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Abstract

In this paper, particle swarm optimization is employed to carry out transmit antenna subgrouping algorithm for massive multiple input and multiple output (MIMO) system. A minimum number of transmit antenna elements are selected to achieve a similar quality of service (QoS) as that of a single user MIMO system. Simulation results show that our proposed algorithm achieves similar capacity performance as compared to massive MIMO systems when employing exhaustive search for transmit antenna selection.

1. Introduction

Mobile networks are under constant pressure to ensure customer satisfaction as data demands are rapidly increasing [1]. Multiple input and multiple output (MIMO) systems have the ability to serve multiple users from a single base station [2], [3]. However, it is observed that by increasing the number of users at the base station (BS) the performance of multi-user (MU)-MIMO decreases as compared to a single user (SU)-MIMO. The loss in performance in desired quality of service (QoS) is due to the increased spatial interference. Millimeter wave (mm-Wave) has been considered as one of the potential candidates to fulfil these data demands [1]. Mm-Wave system has shorter wavelengths, allowing more antennas to be packed in the same area [2], giving rise to massive (M)-MIMO system. The gain of antennas is further enhanced by the three-dimensional (3D) channel as it takes advantages of both azimuth (horizontal) and elevation (vertical) planes [4]. Therefore, combining M-MIMO with mm-Wave is thought as a viable solution for constantly satisfying increased mobile user data demands [5]-[7].

The structure of the BS transmits antenna array plays a significant role in mitigating spatial interference [8]. By determining the QoS for the desired user equipment (UE) antenna element selection can be employed which is a key issue [9] in M-MIMO system. In this paper, the optimal selection of antenna elements is found by an exhaustive search over all possible combinations for M-MIMO. However, the complexity is extremely high due to a large number of combinations [10]. Therefore, selection of antenna element is carried out with the assistance of particle swarm optimisation (PSO). PSOs are non-deterministic polynomial-time (NP)-hard problems and are one of the most intensively and widely studied combinatorial optimization problems in the literature [11]. In the last decade, PSOs have attracted both theorists and practitioners from different fields [12]-[15]. PSO has been applied in selected areas of signal processing and wireless communications such as radar, resource allocation, relay selection, content sharing and antenna switching [12]-[15].

In this paper, we formulate the combinatorial optimization problem for selecting transmit antenna elements such that desired level of QoS of each user is achieved. PSO helps to determine the minimum number of transmit antenna elements to achieve a desired QoS for the UE. Depending on the particular level of QoS of each UE, threshold values are chosen which results in different selected number of transmit antenna elements at the BS. Furthermore, PSO respects the limitation that each antenna is assigned only to a given user. Therefore, in this paper M-MIMO transmit antenna element selection with PSO is proposed. From simulation results, it is observed that PSO assists in selecting a minimum number of transmit antenna elements. The selection of transmit antenna elements depends upon the chosen threshold value. The higher the threshold value, the higher will be the number of transmit antenna elements required to achieve the desired level of QoS.

2. System Model

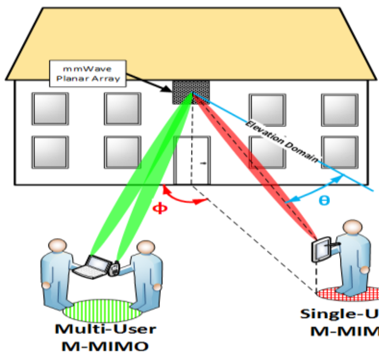

Figure 1. mm-Wave Small Cell

We consider the downlink of a 3D-MIMO system which consists of mm-Wave base station (BS) equipped with M antennas as shown in Fig.1, transmitting data to K users having N receive antennas. The BS is equipped with a planar rectangular array where the total number of transmit antennas is M, where $M = M_h \times M_v$, equally spaced elements. M_h and M_v represent the number of transmit antenna elements in the horizontal and vertical axis, respectively. The antenna elements' radiation pattern is adjusted based on the user's spatial location (θ, φ) which is determined by the difference in height and distance from the BS by employing active antenna systems (AAS) in 3D MIMO.

