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An Efficient Subcarrier and Power Allocation Scheme for Multiuser MIMO-OFDM System

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***Abstract* - Multiuser multi-input multi-output orthogonal frequency division multiple (MU MIMO-OFDM) is a very promising technology for enhancing the flexibility and efficiency of cellular and future communication systems. A joint optimization problem for resource allocation is solved by a combine scheme of multiple-input multiple-output with orthogonal frequency division multiple (MIMO-OFDM) and used for broadband wireless applications. In this paper, we address the assignment of subcarriers and power to all users to optimize the sum of user average data rates subject to constraints on signal to noise ratio, total available transmitted power, and proportionality among users, subcarriers. We compare the proposed rate adaptive scheme that maximizes the average data rate of multiuser multi input multi output orthogonal frequency division multiplexing (MU MIMO-OFDM) systems with others conversional schemes. The total power allocation scheme for MU OFDM system is proposed on convex optimization environment. As the current optimization techniques either use uniform power allocation or process only subcarrier allocation and power allocation independently. In this paper, we propose an algorithm that process subcarrier and power allocation simultaneously under data rate constraint. In this paper, a rate adaptive resource-allocation scheme, which includes adaptive power distribution, subcarrier allocation according to instantaneous channel conditions, is proposed for multiuser MIMO-OFDM system. Simulation results show the large performance improvement of proposed rate adaptive scheme over other adaptive and fixed allocation schemes.**

***Index Terms*-- Multiple input multiple output (MIMO), Orthogonal frequency division multiple (OFDM), Multiuser (MU), Convex optimization, Rate adaption, Resource allocation, Water-filling scheme**.

I. INTRODUCTION

In recent years, multiuser MIMO-OFDM system is especially suitable the high-data rate applications for digital audio broadcasting (DAB), digital video broadcasting (DVB), wireless local area networks (LANs) (IEEE 802.11a, IEEE 802.11g) and fourth generation cellular systems, including third generation partnership project-long-term evolution (3GPP-LTE) and Wi-MAX [1] [2]. MIMO-OFDM divides the entire transmission channel bandwidth into *N* orthogonal sub channels.

Here, a cyclic prefix (CP) is added to each OFDM character to remove both inter carrier interference and inter symbol interference and the sub channels seem to be circular if the CP length is longer than the channel length. Two types of resource allocation methods are found: fixed resource allocation assignments [4] and dynamic resource allocation assignments [5] [7].

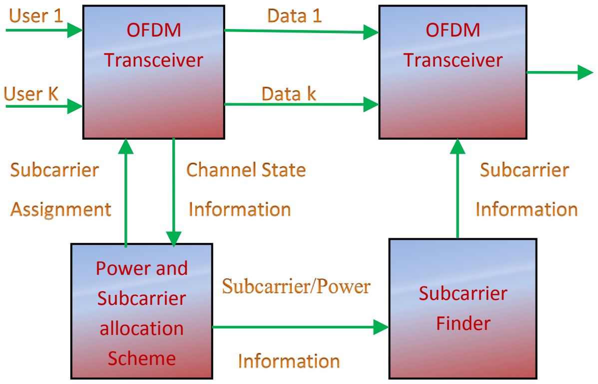

Fig-1: Block Diagram of Multiuser MIMO-OFDM system

A fixed resource allocation assignment is not efficient because the method is fixed irrespective of the current channel condition. Another important thing is that the dynamic resource assignment scheme allocates a dimension adaptively to different users according to their current and effective channel gains. Two classes of optimization methods have been named in the dynamic multiuser MIMO-OFDM survey: margin adaptive (MA) allocation scheme [5] and rate adaptive (RA) allocation scheme [6], [7]. Instead of trying to maximize the minimum user capacity as in [7], the proposed RA optimization tries to maximize the average data rate while maintaining proportional fairness among users. In the paper [5], a rate adaptive resource allocation method has given for multiuser OFDM system which considers user data rate proportionality also subcarriers and power are allocated separately which remove the computational complexity. Later on, [14] has proposed a scheme to maximize the average data rate of multiuser orthogonal frequency division multiplexing (MU OFDM) systems. But in [14], user fairness is not explained.

In [15], it discusses about an optimization problem that balances the trade-off between total system capacity and fairness among the users. In paper [16], a scheme is proposed for resource allocation for uplink MIMO-OFDM system. Bits are loaded dynamically, this bit loading scheme increases the total system capacity with the power constraint and signal to noise ratio for each user and this method also makes proportional data rate fairness among the users. In recent years, game theory has started to use in wireless communication systems, which help to give solution for resource allocation problems. Under the game theory, bargaining games and their solutions have been used in future communication systems which provide better trade-off between the fairness among the users and the system capacity.

