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Power- and time-optimized MMSE-based joint beam-forming with relay selection for future generation MIMO networks using Modified Cuckoo-Search Optimization algorithm

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Abstract. Multiple Input Multiple Output (MIMO) networks operating in millimeter wave frequency band bring promising solutions for the increased demand of future generation networks in terms of data rate, signal quality, power optimization and computational complexity. A joint beam-forming (JBF) system working concurrently on source–relay–destination nodes leads to faithful delivery of signals by mitigating the effect of interferences. The traditional JBF designs in MIMO networks yield power wastage due to undesirable participation of intermediate relay nodes for message forwarding. The computational delay in beam-forming (BF) matrix update is tedious in traditional systems. This paper proposes a novel design of power-optimized JBF that facilitates optimum relay selection for solving power wastage issues. The selected relays co-operate in BF with the power constraint, and all other relays are powered down and enter into sleeping mode. Modified Cuckoo-Search Optimization (MCSO) algorithm is used for relay selection and minimum mean square error algorithm is used for BF matrix calculation. The proposed JBF is able to maximize Achievable Sum Rate (ASR) for optimum value of transmission power. The maximum power efficiency is achieved for distant communication with the aid of selected relays contributing to maximizing the ASR value. The proposed work minimizes the sum of mean square error and concurrently computes optimum time slot for BF matrix update, and hence computational delay is reduced. Thus a hybrid optimization for power and time in JBF design is achieved with relay selection and it can be widely used in future generation networks for high-quality and interference-free communication.

Keywords. Achievable Sum Rate; Joint beam-forming; MIMO networks; Minimum mean square error; Power efficiency; Relay selection.

1. Introduction

The emerging design trends in wireless applications are formulated to meet wider demands of future generation networks in terms of data rate, signal quality and coverage range. Though the use of relay units equipped with multiple antennas increases diversity, coverage distance and speed of communication, it results in severe interference issues [1–4]. This can be addressed by adopting proper signal processing techniques associated with Multiple Input Multiple Output (MIMO) antennas. The energy efficiency of the two-way relay networks in MIMO system is determined using the robust optimization algorithms used for beam steering [1]. The lack of relay selection methodologies for information transfer leads to considerable power wastage [2, 3]. Hence beam-forming (BF) is implemented jointly in an end-to-end basis, from source to destination through the selected relay in order to nullify the effect of interferences. The conventional joint beam-forming (JBF) system [4] for millimeter wave (MMW) frequency band facilitates higher data rate. It causes severe power loss due to undesirable relay participation in beam formation, which consequently degrades the system performance.

Recent research works on relay-based BF in MIMO networks used different approaches for optimizing certain parameters and compromising other metrics. A channel diagonalization algorithm based on the generalized singular value decomposition is used in [1] under the worst-case transmit power constraints at the sources and relay, which has lower complexity. A suboptimal BF and relay selection solutions are presented in [2], based on eigenvalue decomposition for both total and individual power constraints without the need for solving semi-definite programming problems. A deep-learning model for highly mobile MMW applications that learns prediction of the BF vectors at the base stations is presented in [3]. An optimally balanced relay