A. 3D mm-Wave Channel Model

3D mm-Wave channel is based on the geometry based stochastic model as shown in [16]–[17]. This 3D channel parameters incorporate shadow fading, the Ricean K-factor (only in the LOS case), delay spread, azimuth angle spread of departure and arrival, including zenith angle spread of departure and arrival. The channel between the s-th BS antenna element and the u-th UE antenna element is given by

$$H_{u,s}(t) = \sqrt{\frac{P}{L}} \sum_{l=1}^{L} \begin{bmatrix} \mathrm{F}_{\mathrm{rx,u,\theta}}\left(\theta_{l,ZOA}, \phi_{l,AOA}\right) \\ \mathrm{F}_{\mathrm{rx,u,\phi}}\left(\theta_{l,ZOA}, \phi_{l,AOA}\right) \end{bmatrix}^T \begin{bmatrix} e^{j\Phi_l^{\theta\theta}} & \sqrt{\kappa_l^{-1}} e^{j\Phi_l^{\theta\phi}} \\ \sqrt{\kappa_l^{-1}} e^{j\Phi_l^{\theta\phi}} & e^{j\Phi_l^{\phi\phi}} \end{bmatrix} \begin{bmatrix} \mathrm{F}_{\mathrm{tx,s,\theta}}\left(\theta_{l,ZOD}, \phi_{l,AOD}\right) \\ \mathrm{F}_{\mathrm{tx,s,\phi}}\left(\theta_{l,ZOD}, \phi_{l,AOD}\right) \end{bmatrix}. \, e^{j2\pi\lambda_0^{-1}(r_{rx,l}^T \cdot d_{rx,u})} e^{j2\pi\lambda_0^{-1}(r_{tx,l}^T \cdot d_{tx,s})} e^{j2\pi v_l \cdot t} \quad (1),$$

where P is the power associated with the desired user, L is the number of resolvable multipaths, $F_{rx,u,\theta}$ and $F_{rx,u,\phi}$ are the field patterns of the receive antenna element u in the direction of θ and ϕ, respectively. $F_{tx,u,\theta}$ and $F_{tx,u,\phi}$ are the field patterns of the transmit antenna elements in the direction of θ and ϕ. ZOA, ZOD, AOA, and AOD are the zenith angle of arrival, zenith angle of departure, angle of arrival and angle of departure, respectively. κ_l represents the cross polarization power ratios for resolvable path. $\Phi^{\theta\theta}$, $\Phi^{\theta\phi}$, $\Phi^{\phi\theta}$, and $\Phi^{\phi\phi}$ are random initial phases for four different polarization combinations. The terms $r_{rx,l}$ and $r_{tx,l}$ are the receiver and transmitter spherical unit vectors expressed in Cartesian coordinates. $d_{rx,u}$ and $d_{tx,u}$ are the location vectors of receive and transmit antenna elements, respectively. v_l represents the Doppler frequency shift which is calculated from the AOA, ZOA and the user's velocity vector. The N by M MIMO channel matrix for the kth user is given by

$$H_k = \begin{bmatrix} H_{1,1} & H_{1,2} & \cdots & H_{1,m} \\ \vdots & \vdots & \ddots & \vdots \\ H_{n,1} & H_{n,2} & \cdots & H_{n,m} \end{bmatrix}. \quad (2)$$

B. Transmitter

The signal vector transmitted by the BS antenna array with beamforming is defined as

$$\boldsymbol{x} = \textstyle\sum_{k=1}^{K} \boldsymbol{t}_k \boldsymbol{b}_k \quad (3)$$

where $\boldsymbol{x}$ represents the transmitted data, $\mathbf{t}_k$ represents the beamforming vector and b_k represents the data symbol to be transmitted to the k-th user.

C. Receiver

The receive combining vector $\mathbf{w}_k$ is employed at the receiver of the k-th user to process the received signal y_k, given as

$$y_k = \boldsymbol{w}_k^H \boldsymbol{H}_k \boldsymbol{t}_k \boldsymbol{b}_k + \boldsymbol{w}_k^H \boldsymbol{H}_k \textstyle\sum_{j\neq k} \boldsymbol{t}_j \boldsymbol{b}_j + \boldsymbol{w}_k^H \boldsymbol{n}_k, \quad (4)$$

where $\mathbf{n}_k$ is the Additive White Gaussian Noise (AWGN) with zero mean and variance σ^2.