This is two-step process which distributes the available power in efficient way. First the allocation of the power to users is done by solving some finite nonlinear equations. Then, the total OFDM system capacity for each user is maximized with water-filling scheme. In water filling method, there is many computational complexity and for reducing the computational, they proposed a simple scheme to allocate the available power among the all subcarriers in equal way after the allocating the subcarriers to the users. There is an important result shown that the average data rate for the two proposed transmit power adaptation schemes significantly increases with the number of users and adaptive allocation performance is much better than that of the conventional fixed allocation scheme. However, the scheme proposed in [9] uses the numbers of non-linear equations, which needs lot of computationally costly operations and is thus not favorable in a cost-effective manner. This paper extends the process in [9] by developing a subcarrier allocation method along with water filling and equal distribution methods that linearizes the efficient rate allocation problem with approximate power proportionality.

This paper is organized as follow. Section II involves the multiuser MIMO-OFDM system model and shows the objective function for the system using convex optimization. In Section III, the efficient multiuser rate adaptive allocation scheme is developed. Simulation result discussion is presented in Section IV. Conclusions behind the simulation results are drawn in Section V.

II. SYSTEM MODEL

In MU MIMO-OFDM system , the high speed data rate is divided into M small narrowband data rates, M represents the number of the subcarriers or sub channels i.e. One MU OFDM symbol contains M different symbols modulated by QAM or PSK. As a result, the symbol duration of MU OFDM is M times longer than in a single carrier system with the same symbol rate. The symbol duration is made longer by addition of a cyclic prefix to each symbol. Due to large the cyclic prefix to the channel delay spread, OFDM provides inter-symbol interference (ISI) free transmission. The combination of multiuser MIMO with OFDM technique is a strong methodology for next-generation wireless systems, like fourth-generation mobile communications. MIMO-OFDM improves the transmission rate, the transmission range and the transmission reliability simultaneously of a wireless system [1]. A block diagram of the multiuser MIMO-OFDM system is shown in Figure 2.This figure depicts a set of data symbols for the kth user and shows the total transmit power assigned to the kth user's and mth subcarrier. The modulation and demodulation scheme with a number of orthogonal subcarriers are calculated with the help of inverse fast Fourier transform (IFFT) and fast Fourier transform (FFT) methods, respectively. Since the total transmits power distribution requires about channel site information (CSI) for all the users and subcarriers (SC). We assume that the AWGN channel parameters are exactly known by both transmitter and receiver side. When the CSI is present at the transmitter, the transmitter can change its transmit power for each user's and subcarrier signal in a symbol-by-symbol manner to improve the average data rate [12].

