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An Optimal Approach for Margin Adaptive Resource Allocation in Multiuser OFDM System

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Abstract— High data rate applications are the demand of current user population for great multimedia connectivity. Multiuser orthogonal frequency division multiplexing (MU OFDM) with multiple-input multiple-output requires not only the large subscribers but also the high output for each user in future wireless communication systems. In this paper, a fast and adaptive margin allocation scheme is proposed for the joint communication in multiusers (MU) multi input multi output (MIMO) with orthogonal-frequency-division multiplexing (OFDM). The total power consumption is reduced with constraints on bit-error rate (BER). Total transmission data rate for different types of service for users is formulated and simple schemes with better performance are derived. Two steps are used to solve the joint allocation problem. In first step, total number of the subcarriers that each user will allocate is found with the help of average signal-to-noise ratio. In the second step, algorithm finds the efficient allocation of subcarriers to each user. With convex optimization methods, this paper proposes an optimal solution to reduce the total transmit power subject to data rate requirement of each user. Simulation results shows that the proposed scheme offers better performance than the existing subcarrier schemes

Keywords— Convex optimization, Multiple-input multiple-output (MIMO), Resource allocation, Subcarrier selection, Multiuser (MU), Orthogonal-frequency-division multiplexing (OFDM), Margin adaptive, Power control, Water filling.

I. INTRODUCTION

Multiple-input multiple-output (MIMO) orthogonal frequency-division multiplexing (OFDM) in wireless link can improve the overall system performance with the help of multiple antennas at both the transmitter and the receiver. Architecture of multiuser (MU) orthogonal frequency-division multiplexing (OFDM) combines multiple-input multiple-output (MIMO) is a powerful approach to transmit high date rates over wireless communication network [1]. It is very complicated to design optimal resource allocation schemes to full utilization of the potential of MU OFDM-based networks, including the set of subcarriers to operate on which user, and with how much power to transmit the signals [2]. Multiuser (MU) orthogonal frequency-division multiplexing (OFDM) system makes use of a random MIMO channel that has a capacity grows with the minimum number of antennas at transceiver with no additional power requirement. The combination of these two schemes is called MIMO-OFDM [3]. Convex optimization [4], [5] offers optimal methods for finding many different nonlinear communications problems. [6] – [7] give the solution of the power minimization, given user target data rates, with the convex optimization.

