ISSN 2047-3338

Efficient Scheduling for Multiuser MIMO Systems with Block Diagonalization Precoding in Millimeter Waves Channel

M. A. Mangoud

Electronics and Electrical Engineering Department, University of Bahrain, Isa Town, P. O. Box 32038, Bahrain

***Abstract*—In this paper, an efficient scheduling technique for multiuser MIMO downlink with block diagonalization precoding in millimeter waves channel is presented. The scheduling technique is based on employing hybrid DE/EPSO optimization method to maximize the sum rate capacity for selected number of users for outdoor cellular systems. The proposed scheduling scheme achieves almost similar capacity performance to the optimum exhaustive search algorithm and compared with classical genetic algorithm technique. In this paper, block diagonalization beamforming performance is considered for different number of mobile users and different numbers of antennas at the receivers under correlated millimeter wave channel model.**

***Index Terms*—Multiuser MIMO, Scheduling, PSO, DE, Beamforming and Millimeter Waves**

I. INTRODUCTION

SCHEDULING has been widely used nowadays as an effective approach to increase the sum rate capacity in multiuser MIMO downlink wireless systems. The concept of multi-users scheduling is that the base stations (BS) selects the best mobile stations (MS) which doesn't experience a deep fading. Millimeter wave (mmWave) communication is a promising technology to be used in the future outdoor cellular systems as it utilizes the large bandwidth available at mmWave spectrum to provide gigabit per second data rates in outdoor wireless communications. This paper focuses on investigating efficient scheduling techniques for MU-MIMO with precoding/ beamforming techniques are applied on top in mmWave channels that exhibits rich scattering and deep multi-path fading at MS locations. In the multiuser MIMO (MU-MIMO) systems, the signal for each user can be precoded or preprocessed separately by multiplying the data for the user by a beamforming matrix. The beamforming matrices can be designed to remove some or all of the interference from other users at the target receiver. Simple linear precoding/beamforming schemes, such as zero-forcing (ZF) or Channel inversion (CI) and linear minimum mean-square error (MMSE) also called regularized channel inversion (RCI), are able to approach the optimal capacity performance achieved by the complex dirty paper coding (DPC) as the number of antennas goes to infinity. If BSs and MSs are both equipped with multiple antennas, then the ZF processing that cancels the inter-user interference through channel inversion can be generalized as block diagonalization (BD) [1]. Various heuristic scheduling algorithms were previously introduced to select the subset of users to serve in order to maximise the total system capacity [2]-[4].

In this paper, DE/EPSO [5]-[6] will be applied to implement an efficient scheduling for MU-MIMO with BD precoding in mmWave environment. Therefore, we consider MU-MIMO downlink scenario where the transmitters base stations equipped with multiple antennas am utilize and efficient beamforming technique over mmWave channels. The remaining paper is organised as follows, system model is presented in section II. Section III gives a brief description of block diagonalization technique for MU-MIMO system and millimeter wave channel model used in this paper. In section IV, the EPSO/DE heretic optimization technique that is used for multiuser scheduling strategy is reviewed. Then the simulation results are compared and analyzed in section V. Finally conclusion is drawn in section VI

II. SYSTEM MODEL

In this paper, the downlink communications of Multiuser MIMO system with BD precoding has been considered in mmWave cellular system as shown in Fig. 1.

The figure shows one base station (BS) equipped with N_s antennas sends signals to K mobile stations each equipped with N_r antennas. It is assumed that all Mobile station (MS) share the same spectrum allocations. Since all signals are broadcasted from BS, each MS receives not only its desired signal but also unintended signals from the other MSs. The received signal at the k^{th} MS can be expressed as:

M.A. Mangoud is with the Electronics and Electrical Engineering Department, University of Bahrain, Isa Town, P. O. Box 32038, Bahrain, (Email: mmangoud@uob.edu.bh)