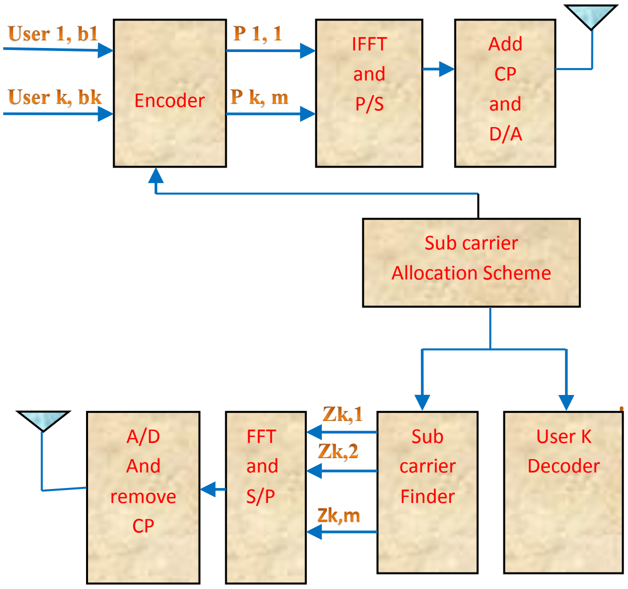

Fig-2: Multiuser OFDM system with transmit power adaptation

Consider the fading characteristics of the AWGN channel are to be constant over one OFDM symbol period, but change for symbol-to-symbol. We assume a wideband multipath AWGN fading channel. We developed a power allocation scheme for practical multiuser MIMO-OFDM downlink system which makes the average data rate maximum with the user's power and SNR constraints. A subcarrier is used by multiple users [3].When more than one user are allowed on same subcarrier and if one user increases his transmit power for that subcarrier , then other user's interference who use same subcarrier is also increased. As a result, the allocation of power which will increase the total data rate to the maximum value turns into a complex problem [13]. Therefore, in their work, distribution of the available power is done in two steps: first, subcarrier is assigned to the users then power is distributed to the subcarriers according to the water filling and equal distribution algorithms .When the transmitter has total knowledge about the channels, the transmitter allocates its available power among the subcarrier signals of the users which improve its data rate; channel fading is treated as constant over one OFDM symbol period. Assume the total numbers of users in OFDM system are K and total numbers of subcarriers in OFDM system are M. The received signal $Z_{k,m}$ for the kth user of mth subcarrier data symbol is represented by

$$Z_{k,m} = b_{k,m}\sqrt{P_{k,m}}h_{k,m} + \sum_{j=1,j\neq k}^{K} b_{j,m}\sqrt{P_{j,m}}h_{k,m} + N_m \qquad (1)$$

Where $b_{k,m}$ is the data rate of kth user and mth subcarrier, $P_{k,m}$ is the power assigned to mth subcarrier of kth user and $h_{k,m}$ is named as channel co-efficient factor for the mth sub channel between the base station and the kth user. N_m represents the additive white Gaussian noise (AWGN) in channel which has unity variance and zero mean .The first factor in the right-hand side of equation (1) points the wanted signal and the remaining factors show the noise disturbances which are the signals from unwanted users on the same type of subcarrier. So, the received signal to noise ratio with interference (SINR) for the kth user of mth subcarrier is represented by

$$\gamma_{k,m} = \frac{E\left[\left|b_{k,m}\sqrt{p_{k,m}}h_{k,m}\right|^2\right]}{E\left[\left|\sum_{j=1,j\neq k}^{K} b_{j,m}\sqrt{p_{j,m}}h_{k,m} + n_m\right|^2\right]} = \frac{p_{k,m}\left|h_{k,m}\right|^2}{\sum_{j=1,j\neq k}^{K} p_{k,m}\left|h_{k,m}\right|^2 + N_0} \qquad (2)$$

Where E [.....] shows the expectation factor and N_0 is the power spectral density factor of noise.

III. POWER ADAPTION

Now, the average data rate of the MU-OFDM system can be optimized when available power is distributed adaptively among the subcarriers and users by Channel Site Information. The total transmit power is given by

$$\sum_{k=1}^{K}\sum_{m=1}^{M} p_{k,m} = P \qquad (3)$$

Where P is named as the total transmitted power. The rate optimization problem with the power constraint (3) is a complex scheme as many users in system are work on a same subcarrier. System complexity is reduced by allocated a subcarrier to only one user adaptively and the power is distributed among subcarriers using water filling scheme. The allocation of subcarrier to the user is done in such a way so that channel gain is the highest for that subcarrier. For power allocation, multiuser OFDM system is treated as a single user OFDM system practically and transmits power distribution is assumed only for the subcarriers. Now, the average data rate with constraint on the total transmit power is written as

$$R = \frac{B}{M}\sum_{m=1}^{M}\log_2\left(1 + p_{k_m^*}\left|h_{k_m^*}\right|^2\frac{M}{N_0 B\Gamma}\right) \qquad (4)$$

Where $k_m^* = \mathrm{Arg}_k \max\{\left|h_{1,m}\right|^2, \left|h_{2,m}\right|^2, \ldots, \left|h_{K,m}\right|^2\}$ for m=1,2,. . . ,M and

$$\sum_{m=1}^{M} p_{k_m^*} = P \qquad (5)$$

To solve the power optimization problem that results the maximum data rate for the MU-OFDM system is found by applying the Lagrange multiplier scheme. The Lagrangian method for the above problem is given as

$$L = \frac{B}{M}\sum_{m=1}^{M}\log_2\left(1 + p_{k_m^*}\left|h_{k_m^*}\right|^2\frac{M}{N_0 B\Gamma}\right) + \lambda\left(\sum_{m=1}^{M} p_{k_m^*} - P\right) \qquad (6)$$