3. Problem Formulation

In MU-MIMO, the achievable capacity of k-th user, employing all the antennas at the BS with receive combining $\mathbf{w}_k$, based on (4) is given as

$$\tilde{C}_k = log_2\left(1 + \frac{\frac{P}{M}|\boldsymbol{w}_k^H \boldsymbol{H}_k t_k|}{\frac{P}{M}\sum_{j\neq k}|\boldsymbol{w}_k^H \boldsymbol{H}_k \boldsymbol{t}_j| + \sigma_k^2}\right) \quad (5)$$

The SU-MIMO rate of the k-th user, when employing M transmit antenna elements, is given by

$$\bar{C}_k = log_2\left(1 + \frac{P\,|\boldsymbol{w}_k^H \boldsymbol{H}_k t_k|}{\sigma_K^2}\right) \quad (6)$$

The SU-MIMO capacity is always greater than the achievable MU-MIMO capacity because there is no spatial interference. Therefore, the objective of this paper is to develop a transmit antenna subgrouping algorithm achieving the C_k of SU-MIMO.

A. Formulation and Selection of Antennas

It is required that each transmit antenna selected is assigned to a particular user. It is important to determine the number of elements that would be required to guarantee a certain QoS. From (5) and (6), the QoS in between

$$\widetilde{C_k} \leq C_k \leq \overline{C_k}, \quad (7)$$

where C_k is the required QoS for the k-th user. Let $C_k = \alpha_k \overline{C_k}$, where $\overline{C_k}$ is the maximum achievable SU-MIMO capacity and α_k is the threshold value which is used to achieve a certain level of QoS. The value of α_k varies between $\widetilde{C_k}/\overline{C_k}$ and 1 which means that all antenna elements are assigned to the k-th user. For $\alpha_k = \widetilde{C_k}/\overline{C_k}$, minimum number of antenna elements are selected for the k-th user. For an arbitrary value of α_k let us suppose M_S antennas are selected, then the capacity will be given as,

$$C_k = log_2\left(1 + \frac{\frac{P}{M_S}|\boldsymbol{w}_k^H \boldsymbol{H}_k \boldsymbol{S}_k t_k|}{\frac{P}{M_{US}}\sum_{j\neq k}|\boldsymbol{w}_k^H \boldsymbol{H}_k \boldsymbol{S}_k t_j|^2 + \sigma_k^2}\right) \quad (8)$$

where M_{US} are the antenna elements not selected for the k-th user and $\mathbf{S}_k$ represents the selection matrix.

B. Selection Matrix by Exhaustive Search

Finding the optimal selection matrix $\mathbf{S}_k$ can be carried out by an exhaustive search over all possible combinations. However, the number of selected antennas will depend upon the achievable QoS per user which in our case is the user capacity. Here we let s_m be a binary decision variable with $s_m = 1$ if the m-th antenna element is selected, and $s_m = 0$ otherwise. Therefore, the status of the mth antenna, is given as

$$s_m = \begin{cases} 1 & \textit{transmit antenna is selected,} \\ 0 & \textit{Otherwise} \end{cases} \tag{9}$$

C. Selection Matrix by PSO

Particle swarm optimization (PSO) is a heuristic algorithm and it guarantees the global solution [11]. The details of the PSO can be found in [11], and the references therein. PSO is a stochastic optimization technique inspired by social behaviour of fish schooling or bird flocking [18]. The population of individuals, called particles, is randomly initialized within the search space. The coordinates of a particle, which represent the solution to the problem are called position of the particle. In PSO at each iteration, trajectory of each particle is adjusted towards the best location and toward the best particle of the swarm.

5. Results

In this section, the performance of uniform rectangular planar arrays (URA) employed at the BS is presented. Initially, the simulations results for the achievable capacity of the 3D beamforming are presented when the antenna selection is carried out with the assistance of PSO. Selection of the minimal number of transmit antenna elements for a given threshold values are also given. Finally, the performance of transmit antenna selection in a multiuser scenario is shown.

5.1 Figures

The results of transmit antenna selection are shown in Fig. 2. In this figure, the capacity of M-MIMO system with transmit beamforming is evaluated at signal to noise ratio (SNR) of 0 dB. The transmitter array structure consists of $M_T = M_h \times M_v$ antennas and the receiver array structure is $N_R = N_h \times N_v$ antennas. The capacity threshold, which is derived in (6) and (7), gives a good indication where the minimum number of antennas in MIMO system that can be selected and therefore increasing the number of transmit antennas gives marginal capacity gain.

Fig. 3 shows the performance of MU-MIMO with 2 users, where the BS has a 16x16 URA and each UE has a 2x2 URA. The figure also shows the capacity performance for different values of threshold, α, are compared with SU-MIMO and MU-MIMO. From the figure, it can be observed that the capacity of MU-MIMO, C_{min}, saturates due to spatial interference. The capacity of the system improves when the value of α increases from 0.8 to 0.9. However the capacity of the antenna selection using PSO is still lower than the SU-MIMO case.