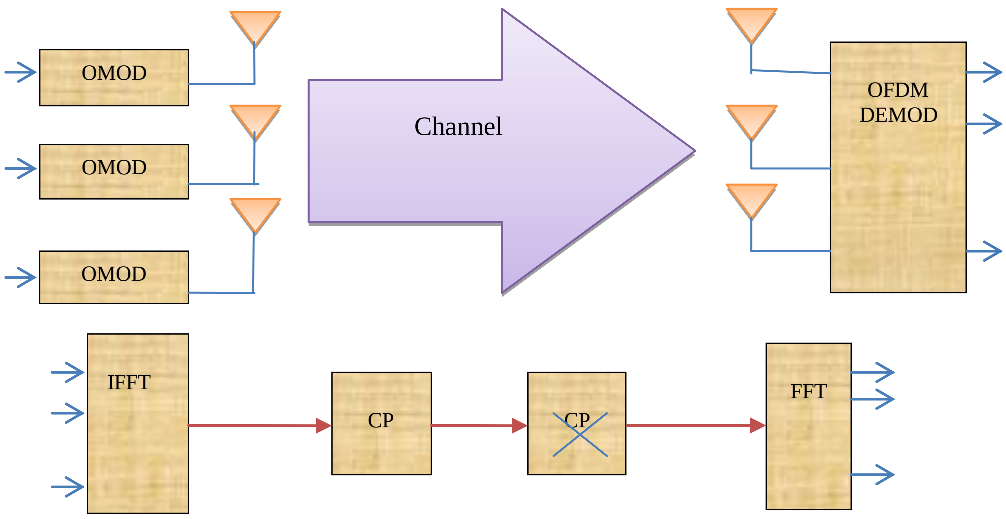

Fig-1: Block diagram of MIMO-OFDM System

In margin adaptive solution, transmit power is reduced subject to user data rate constraints. Transmit power minimization at the base station has many advantages in terms of Multi-User Interference (MUI) reduction, better battery life or allowing access to all the users in the system to limited base power [8]. Margin adaptive scheme is applied to delay highly sensitive traffic like voice transmission and real time video applications where target data rate needs to be fulfilled the entire requirement. A margin adaptive scheme with the constraints of constant data-rate and target bit error rate (BER) is proposed in [9], where the subcarrier is assigned to the user who has the maximum received signal-to-noise ratio (SNR). The method is shown to perform better than static resource allocation scheme. This scheme allocates a subcarrier to only one user with maximum SNR, limiting the spectral efficiency and the number of users in the system. Considerable progress has been done in the formation of schemes that allow multiple users to transmit on the same subcarrier to reducing the co-channel interference (CCI) using dirty paper coding (DPC), zero-forcing beamforming (ZFBF) or block diagonalization (BD) [10]. However, any such solution like DPC requires a high complexity for implementation point. Beamforming techniques are less computationally complex for Multi-User MIMO (MU-MIMO) system. One of those techniques is Zeroforcing Beamforming (ZFBF) which gives beamforming vectors in such a manner that MUI is minimized and spatial vectors for different users is mutually orthogonal. In [11], authors gave a scheme in which resource allocation methods for every user are found. This proposed scheme is less complex in terms practical implementation. Thus, the joint subcarrier-bit-and-power-optimization problem is transformed into easy one-user optimization problem and complication of the original problem is significantly decreased.

This proposed scheme shows higher diversity and power gain than the static systems. In [12], a grouping algorithm is proposed which separates beam-forming from allocation problem, this algorithm has less complexity. Each user-group is assigned the best subcarrier keeping the data rate constraints of each user. Now, for each subcarrier, the best user group is found. They formed this problem on a convex optimization and used Lagrange dual decomposition scheme to obtain the solution of resource allocation problem. The MIMO channel can be divided into many parallel scalar Eigen-mode sub channels with the help of singular value decomposition (SVD) method. The resources allocation with SVD minimizes the total transmitted power. But all methods allow only one largest Eigen-mode sub-channels which are used in transmitting the data. In [13]-[17] authors have given the optimal resource allocation which reduces the total transmitted power with constraints of target data rates of all the users. This scheme allocates the subcarrier, power, and data rate by using the diversity system.

The organization of this paper is expressed as follows. An efficient solution based on convex optimization is obtained in Section II which gives the channel model for low power resource allocation. Simulation results and discussion are shown and explained in Section III. Conclusion of this effective resource allocation scheme is discussed in Section IV.

II. SYSTEM MODEL

The power consumption is the main problem in wireless communication system which has to be removed, this helps in Multi-User Interference (MUI) reduction in multi-cell environment, longer battery life or allowing access to more users in the system when BS has a constraint on total transmit power. We get the above advantages if resources like subcarrier, bit, power etc. are allocated adaptively. These dynamic resource allocation schemes are called Margin Adaptive (MA) resource allocation schemes. In this paper, Margin adaptive (MA) resource allocation in multiuser MIMO-OFDM system presents an efficient solution for power minimization.

A. Margin Adaptive Allocation

In this paper, an efficient method based on convex optimization theory is designed to minimize the total transmit power for MIMO-OFDM communications, subject to individual user rate constraints. This strategy requires only linear transmit and receive processing. Therefore, it is applicable to both the downlink and the uplink. The problem is divided into M different sub problems with the help of Lagrangian dual for sum power objective function, where M is the total number of subcarriers. So complexity is minimized from one exponential in M to one linear in M. Given that M is typically large for multicarrier systems; this represents a large amount of savings. The super-gradient of the dual function is used to update the Lagrange multipliers in finite step sizes. The step sizes are adjusted based on the convergence behavior to speed up the convergence of the algorithm. However, the scheme can adjust with changing channel situations. It has been found that methods that are based on dual decomposition could possibly suffer from uniformity among the subcarriers, which results in large oscillations within the algorithm.