Where λ is the Lagrange multiplier factor, now to find efficient solution, equation (6) is differentiated with respect to $p_{k_m^*}$ and equated to zero, i.e.$\frac{\partial L}{\partial p_{k_m^*}} = 0$. Finally, the total transmit power is calculated by

$$p_{k_m^*} = \frac{N_0 B\Gamma}{M}\left[\frac{1}{\lambda_0} - \frac{1}{\left|h_{k_m^*}\right|^2}\right]^+ , \quad \text{for } m = 1,2,\ldots,M \qquad (7)$$

$$p_{k_m^*} = 0 , \quad \text{for } k \neq k_m^* \qquad (8)$$

Where $[x]^+ \triangleq \max\{x, 0\}$ and λ_0 is a constant factor to be calculated by the total available power constraint in equation (7). This equation represents the water filling method i.e. the subcarrier that has largest channel gain finds high power and channel having low gain gets small power. Thus, the total transmit power scheme (8) gives spectral diversity and multiuser diversity.To find λ_0 in (7) is highly complicated task for computation. So, to reduce computational pressure, a simple equal power allocation for all subcarriers are used in which total available power is allocated equally to the all subcarriers after allocation of all subcarriers. There is very small difference in the performance of the MU OFDM system when power is allocated equally or using the water filling scheme.

The equal power allocation scheme is shown as:

$$p_{k_m^*} = \frac{P}{M}, \quad \text{for } m = 1, 2, \ldots, M$$

$$p_{k_m^*} = 0, \quad \text{for } k \neq k_m^* \qquad (9)$$

The average signal to noise ratio (SNR) is calculated by

$$\mathrm{SNR} = \frac{P}{MN_0} \qquad (10)$$

It is taken that QAM modulation and demodulation with proper phase are used as the upper bound for the bit error rate (BER) for the kth user of mth subcarrier signal is given by

$$\mathrm{BER} \leq \frac{1}{5}\exp\left(\frac{-1.5\,\gamma_{k,m}}{2^{q_{k,m}} - 1}\right) \qquad (11)$$

Here $q_{k,m}$ shows the number of bits present in each data character. On reforming (11), we find the value of maximum bits in a data symbol that can be send for the kth user of mth subcarrier as

$$q_{k,m} = \log_2\left(1 + \frac{\gamma_{k,m}}{\Gamma}\right) \qquad (12)$$

Where Γ is called SNR gap which finds the degradation of SNR with respect to channel capacity, and it is the depends only required bit error rate and is expressed as

$$\Gamma = -\ln(5\mathrm{BER})/1.5. \qquad (13)$$

In multiuser MIMO-OFDM system, the average data rate is obtained by the summation of data rates of all available subcarriers that are assigned to all users.

Thus, the average data rate of the multiuser MIMO-OFDM system is expressed by

$$R = \sum_{k=1}^{K}\sum_{m=1}^{M}\frac{q_{k,m}}{T} = \frac{B}{M} \qquad (14)$$

Where $T = \frac{M}{B}$ is the OFDM symbol period.

IV. SIMULATION RESULTS

Simulation of the results of multiuser MIMO-OFDM system is done using MATLAB software and we observed the effect of different parameters on the system capacity. In the simulation methods, signal to noise ratio (SNR) values, number of users (K), number of subcarriers (M) are varied or kept constant as per requirement of observation in that process. Cyclic prefix of length 16 equal to channel taps are assumed to eliminate Inter Symbol Interference (ISI). AWGN noise variance is being considered equal to 10^{-3} and required Bit Error Rate (BER) value is kept to 10^{-3}. Figures 3 – 19 show average data rate normalized by total channel bandwidth is for different sections of the process. In 'Efficient Subcarrier Allocation (ESA) & Water Filling Distribution (WFD)', subcarriers are assigned dynamically and power is distributed according to water filling scheme. In 'Efficient Allocation (ESA) & Uniform Distribution (UD)', subcarriers are allocated adaptively and power is distributed uniformly. In 'Fixed Allocation (FA) & Water Filling Distribution (WFD)', subcarriers allocation are predetermined and power is distributed according to water filling scheme. In 'Fixed Allocation & Uniform Distribution', subcarriers allocation is predefined and power is distributed equally. Power distribution scheme (7) (8) ('Efficient Subcarrier Allocation (ESA) & Water Filling Distribution (WFD)') and (9) ('Efficient Subcarrier (ESA) & Uniform Distribution (UD)') is compared with conventional Fixed Allocation schemes. AWGN channel capacity is obtained from channel capacity formula

