Trans. Vehicul.Techn.*, vol.59, no.1, pp. 406-419, Jan. 2010.

[7].Guidelines for the evaluation of radio transmission technologies for IMT-2000,” *Recommendation, ITU-R M.1225*, 1997.

[8]. Madhow, U. *Fundamentals of Digital Communication*, Cambridge University Press, 2004.

[9]. Moon, T. *Error Correction Coding, Mathematical Methods and Algorithms*, John Wiley andSons, INC., Canada, 2005.

[10]. Chung and A. Goldsmith, S. “Degrees of freedom in adaptive modulation: a unified view,”*IEEE Trans. Commun.*, vol. 49, no. 9, pp. 1561-1571, Sep. 2001.

[11]. Al-Janabi, M. C. Tsimenidis, B. Sharif and S. Le Goff, “Simulated and semi-analyticalthroughput evaluation for AMC-OFDMA systems,” *CSNDSP 2010 conf.*, pp. 184-188.

[12]. Bertsekas, D. *Constrained Optimization and Lagrange Multiplier Methods*, Athena Scientific,USA, 1996.

[13]. Devillers, B. J. Louveaux and L. Vandendorpe, “Bit and power allocation for goodputoptimization in coded parallel subchannels with ARQ,” *IEEE Trans. Signal Process.*, vol.56, no. 8, pp. 3652-3661, Aug. 2008.