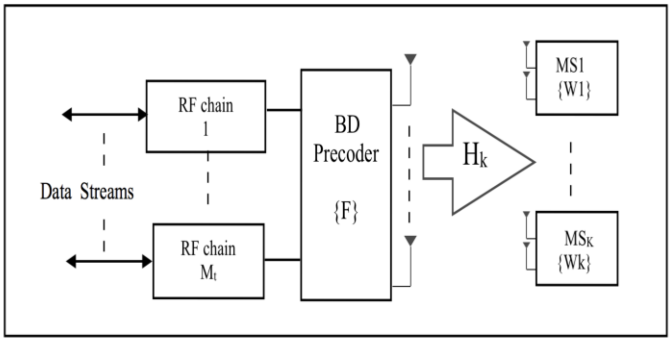

Fig. 1. Diagram of multiuser MIMO System with BD Precoding in mmWave channel

$$y_k = H_k s = H_k F_k x_k + \sum_{l=1, l \neq k}^{K} H_k F_l x_l + n_k \qquad (1)$$

where H_k is the channel matrix with dimensions $[N_r \times N_s]$ and F_k is the precoding matrix for the k^{th} user for the first term is the desired signal, the second term is inter user interference and the third term is the noise. where $y_k \in \mathbb{C}^{Nr \times 1}$ is the received signal at the k^{th} MS and $n_k \sim CN(0, \sigma_k^2 I_{Nr})$is a complex Gaussian noise vector at the k^{th} MS. To recover the desired signal, the MSs apply the decoding combining matrix $W_k \in \mathbb{C}^{Nr \times d}$ to the received signal yielding

$$\hat{x}_k = W_k^H y_k = W_k^H H_k F_k x_k + \sum_{l=1, l \neq k}^{K} W_k^H H_k F_l x_l + W_k^H n_k \qquad (2)$$

The sum rate channel capacity for all K MS users can be expressed as follows [7]

$$R = \sum_{k=1}^{K} w_k (\log 2 \left| I_{Ns} + \frac{P}{Ns} R_n^{-1} W^H H F F^H H^H W \right|) \qquad (3)$$

where $\omega_k \geq 0$ is the weight factor to present the different priority for the MSs. The problem of interest is to design the precoding matrices F_k and post-processing matrices Wk in order to obtain the maximum R over K MSs. R_n is the post-processing noise and interference correlation matrix can be written as

$$R_n = W^H (\sum_{l=1, l \neq k}^{K} H_k F_l x_l + n_k) W \qquad (4)$$

III. Block diagonalization for downlink MU-MIMO in mmWave channels

Block diagonalization (BD) is a generalization of channel inversion when both the transmitter and the receiver have multiple antennas. When BD is employed in [1] the precoding matrices for the considered MU-MIMO system are defined as $\boldsymbol{F}_j$, for user j and are chosen such that . The received signal y_k is interference free at the *k-th* user, the effective channel matrix $\{H_k F_l\}_{l \neq k}$ should follow:

$$H_k F_l = 0 \quad \forall\, l \neq k \qquad (5)$$

Hence, the received signals y can be written as follows,

$$\begin{bmatrix} y_1 \\ y_2 \\ ... \\ y_K \end{bmatrix} = \begin{bmatrix} H_1 F_1 & ... & ... & 0 \\ 0 & ... & ... & 0 \\ 0 & ... & ... & 0 \\ 0 & ... & ... & H_K F_K \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ ... \\ x_K \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ ... \\ n_K \end{bmatrix} \qquad (6)$$

In order to fulfill the condition in (6), the precoding matrix F_k should be designed so that it lies on the null space of all other users channels except user k, which is defined as $\widetilde{H}_k = [H_1^T ... H_{k-1}^T H_{k+1}^T ... H_K^T]$. This can be obtained by singular value decomposition (SVD) of $\tilde{H}_k$ as follows.