$$[R = B\log_2(1 + \mathrm{SNR})].$$

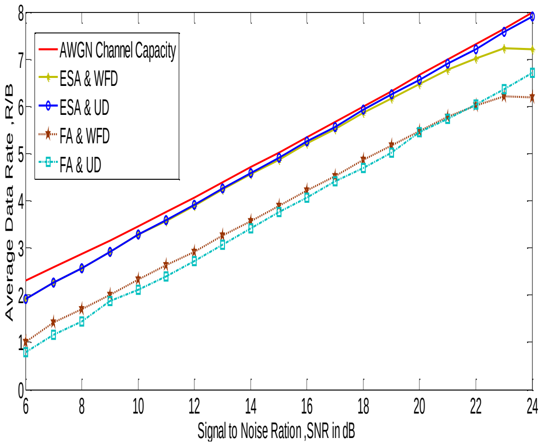

Fig-3: Average data rate versus signal to noise ratio for K=16, M=256, n_k=2

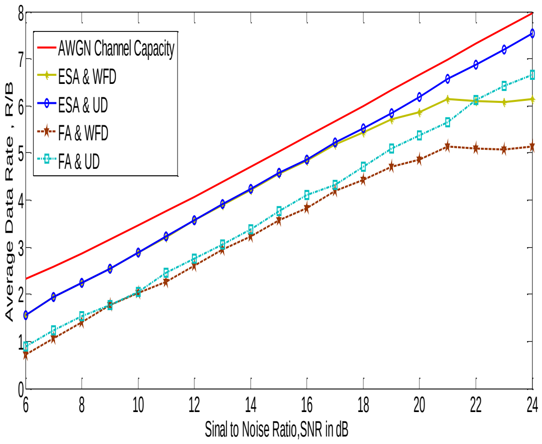

Fig-4: Average data rate versus signal to noise ratio for K=8, M=256, n_k=2

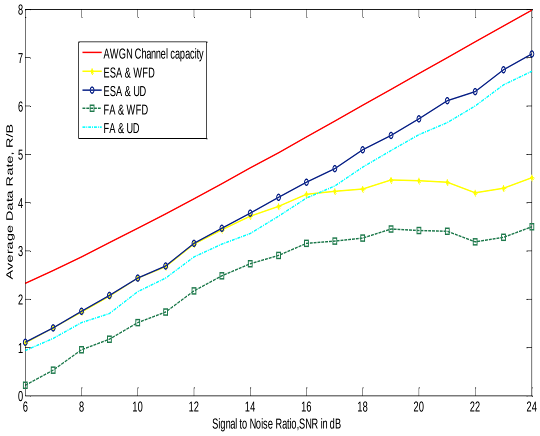

Fig-5: Average data rate versus signal to noise ratio for K=4, M=256, n_k=2

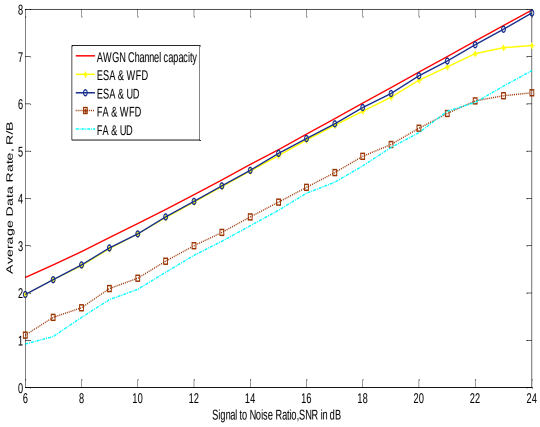

Fig-6: Average data rate versus signal to noise ratio for K=16, M=512, n_k=2

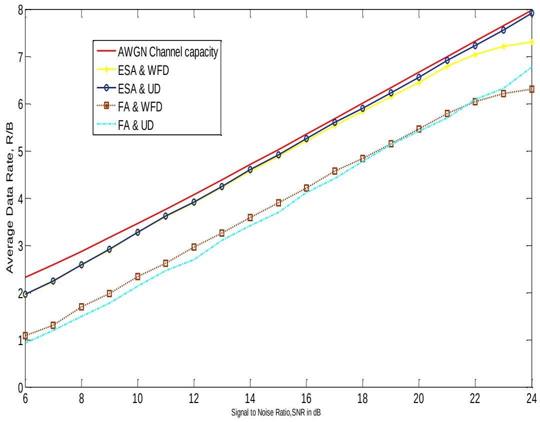

Fig-7: Average data rate versus signal to noise ratio for K=16, M=128, n_k=2

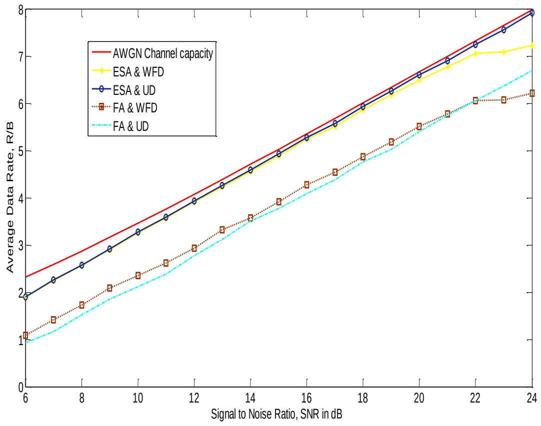

Fig-8: Average data rate versus signal to noise ratio for K=16, M=256, n_k=2

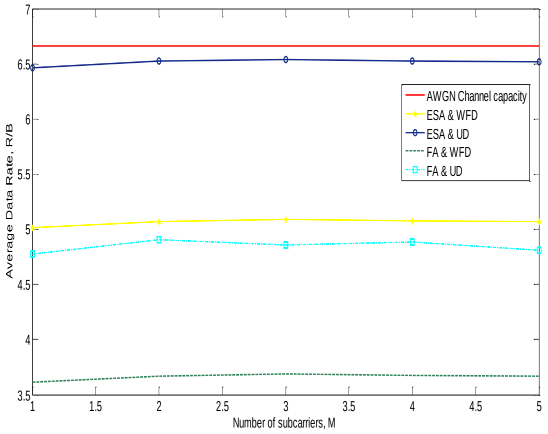

Fig-9: Average data rate versus number of subcarriers for K=16, SNR=20,n_k=4

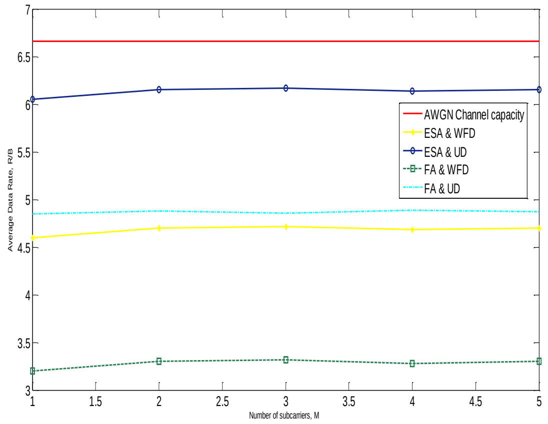

Fig-10: Average data rate versus number of subcarriers for K=8, SNR=20, n_k=4

Analysis the effect of increasing SNR values on the system total data rate, the average data rate versus signal to noise ratio for various transmit power allocation methods for the total number of users, K=4,8,16 and total number of subcarriers, M=128,256,512 is plotted in figures 3 - 8 for the number of transmitting antenna, n_k=2. In starting, noise level is fixed and SNR is increased then, total available transmit power is obtained according to the defined SNR values with help of equation (1.12). This figure depicts that the average data rate for the system increases with the increasing values of SNR for all subcarrier and power distribution schemes Average data rate in efficient subcarrier allocation is very near to the Shannon channel capacity limit and also, this is 1.3 bps/Hz is greater than in fixed allocation scheme.