Margin adaptive solution of resource allocation results in transmits power reduction subject to user's data rate. Many design constraints are imposed on MA schemes depending on the transmitting user's needs. The general constraints gave on the MA schemes are:

1. User's date-rate.
2. User's fairness.
3. Target BER.
4. QoS requirements etc.

An efficient method is devolved which reduces the total transmit power in multiuser MIMO-OFDM communications with user data rate constraints. This method is based on convex optimization theory. This scheme needs linear processing at the transmitter and the receiver. So, it can be applied to both the downlink and the uplink MIMO-OFDM system. Lagrangian dual of the sum power objective function is formed which converts the optimization problem into M independent sub problems, where M refers to the number of subcarriers in system. In this way, the computational complexity reduces from one exponential in M to one linear in M. This process saves a large amount of computation for a multicarrier system, where number of subcarriers in the system is very large. The super gradient of the dual function is calculated to update the Lagrange multiplier.

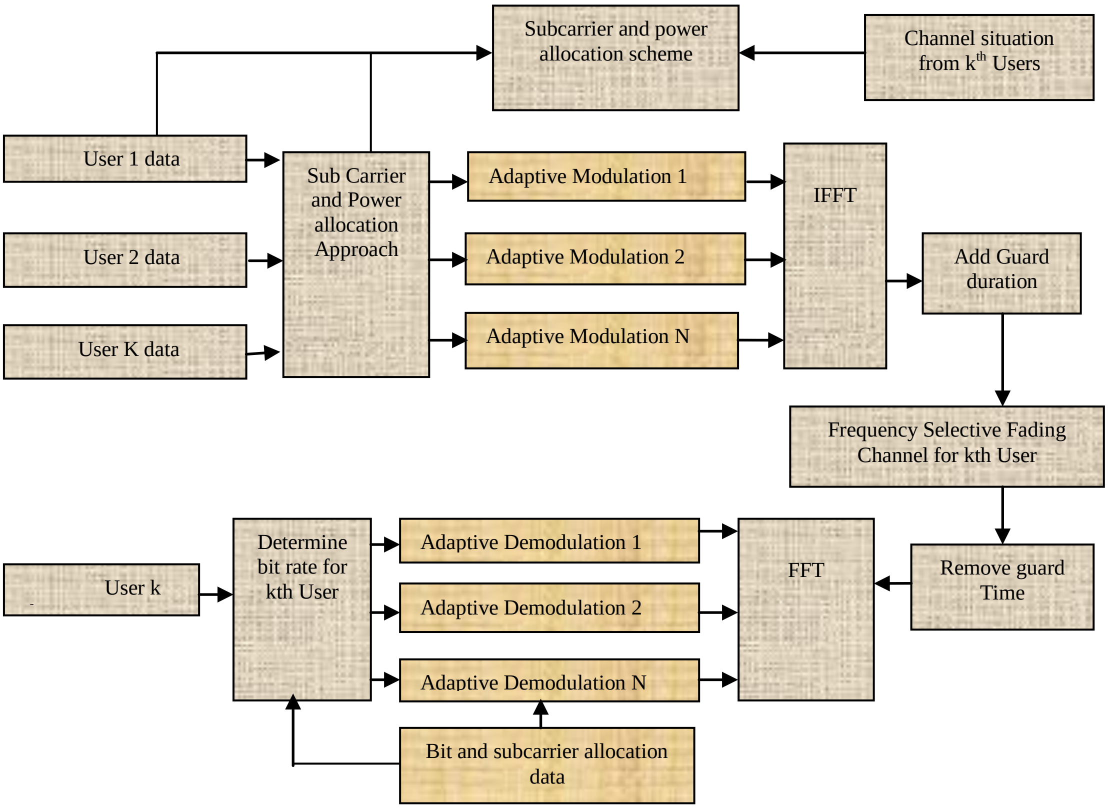

Fig-2: Multiuser OFDM system with Margin Adaptation Allocation

B. Optimum Problem Formulation

The aim of MA resource allocation is to obtain the efficient subcarrier allocation $\{\sigma_{k,m}\}$ and power allocation $\{p_{k,m}\}$ that reduce the total transmit power in the system subject to satisfy the user's average data rate requirement $\bar{R}_k$ in bits per second per hertz (bps/Hz).