$$\widetilde{H}_k = \tilde{U}_k \tilde{\Sigma}_k \left[\tilde{V}_k^{(1)} \tilde{V}_k^{(0)} \right]^H \qquad (7)$$

where $\tilde{U}_k$ is an $N_r \times$ rank($\tilde{H}_k$) unitary matrix, $\tilde{\Sigma}$ is a rank($\tilde{H}_k$) $\times$ rank($\tilde{H}_k$) diagonal matrix of singular values arranged in decreasing order, and $\tilde{V}_k$ is a $Ns \times$ rank($\tilde{H}_k$) unitary matrix. The combining and the Precoding matrix, W and F_k are simply the $\tilde{V}_k^{(1)}, \tilde{V}_k^{(0)}$ obtain form (7) respectively. MIMO channels have been modelled previously with accurate parameterized physical or idealized statistical models for example as in [8], however this work considered the operating frequencies to be in the range frequencies of 2 to 5 GHz. In this paper, the MU-MIMO system will be considered to operate at mmWaves frequencies. mmWave channels which is different from lower frequencies channels can be best modelled by geometric channel model with limited scattering objects [7] and [9] which is based on the model introduced by [10] which provided simple geometric interpretation of the scattering multi-antenna fading channels. In the paper, considering L scatterers, the mmWave is modelled with each scatterer is further assumed to contribute a single propagation path between the BS and MS. Therefore, the channel H can be expressed as

$$H = \sqrt{\frac{N_s N_r}{\rho J}} \sum_{j=1}^{J} \alpha_j A_{MS}(\theta_j^{MS}) A_{BS}^H(\phi_j^{BS}) \qquad (8)$$

where J is the number of scatterers in the model and each one is further assumed to be a single propagation path. α_j is the average pathless between BS and MS. ρ is the complex gain p_f the j^{th} path. $A_{MS}(\theta_j^{MS})$ and $A_{BS}(\phi_j^{BS})$ are the antenna array response and steering vectors at MS and BS respectively. $\theta_j^{MS}$and ϕ_j^{BS} are the j^{th} path azimuth angles of arrival and departure respectively, and they are assumed to be uniformly random variables $\in [0, 2\pi]$. Also, one-dimensional uniform linear arrays (ULAs) at both MS and BS are considered. The steering vector can be expressed as follows.

$$A_{BS}(\phi_j^{BS}) = \frac{1}{\sqrt{N_r}} \left[1, e^{i \frac{2\pi}{\lambda} d \sin(\phi_j^{BS})}, ..., e^{i(N_r - 1)\frac{2\pi}{\lambda} d \sin(\phi_j^{BS})} \right] \qquad (9)$$

where λ is the signal wavelength and d is the distance between array elements. The response vector at MS can be expressed in a similar form.

IV. HYBRID EPSO/DE ALGORITHM OPTIMIZATION TECHNIQUES

Evolutionary optimization algorithms such as genetic algorithms (GAs), differential evolution (DE) and particle-swarm optimizers (PSO) have been broadly used in wireless communications applications. to improve global optimization performance either we perform the same optimization scheme successively with different initializations or we improve the optimization algorithm itself by introducing a modified version with enhanced searching capability. In [6], enhanced version of PSO was developed, where the global search ability of the classical PSO has been improved by modifications to particles positions and velocities updating formulas. An efficient hybrid technique that combines Enhanced PSO (EPSO) with DE was introduced [5] and [11], in which Hybrid EPSO/DE was found to be an excellent optimization tool and outperform optimization techniques for the problem of null steering using selected position perturbed array elements for different geometries. Hybrid EPSO/DE Algorithm can be summarized as shown in the flow chart given in Fig. 2. In this hybrid method, Initially *P* particles (individuals) population with *N* length equal *N* are generated with both EPSO and DE Evolutionary algorithms simultaneously. Then, the two generations ate merged together to have one generation with 2*P* particles. The fitness function is then evaluated for all particles of the merged generation and the *best particle* that has the minimum fitness function is detected. Next step is divide the 2*P* particles generation into two generations of *P* particles with each one include the best particle selected from the previous step. At this point a convergence test is performed if the algorithm doesn't converge, then previous steps are repeated. In the case of no convergence, the two groups of *P* particles are passed to both EPSO and DE algorithms to evolve new generations.