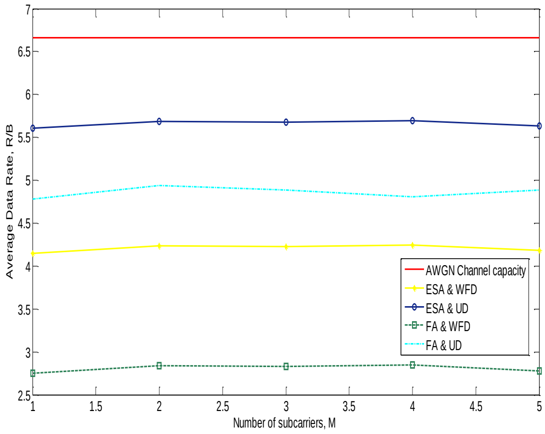

Fig-11: Average data rate versus number of subcarriers for K=4, SNR=20, n_k=4

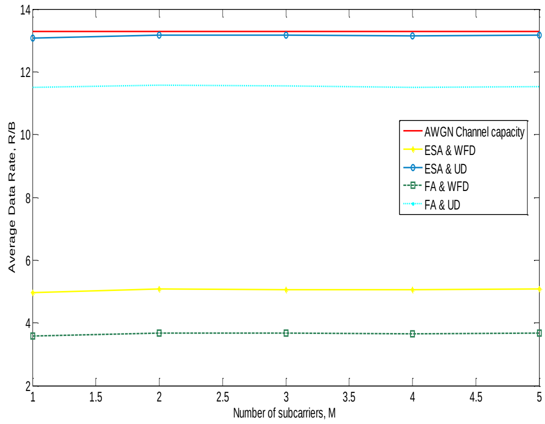

Fig-12: Average data rate versus number of subcarriers for K=16, SNR=40, n_k=4

For determining the effect of increasing number of subcarriers in the OFDM system on the system total data rate, the average data rate versus number of subcarriers, M, for various transmit power distribution methods for the total number of users, K=4,8,16 and SNR = 20,40,60 dB for the transmitting antenna , n_k = 4 is plotted in figures 9 - 13

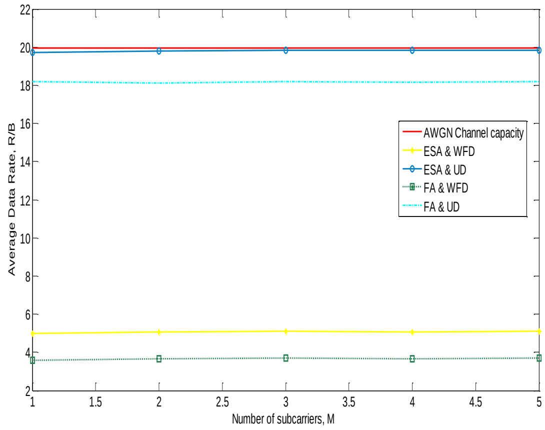

Fig-13: Average data rate versus number of subcarriers for K=16, SNR=60, n_k=4

For analysis the effect of increasing number of users in the OFDM system on the system total data rate, the average data rate versus number of users, K, for different transmit power allocation methods for fixed number of total subcarriers, M =128,256,512,1024 and SNR = 15,20,40 dB is plotted in figures 14 - 18. Total numbers of users, K are varied from 1 to 256. Figures show that data rate of ‘Efficient Subcarrier Allocation & Water Filling Distribution’, ‘Efficient Subcarrier Allocation & Uniform Distribution’ and ‘Fixed Allocation & Water Filling Distribution’ increases with the increase in the number of system users.