Mathematically, the MA problem can be shown as

$$\underset{\{\sigma_{k,m}\},\{p_{k,m}\}}{\text{minimize}} \sum_{k=1}^{K}\sum_{m=1}^{M} p_{k,m}$$

Subject to

$$\sum_{m=1}^{M} r_{k,m} \geq M\bar{R}_k \forall k, m$$

$$p_{k,m} \geq 0 \qquad \forall k, m \qquad (1)$$

Where $r_{k,m}$ gives to the data rate of user k on subcarrier m and K refers to number of active users. The Bit Error Rate (BER) of M-ary square quadrature amplitude modulation (L-QAM) with gray bit mapping for user k on sub-channel l of subcarrier m is given by

$$\text{BER} = 0.2 \times \exp\left(-\frac{1.5 \times \text{SNR}}{(L-1)}\right)$$

$$= 0.2 \times \exp\left(-\frac{1.5 . p_{k,m,l} . s_{k,m,l}^2}{(L-1). N_o}\right)$$

$$= 0.2 \times \exp\left(-\frac{1.5 . p_{k,m,l} . s_{k,m,l}^2}{(2^{r_{k,m,l}}-1). N_o}\right) \qquad (2)$$

Where $p_{k,m,l}$ and $r_{k,m,l}$ are shown the power and bit-rate of the user k on sub channel l of subcarrier m and $s_{k,m,l}$ is the l^{th} diagonal element of user k's singular matrix $\tilde{S}_{k,m}$.

Rearranging the above equation (2) in terms of the power as a function of data rate and data rate as a function of power, we have

$$p_{k,m,l} = \frac{2^{r_{k,m,l}}-1}{1.5} \times \frac{N_o}{s_{k,m,l}^2} \ln\left(\frac{1}{5\text{BER}}\right)$$

$$= (2^{r_{k,m,l}}-1) \times \frac{\Gamma N_o}{s_{k,m,l}^2} \qquad (3)$$

$$r_{k,m,l} = \log_2\left(1 + \frac{p_{k,m,l}s_{k,m,l}^2}{\Gamma N_o}\right) \qquad (4)$$

Where Γ, SNR gap is defined as

$$\Gamma = -\frac{\ln(5\ \mathrm{BER})}{1.5} \qquad (5)$$

The data rate of user k on subcarrier m can be written as

$$r_{k,m} = \sum_{l=1}^{\eta_{k,m}} r_{k,m,l}$$

$$r_{k,m} = \sum_{l=1}^{\eta_{k,m}} \log_2\left(1 + \frac{p_{k,m,l}s_{k,m,l}^2}{\Gamma N_o}\right) \qquad (6)$$

Where $\eta_{k,m}$ is given as the rank of channel matrix of user k on subcarrier m and $0 \leq \eta_{k,m} \leq \min(n_k, n_T)$. $r_{k,m}$ is defined as the data rate of user k on subcarrier m. Thus, $\{s_{k,m,l}\}$ is dependent on the user selection $\{\sigma_{k,m}\}$ on subcarrier m and

$$p_{k,m} = \sum_{l=1}^{\eta_{k,m}} p_{k,m,l} \qquad (7)$$

If $\sigma_{k,m} = 0$, set $p_{k,m} = 0$, $s_{k,m,l} = 0\ \forall l$, and $r_{k,m}=0$

Using equation (6) and (7), the optimization problem given in equation (1) reduces to

$$\underset{\{\sigma_{k,m}\},\{p_{k,m}\}}{\text{minimize}} \sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{l=1}^{\eta_{k,m}} p_{k,m,l}$$

Subject to

$$\sum_{m=1}^{M}\sum_{l=1}^{\eta_{k,m}} r_{k,m,l} = M\overline{R}_k$$

$$p_{k,m,l}, r_{k,m,l} \geq 0 \qquad \forall\, k, m, l \qquad (8)$$

To find a globally optimal solution for the optimization problem in equation (8), a complete search is required over all possible carrier allotments{ k, m} and there will be total 2^{KM} possible sets to search, then K water filling methods will also be used for each possible chance. So, computational complexity will be very high. If only one user constraint on one carrier is imposed, there would be KM possible combinations to search which is also a very high complex method. Less complex and efficient solution have been obtained to optimize problem in equation (8) using Lagrange dual decomposition method.

III. SIMULATION RESULTS

To determine the effect of different parameters on the system performance in margin adaptive resource allocation, Multiuser MIMO-OFDM system is simulated in MATLAB software. There are total 64 number of subcarriers (M=64), number of users are K and each user has two receiving antennas (n_k=2) and base station has total six transmitting antennas (N_T=6). The normalized data rate need of each user is 2.4 bps/Hz ($\overline{R}_k$ =2.4).