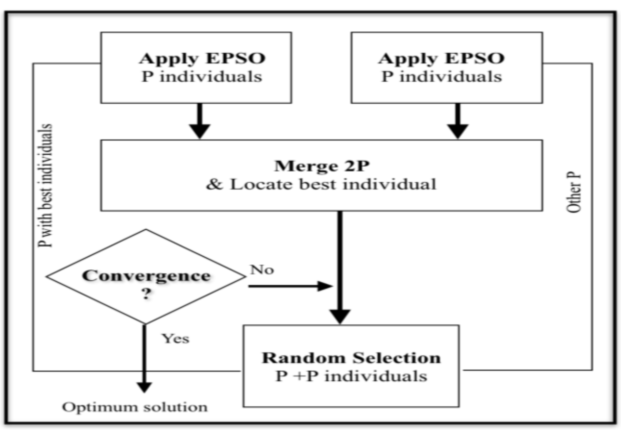

Fig. 2. Flowchart of the Hybrid DE/EPSO algorithm

V. MIMO MULTIUSER SCHEDULING SCHEME

Exhaustive search (ES) is the optimal user scheduling which search all possible grouping of subsets of simultaneously supported users. The main drawback of this technique is that it is computationally very complex. The main objective of this paper is to investigate and apply heuristic optimization to compare the performance of lower complexity EPSO/DE and genetic algorithm scheduling algorithms for BD, assuming mmWave channel. Recall that the capacity expression deduced in (3), for the purpose of maximize the system sum rate capacity. Note that, the channel matrix H in (3) is obtained by concatenation of channel vectors of all the MSs in the scheduled group should maximize. The objective function which is evaluated using the Genetic Algorithm [12] and EPSO/ED algorithms [5] and [11] is the sum rate capacity R given by (3). Assuming that S MSs are scheduled in each realization of the channel, now the scheduling problem can be simplified to choose S best channels (where, $S \leq K$: total number of active MSs). Namely, S rows hk of H will be selected for transmission based on some specified criteria, and the optimum sum rate capacity can be obtained with this selected scheduled group.

VI. NUMERICAL RESULTS

In this section, MU-MIMO downlink scenario is simulated with BD precoding in mmWave channel realization. First, BER performance analysis of MU-MIMO system has been investigated with BD precoding the simulated MU-MIMO system is considered to have a single BS with Ns = 4 and number of selected MS users equal 2, 3 and 4 with Nr= 2 and 3 antennas. QPSK modulation is assumed with Number of frames/packet and Number of packets = 10 and 2000 respectively. mmWave channel model parameters are as follows: J=3 scatterers (number of paths) with uniform random AOA and AOD. The complex path gain is assumed to be normally distributed with equal variances. Operating carrier frequency = 28 GHz with path-loss exponent n=4. BER verses SNR results are presented in Fig.3. As shown the BD algorithm is implemented successfully for different number of users and number of antennas. BER improves as number of antennas increase and number of simultaneous users decreases, this implementation is next used with scheduling optimization investigations. Next, the evaluation of scheduling for this case study employing MU-MIMO with BD precoding and mmWave channel model channel. Multiuser downlink scenario of a total number M = 16 existing MSs in the cell and antennas, where the scheduled group to be selected using the scheduling scheme is assumed to be 4 MSs. Four different scheduling techniques which are Random, GA, EPSO/DE, ES are implemented and the results are illustrated and compared in Fig. 4. The figure show cumulative density function for the four scheduling techniques at SNR = 15 dB. 10000 channel realizations have been considered. As can be seen, best sum rate capacity is obtained using the exhaustive search (ES) method as expected. The capacity of the proposed EPSO/DE algorithm achieves a similar performance to ES scheme. For the same number of iterations and computational resources EPSO/PSO algorithm outperforms the classical genetic algorithm GA. These system capacities are compared with the randomly scheduling method, which is the worst among all these four algorithms.