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BF and receive BF matrices in closed form based on minimum mean square error (MMSE) is presented in [4], focusing on the cancellation of loop-back self-interferences (SI). Authors of [5] captured a balance between useful signal improvement and SI suppression for further achievable rate improvement. The optimal time split is studied for different transmission modes in [6]. The results reveal that, when the time split is optimized, the full-duplex relaying can substantially boost the system throughput compared with the conventional half-duplex relaying architecture. The success (or failure) to select the best available path depends on the statistics of the wireless channel, and a methodology to evaluate performance for any kind of wireless channel statistics is provided in [7]. The joint robust source–relay BF design is presented in [8] based on the optimization-guaranteed semi-definite relaxation algorithm. The authors of [9] studied the problem of signal BF and relay selection for a cooperative bi-directional relay network. Multiple relays each equipped with single antenna and multiple relays with multiple antennas working on uncoded amplify-and-forward (AF) scheme were considered. Many adaptive BF techniques in smart antennas are closely compared and analysed in [10]. The receive BF at the relay is optimized to maximize the received signal to interference plus noise ratio, while the transmit BF at the relay is optimized to maximize the signal to leakage plus noise ratio [11]. Under the transmit power constraints at sources and relay a BF design problem is formulated, which minimizes the total mean square error (MSE) while still sufficient harvested energy availability is guaranteed at the relay nodes [12]. The total network transmission power is minimized subject to QoS constraints in [13] using a transceiver design at two-way MIMO relay networks. The BF matrix is designed to address the inter-stream interference in the MIMO channels since multiple antennas at the two sources are considered unlike [14]. The effect of residual SI is studied in [15] for a two-way FD-AF relay system with multiple relays and an optimal relay selection scheme is designed. In [16] the intermediate nodes that cannot decode the source signal successfully are selected to act as friendly jammers to transmit artificial noise, and the remaining nodes are exploited as relays to simultaneously forward the source signal through cooperative BF. A single-layer iterative algorithm based on sequential parametric convex approximation and a closed-form algorithm based on zero forcing are proposed in [17] to form a global optimum solution for secrecy sum rate maximization.

Though traditional JBF systems were designed for power optimization, there arise a critical problem of active relay units available at all time slots for beam formation. Undesired relay units, being active at all time slots, lead to power wastage. The BF vectors are updated at each time slot by considering the entire signals received at the previous time slots. This leads to computational complexity and more delay.

A novel BF architecture is proposed in this paper that works jointly with optimum relay selection and promisingly offers maximum Achievable Sum Rate (ASR) and minimum power consumption, and enables beam steering function at optimum time slot. Computational delay is reduced in the proposed JBF design by calculating optimum time slot $\hat{m}$ for BF vector update. MSE algorithm is used for ideal beam steering process in order to achieve minimum MSE at estimated $\hat{m}$. Compared with existing works, the novelty of our proposed work lies on the hybrid optimization on relay selection followed by time-optimized and power-constrained beam formation with the aid of selected relays. The desired number of relays is selected using Modified Cuckoo-Search Optimization (MCSO) algorithm for achieving maximum power efficiency. Meanwhile fast convergence rate, maximum ASR and minimum MSE are guaranteed in proposed JBF design. The proposed JBF design alleviates the power wastage issues at relay nodes by selecting the best relay or combinations of relays. The relays that were not selected for beam formation are forced to be in the sleeping mode for specific time slots.

The performance of proposed system is compared to that of the conventional non-optimum JBF for various numbers of intermediate selected relays in terms of ASR and MSE. The power efficiency at selected relay system using proposed MCSO algorithm is compared to those of conventional Cuckoo Search Optimization (CSO) and Particle Swarm Optimization (PSO) algorithms in which slow convergence issue is dominant in dynamic environment. To establish the novelty of proposed work, simulation metrics of proposed JBF design with optimum relay selection are compared with those of different existing algorithms simulated from our side. The proposed JBF algorithm works for MSE minimization and time optimization with the attributes of selected relay(s) using MCSO algorithm. Due to the lack of identical simulation parameters and architectural differences, the complete problem could not be compared to existing works; however relay selection scheme of proposed work is compared with [2] and it is substantiated that the proposed design outperforms well in terms of SNR for a given number of selected relays and transmitted power.

Section 2 describes the system model used for the proposed JBF system. The proposed JBF design works over selected combination of relays, formulated as a single-objective optimization problem for multiple-relay selections as discussed in section 3. Section 4 deals with optimum relay selection process using MCSO algorithm. MMSE-based JBF design is described in section 5. Section 6 comprises numerical and simulation results, the performance evaluation and the comparison of proposed methodology to the non-optimum JBF.