For the graph, average SNR is given as

$$\mathrm{SNR} = \frac{\sum_{k=1}^{K}\sum_{m=1}^{M} p_{k,m}}{MN_0} \qquad (9)$$

System performance of efficient subcarrier allocation using Lagrange multiplier scheme ('optimal allocation scheme') is compared with other subcarrier allocation schemes like 'Amplitude-craving greedy' (ACG) scheme, 'Localized Transmitter scheme', 'fixed allocation scheme' is done. In 'ACG' scheme, the mean square values of MIMO channel matrix is found, i.e. $c_{k,m}$ = trace $(H_{k,m}^H H_{k,m})$ / $N_T\ n_k$. On each subcarrier, the user having the largest value of $c_{k,m}$ is allocated In 'Subcarrier block allocation scheme', K blocks of consecutive subcarriers are formed. First block is allocated to the user having the highest average channel gain on the subcarriers of this block. Next block is allocated to the remaining one user who has the highest average channel gain on the subcarriers of that particular block. In this way, blocks of subcarrier is allocated to all users one-by-one.

In 'Fixed allocation scheme', K blocks of consecutive subcarriers are formed. Each block is allocated to the user in predefined way. For analysing the effect of increasing SNR on the BER in multiuser MIMO-OFDM system, BER versus SNR for various subcarrier allocation schemes is plotted in figure 3. After channel formation, subcarrier is allocated to users by different schemes for each SNR value. Using Lagrange dual decomposition method, optimal power is determined for each sub-channel of user. Noise power is calculated after finding signal power for given SNR using equation. Noise samples are formed and added to the transmitted signal.

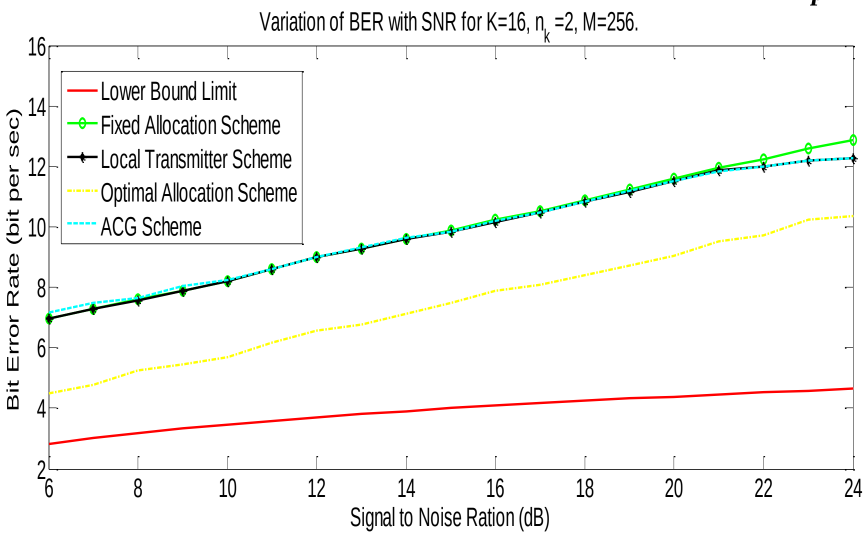

Fig-3: Bit Error Rate versus Signal to Noise Ratio for K = 16, n_k = 2, M = 256.