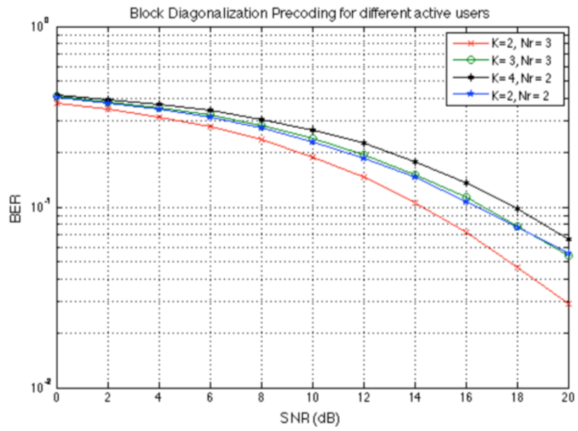

Fig. 3. BER performance versus SNR for MU-MIMO system with BD precoding in mmWave channel for different number of users and different number of antennas

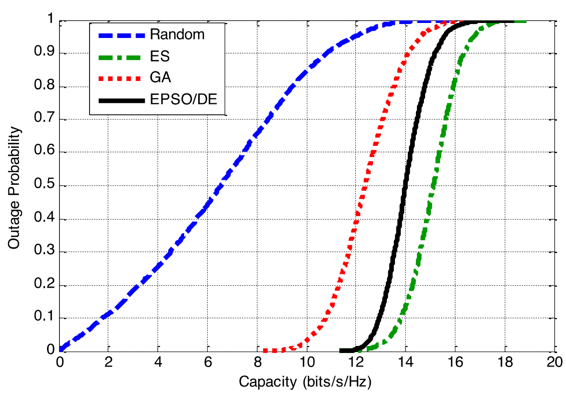

Fig. 4. Probability distribution function for the sum rate capacity of BD-MU-MIMO system using Random, GA, EPSO/DE and ES scheduling schemes at SNR=15dB

ACKNOWLEDGMENT

The author would like to thank the Deanship of Scientific Research at University of Bahrain, Kingdom of Bahrain, for the support of this research work.

VII. CONCLUSION

An application of EPSO/DE optmization technique to perform scheduling for multiuser MIMO systems has been presented in this paper with the objective of increasing the sum rate capacity of outdoor cellular systems. It has been proved that EPSO/DE are a fast, suboptimal, low-complexity method of solving such optimization problems for wireless communications applications. This technique proves its efficiency in maximization of a scheduling fitness function, and can handle arbitrary functions and number of users constraints compared to the classical GA technique. It is demonstrated that that the EPSO/DE performance is close to that of an optimal exhaustive search, but at a greatly reduced complexity. Also, in this paper linear BD precoding has been implemented for different number of users and antennas in mmWave rich scattering environment and have been employed in the simulations of scheduling scheme of MU-MIMO.

REFERENCES

[1]. Shen, Zukang, Runhua Chen, Jeffrey G. Andrews, Robert W. Heath, and Brian L. Evans Jr. "Sum capacity of multiuser MIMO broadcast channels with block diagonalization." *IEEE International Symposium on Information Theory*, pp. 886-890, 2006.

[2]. Hei, YongQiang, XiaoHui Li, KeChu Yi, and Hong Yang. "Novel scheduling strategy for downlink multiuser MIMO system: particle swarm optimization." *Science in China Series F: Information Sciences*, vol 52, no. 12, pp. 2279-2289, 2009.

[3]. U. Sreenivasulu, P. Naganjaneyulu , M. Giriprasad, “Achieving QOS Requirement using Evolutionary Computation Scheduling in 802.16 Networks" *Journal of Theoretical and Applied Information Technology*, Vol. 83, No. 3, pp. 345-352, 2016.