2. System model

A Full-Duplex Amplify-and-Forward (FD-AF) MIMO system shown in Figure 1 consists of two mobile source nodes S_1 and S_2 operating with the aid of relays to facilitate

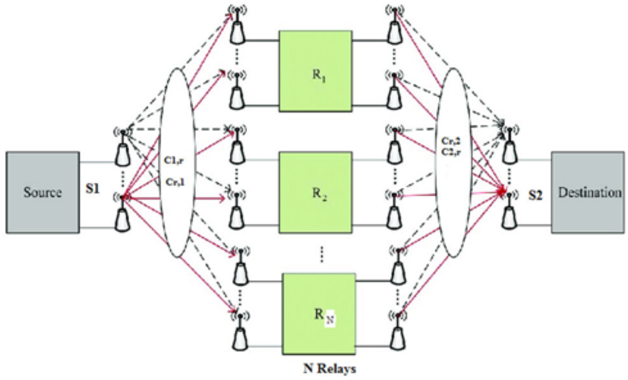

Figure 1. System model. Communication between two source nodes equipped with multiple antennas is facilitated by '*N*' relay nodes with multiple antennas. Channel State Information matrices are explicitly mentioned.

long-distance communication. In this scenario we consider '*N*' relays equipped with multiple antennas, out of which a single relay or combination of multiple relays are necessary for beam formation in desired directions. Consider a scenario having a single relay operating between two distantly spaced source nodes. During zeroth time slot, both communication nodes send their own information to the relay nodes concurrently. During first time slot, the signal received by the relay node is then multiplied by the BF matrix and sent to either nodes. Meanwhile, the source nodes send the next signal to the relay node. Let $S_1^{(t)}, S_2^{(t)}$ and $S_r^{(t)}$ be the signals transmitted by two source nodes and the selected relay unit, respectively. The noises interrupting at the two source nodes and relay unit are represented as $n_i^{(t)}$ for $i \in (1, 2)$ and $n_r^{(t)}$, respectively, and are considered as Additive white Gaussian noise (AWGN) with zero mean. For multiple-relay scenarios, sophistication of system model is required. In multiple-relay model, there are N relays $R_1, R_2, ..., R_N$ operating between the sources S_1 and S_2 that are responsible for FD-AF relaying. If two relay nodes are selected for BF, say R_1 and R_2, then at time slot 0, each source node S_1 and S_2 will engage in delivering its available information to relay R_1 and R_2, respectively. At time slot 1, each relay multiplies its received signal by a BF matrix and forwards it to the other relay. In the next instant, the information received at the previous time slot at the relay unit is forwarded to the source nodes after modifying with a new BF matrix. Meanwhile the source sends the next available signal to these relay nodes during the simultaneous time slot.

The channel characteristics for single- and multiple-relay scenarios are modelled as frequency-flat fading independent channels, which are continuously varying but assumed to be static for a particular time slot. To focus on the effect of residual loop-back SI on FD mode, it is assumed that the CSI between each pair of nodes is precisely known. Since each node has the knowledge of its own transmitted signals and precise CSI value between two nodes, it is very easy to cancel the backward-propagated residual SI. A signal comparison and decision making is done at relay node so as to favour the SI suppression. This is followed by relay BF vector update, which in turn is responsible for relaying useful information to either sources.

Distributed architecture is used for CSI estimation at each relay and source nodes. This reduces system complexity. A pilot training sequence pre-known at all the communication nodes is transmitted from each source node to relay node and vice versa. The received signal at a specific node and the knowledge of transmitted signal are used to estimate the CSI at the current time slot. The assumption that all nodes are static for that time slot is applicable in CSI calculation. Though the channel varies continuously, once the CSI matrix is updated, further message delivery depends on the estimated CSI. A new time slot update would check the corresponding change in position of intended source nodes and relay nodes to facilitate new CSI calculation. Once the CSI is estimated and locked for a specific time slot, further RF message transmission and reception is relayed in AF basis without decoding the message. During BF phase, relay nodes are intended for ensuring connectivity among distantly spaced nodes and not involved in message decoding. This implies that a simple AF architecture is to be proposed in RF signal relaying in the BF phase, though the relay attempts to retrieve the transmitted pilot signal in CSI estimation phase.