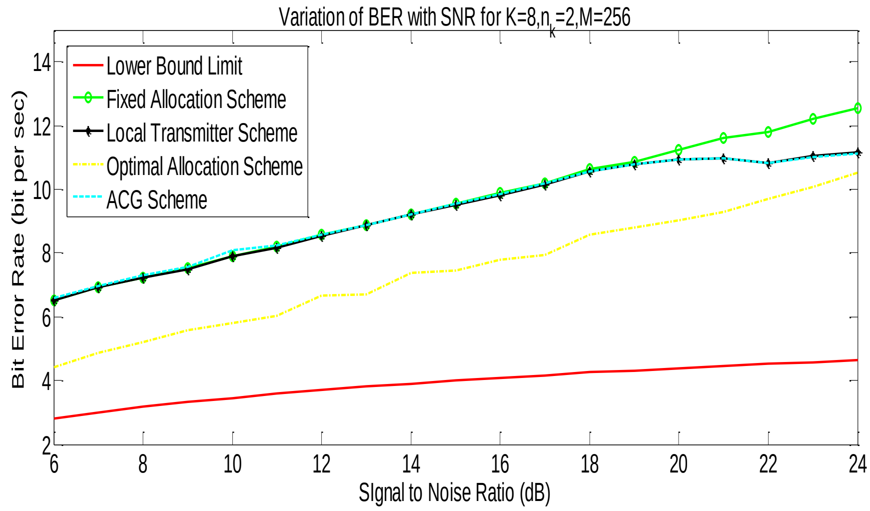

Fig-4: Bit Error Rate versus Signal to Noise Ratio for K = 8, n_k = 2, M = 256.

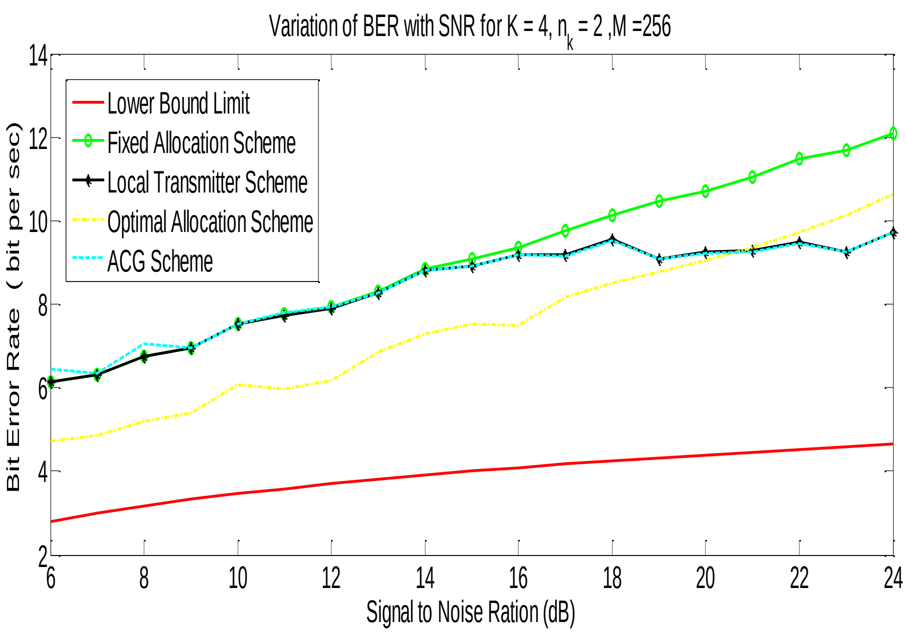

Fig-5: Bit Error Rate versus Signal to Noise Ratio for K = 4, n_k = 2, M = 256.

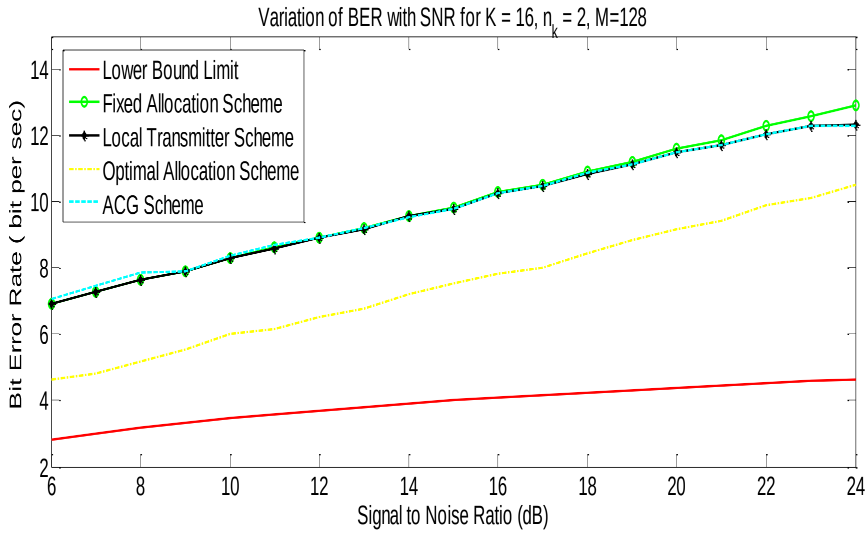

Fig-6: Bit Error Rate versus Signal to Noise Ratio for K = 16, n_k = 2, M = 128.