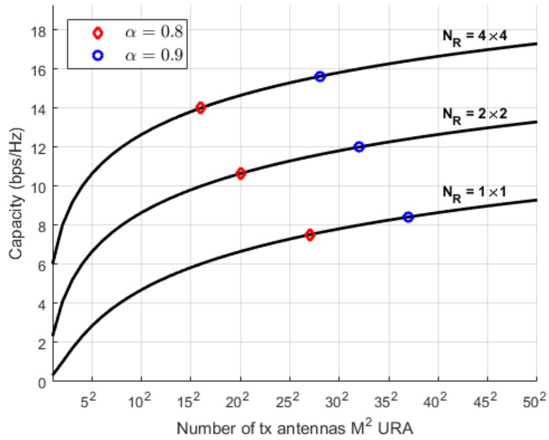

Figure 2: Transmit Antenna Selection in SU-MIMO

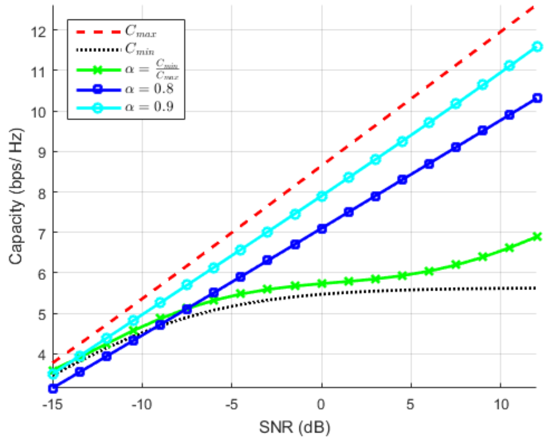

Figure 3: The achievable capacity of selected user in 2 user M-MIMO

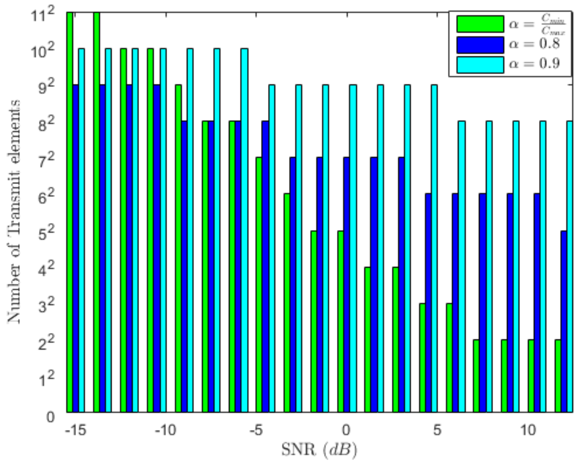

Figure 4: The number of transmit antenna elements selected for user.

Finally, Fig. 4 shows the number of transmit elements required for α = C_{min}/C_{max}, α = 0.8 and α = 0.9 for different SNR values. It is observed that as SNR increases less number of transmit antennas are required to achieve the same QoS. Less elements are required to match the saturated capacity of MU-MIMO when compared to the threshold, however by choosing a threshold value we can mitigate the effect of multiuser saturation. It can also be seen that less antenna elements are required overall by using transmit antenna selection as a PSO, when compared to using the full array for multiuser transmission.

5.2 Tables

From Fig. 2, Table I explains the calculated results for the desired capacities and the transmit antenna selection capacities at the given thresholds of α. We can observe that the transmit antenna selection as PSO algorithm values are near to the calculated capacities. The number of transmit elements required are determined by transmit antenna selection as PSO. For α = 0.8, the number of transmit elements selected are $M_T = 27^2, 20^2, 16^2$ for receive elements $N_R = 1, 2^2, 4^2$, respectively. For α = 0.9, the number of transmit elements selected are $M_T = 37^2, 32^2, 28^2$ for receive elements $N_R = 1, 2^2, 4^2$, respectively.

Table 1: SU-MIMO Transmit Antenna Selection Results

Calculated Capacity			
Receive Array	C_{MAX}	α= 0.9	α= 0.8
1 X 1	9.29	8.361	7.432
2 X 2	13.29	11.961	10.632
4 X 4	17.29	15.561	13.832
Transmit Antenna Selection Results			
1 X 1	9.29	8.423	7.518
2 X 2	13.29	12	10.64
4 X 4	17.29	15.61	14

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