[4]. Yong-qiang, Hei, Xiao-Hui Li, Ke-Chu Yi, and Xiong Li. "Multiuser scheduling in downlink MIMO systems using particle swarm optimization." *IEEE Conference in Wireless Communications and Networking*, WCNC 2009, pp. 1-5, 2009.

[5]. H. M. Elragal, M A. Mangoud, and M. T. Alsharaa. "Hybrid differential evolution and enhanced particle swarm optimisation technique for design of reconfigurable phased antenna arrays." *IET Microwaves, Antennas & Propagation*, Vol. 5, No. 11, pp. 1280-1287, 2011.

[6]. M. A. Mangoud and H. M. Elragal. "Antenna array pattern synthesis and wide null control using enhanced particle swarm optimization." *Progress in Electromagnetics Research B Journal*, Vol. 17, pp. 1-14, 2009.

[7]. A. Alkhateeb, O. El Ayach, G. Leus, and R. W. Heath. "Channel estimation and hybrid precoding for millimeter wave cellular systems." *IEEE Journal of Selected Topics in Signal Processing*, Vol. 8, no. 5, pp. 831-846, 2014.

[8]. M. A. Mangoud, and Z. Mahdi. "Realistic Spatio-temporal channel model for broadband MIMO WLAN systems employing uniform circular antenna arrays." *Journal-Applied Computational Electromagnetics Society* (ACES), Vol. 26, no. 5, pp. 394-400, 2011.

[9]. A. Alkhateeb, M. Jianhua, G. Nuria, and R. W. Heath. "MIMO precoding and combining solutions for millimeter-wave systems." *IEEE Communications Magazine*, Vol. 52, No. 12 , pp. 122-131, 2014.

[10]. A. M. Sayeed, "Deconstructing multiantenna fading channels." *IEEE Transactions on Signal Processing*, Vol. 50, No. 10, pp. 2563-2579, 2002.

[11]. M. A. Mangoud, H. M. Elragal, and M. T. Alshara, “Design of time modulated concentric circular and concentric hexagonal antenna array using hybrid enhanced particle swarm optimisation and differential evolution algorithm”. *IET Microwaves, Antennas & Propagation Journal*, Vol. 8, No. 9, pp. 657-665, 2014.

[12]. M. A. Mangoud, “Optimization of channel capacity for indoor MIMO systems using genetic algorithm.” Progress in Electromagnetics Research C Journal, Vol. 7, pp. 137-150, 2009.

Mohab A. Mangoud received B.Sc and M.Sc from Alexandria university in 1993 and 1996 respectively, Ph.D degree from University of Bradford, Bradford, UK in 2001. He worked as a senior RF Engineer for Airbus-Astrium Space Lmt, Hertfordshire, UK, in the field of space and commercial communications satellites. He was Assistant Professor with Electronics and communications Engineering Department, Arab Academy for Science and Technology and Maritime Transport (AASTMT) Alexandria, Egypt. Later, Dr. Mangoud joined Bradley Department of Electrical & Computer Engineering, Virginia Polytechnic Institute and State University (Virginia Tech.), Blacksburg, Virginia, USA as Adjunct Professor. Currently, he is an Associate Professor of wireless communications, Department of Electrical and Electronics Engineering, University of Bahrain (UOB), Bahrain. He is the coordinator of communications courses, Head of telecommunications research Labs and College of Engineering senior projects coordinator at UOB and Telecommunications consultant for Bahrain Polytechnic. His Current research areas of interest include Wireless, Mobile and Personal Communications, Cooperative and Cognitive networks and MIMO Technology. He has published more than 60 scientific papers in national and international conferences and journals. Dr. Mangoud is a Senior Member of the IEEE, IEEE Communications Society (ComSoc), IEEE Antenna and Propagations Society (APS), Microwave theory and Techniques society (MTT-S) and IEEE Broadcast Technology Society (BTS). Dr. Mangoud is also serving as the counselor of IEEE UOB student branch and IEEE Bahrain section students activities officer. Also, He is currently the Vice Chair of IEEE Bahrain Section, Region 8.