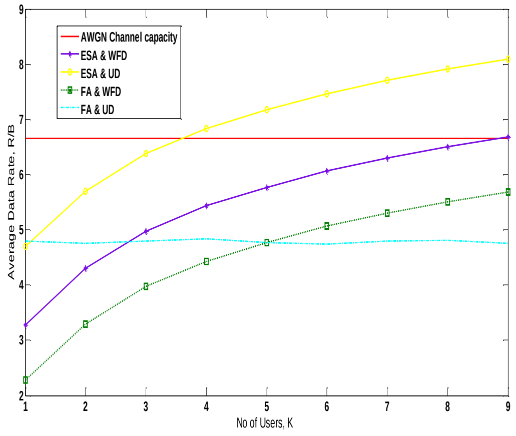

Fig-14: Average data rate versus number of users for n_k=2, SNR=20, M=256

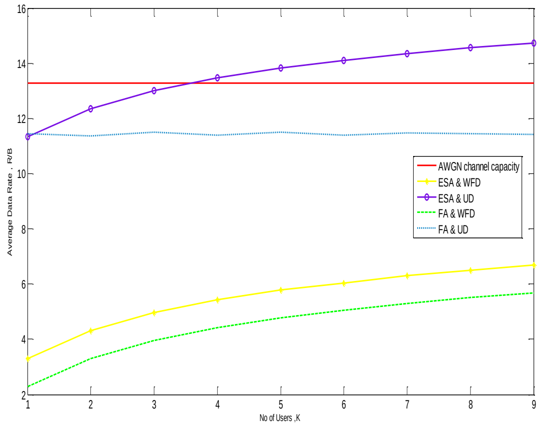

Fig-15: Average data rate versus number of users for n_k=2, SNR=40, M=256

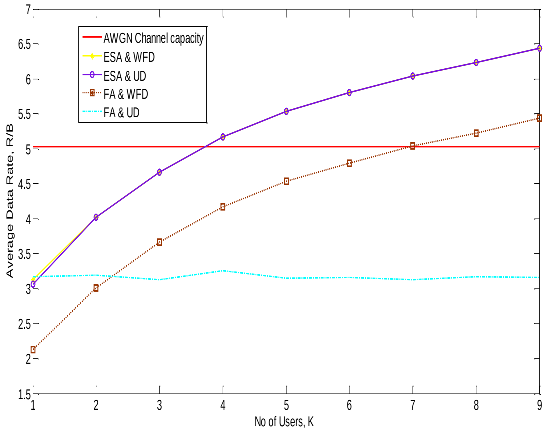

Fig-16: Average data rate versus number of users for n_k=2, SNR=15, M=256

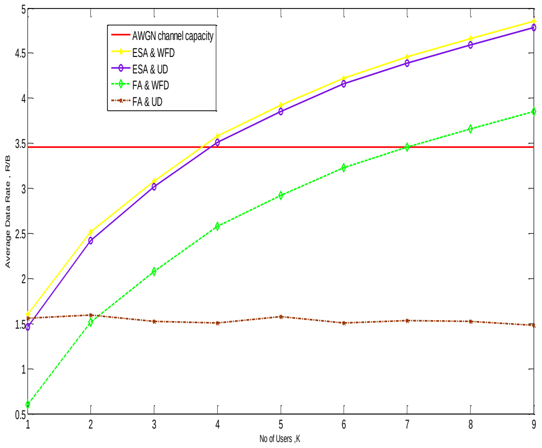

Fig-17: Average data rate versus number of users for SNR=15, M=128

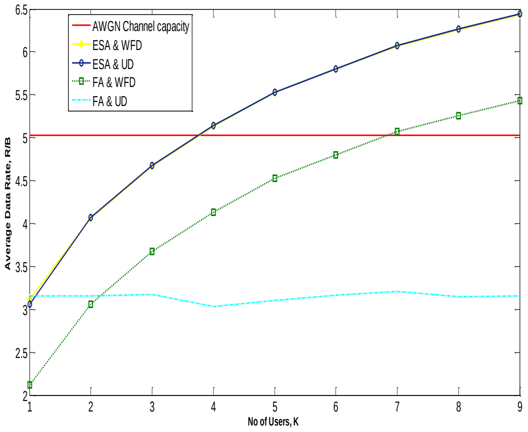

Fig-18: Average data rate versus number of users for n_k=4, SNR=15, M=512

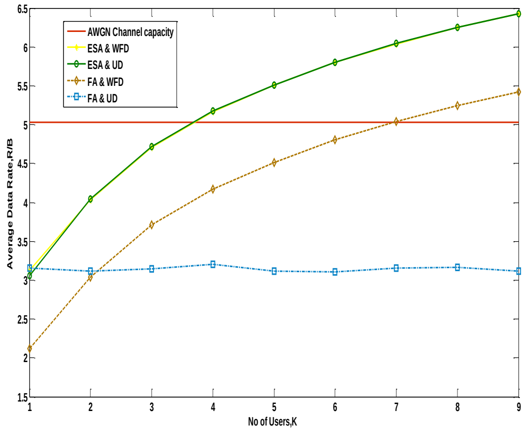

Fig-19: Average data rate versus number of users for n_k=4, SNR=15, M=1024

So, normalized data rate of system on each subcarrier is determined from equation (2) and averaged are calculated over all subcarriers. From figures, we can observe that system data rate of multiuser MIMO-OFDM system can be gone above the AWGN channel capacity limit for large number of users.

V. CONCLUSION

Here, efficient subcarrier allocation method gives better result than other adaptive and fixed allocation schemes. It is shown that the total data rate of the OFDM system is improved with fixed number of users and subcarriers if SNR value of a multiuser MIMO-OFDM system is increased. There is very small difference in efficient and fixed subcarrier assignment with water filling and uniform power distribution scheme for all number of subcarriers. The average data rate of a multiuser MIMO-OFDM system does not depend on total number of users and subcarriers for a fixed value of SNR.

The average data rates goes on increasing and higher than the channel capacity of the AWGN channel but total data rate of 'Fixed Allocation & Uniform Distribution' remains constant for the large number of users. MU OFDM system's data rate of 'Efficient Subcarrier Allocation & Water Filling Distribution', 'Efficient Subcarrier Allocation & Uniform Distribution' and 'Fixed Allocation & Water Filling Distribution' are higher than AWGN channel capacity for large number of users in OFDM system because of high multiuser diversity. In fixed allocation scheme, there is considerable difference in system data rates of water filling method and uniform power distribution but in efficient allocation method, there is very small difference between these two power distribution schemes.

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