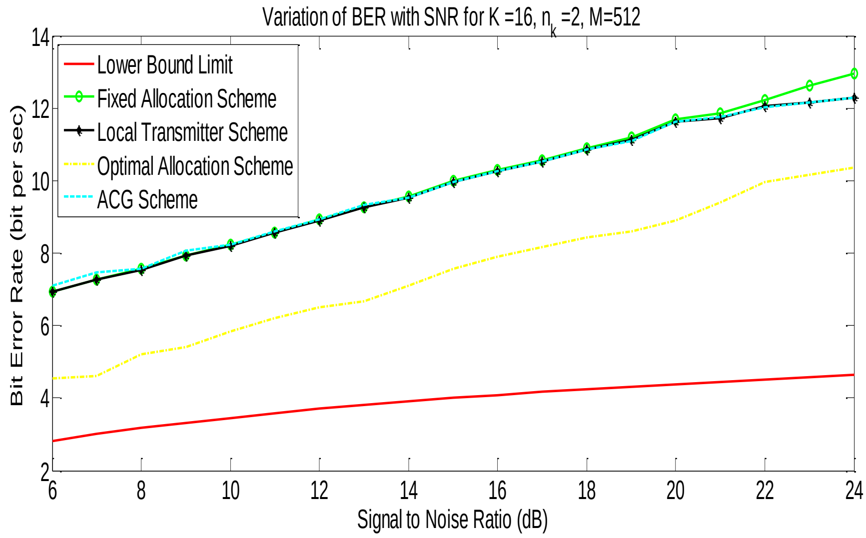

Fig-7: Bit Error Rate versus Signal to Noise Ratio for K = 16, n_k = 2, M = 512.

For reception on user's terminal side, BER is calculated and compared for all subcarrier selection schemes. Upper bound of BER (for LQAM modulation) is given as:

$$\text{BER} \leq 0.2 \times \exp\left(-\frac{1.5 \times \text{SNR}}{(L-1)}\right) \qquad (10)$$

For all subcarrier allocation schemes, Figures 4 - 7 show that BER decreases with increase in SNR values. Among all subcarrier allocation scheme, optimum allocation performance is the best, i.e. optimum allocation scheme needs small SNR value for any BER value, as optimum subcarrier selection scheme assigns the subcarrier to the user in an optimal way. ACG algorithm performance is very close to the optimum scheme as ACG assigns subcarrier to the user who has the highest channel gain for that particular subcarrier. The performance of subcarrier block allocation scheme is better than fixed allocation scheme, but with very small difference.

In subcarrier block allocation scheme, a block of subcarrier is allocated to the user who has the maximum average channel gain for the subcarriers of that particular block and in that subcarrier block. Any subcarriers may not have the best user for this subcarrier. At BER of 10^{-3}, optimum choice is 2.3 dB higher as compared to the fixed allocation method. Since, in fixed allocation scheme, subcarriers are assigned in a predefined way, the BER performance is below the upper bound because every subcarrier has not the best user.

VI. CONCLUSION

High data rate communication is one of the major advantages of MU OFDM. For efficient utilization of system resources, adaptive and fast optimization schemes are required. An efficient algorithm for allocating power and subcarriers among users in a multicarrier system has been given. Dividing the total problem into two steps enabled the design of schemes with low complexity, which operates well under practical channel and data traffic conditions. An effective and adaptive approach based on convex optimization principle is given to obtain the subcarrier, power, and rate assignments that utilize the diversities of the system. Linear beam forming is performed at the transmitter and the receiver to give a low-complexity implementation. Therefore, this solution is immediately applied to both the downlink and the uplink. Simulation results show a large performance gain over a fixed subcarrier allocation scheme. The performance of subcarrier, bits and power allocation using the convex optimization method in margin adaptive resource allocation scheme is better among the other subcarrier allocation method. As data rate requirement of each user goes on increasing, total transmit power requirement increases. It is also found that average SNR value is increasing with increase in the number of users in the system for all subcarrier allocation schemes because total data rate of the system increases.

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