Algorithm 1 CSI estimation procedure

1: Initialize the time slot, current positions of source nodes and available relay nodes.
2: Transmit a predetermined pilot signal P_0 from S_1 to all the available relay nodes concurrently. Note that the pilot signal is a training sequence known to all user nodes and relays.
3: Each relay receives the signal P_0' and compares the received signal to P_0 to estimate CSI $C_{1,i}$, where $i = 1, 2, \ldots, N$.
4: Being a two-way relaying system, all the relays send the same training sequence P_0 to S_1 and S_2 simultaneously to receive P_0'. With known P_0 and received P_0', source S_1 and S_2 can estimate the CSI $C_{i,1}$ and $C_{i,2}$, where $i = 1, 2, \ldots, N$.
5: Now transmit a predetermined pilot signal P_0 from S_2 to all the available relay nodes concurrently. Each relay receives the signal P_0' and compares the received signal to P_0 to estimate CSI $C_{2,i}$, where $i = 1, 2, \ldots, N$.

The Channel State Information (CSI) matrix between each source node and the available relay units in the communication field for dual way are denoted as $C_{1,r}^{(t)}, C_{2,r}^{(t)}, C_{r,1}^{(t)}, C_{r,2}^{(t)}$. The channel model also considers the issues of propagated loop-back interferences. The system design uses loop-back channel matrices at each source S_1, S_2 and the selected relay, which are represented as $C_{i,i}^{(t)}$ for $i \in (1,2)$ and $C_{r,r}^{(t)}$, respectively.

The relationship between the exact channel matrix and the estimated channel matrix is modelled as follows:

$$C_{i,i}^{(t)} = \hat{C}_{i,i}^{(t)} + \Delta_{i,i}^{(t)} \text{ for } i \in (1,2). \tag{1}$$

The selected relay units do not send signals at time slot 0, even though source nodes send their own signals to the respective relay nodes. Hence FD operation ultimately starts from time slot 1, at which relay node begins to forward the received signals to the corresponding source nodes. Initially, at zeroth time instant, each node concurrently transmits its signals $S_1^{(0)}$ and $S_2^{(0)}$ to the selected relay and then the received signal at the relay is given by

$$y_r^{(0)} = C_{1,r}^{(0)} S_1^{(0)} + C_{2,r}^{(0)} S_2^{(0)} + n_r^{(0)}. \tag{2}$$

During time slot 1, the relay multiplies the received signal with relay BF matrix $R^{(1)}$ and forwards it to the sources, where the transmitted signal $S_r^{(1)}$ at the selected relay is defined by

$$S_r^{(1)} = R^{(1)} y_r^{(0)}. \tag{3}$$

The relay node suppresses the loop-back SI and consequently the received signal at the selected relay during first time slot is defined by

$$\begin{aligned} \hat{y}_r^{(1)} =& C_{1,r}^{(1)} S_1^{(1)} + C_{2,r}^{(1)} S_2^{(1)} \\ &+ \Delta_{r,r}^{(1)} S_r^{(1)} + n_r^{(1)}. \end{aligned} \tag{4}$$

The propagated SI effect is mitigated by subtracting the loop-back interferences from the received signal and the resultant signal at source l during first time slot is given by

$$\begin{aligned} \bar{y}_l^{(1)} =& C_{r,l}^{(1)} R^{(1)} C_{\bar{l},r}^{(0)} S_{\bar{l}}^{(0)} + C_{r,l}^{(1)} R^{(1)} n_r^{(0)} \\ &+ \Delta_{l,l}^{(1)} S_l^{(1)} + n_l^{(1)}. \end{aligned} \tag{5}$$

$\bar{l}$ is used to identify the other source out of two available in the communication environment. There exists a signal processing algorithm at relays to suppress SI. The current received signal is affected by the BF matrices in the past time slots. Subtracting the propagated SI, $C_{r,l}^{(t)} R(t) C_{l,r}^{(t-1)} S_l^{(t-1)}$, and the loopback SI, $C_{l,1}^{(t)} S_l^{(t)}$, from the received signal, the resultant signal at source l in time slot 't' ($t \geq 2$) is obtained as (6). Here, the transmitted signal at the previous time slot is propagated back to the source node through full-duplex two-way relaying protocol. The SI is eliminated by discarding the interference component with the knowledge of previous transmitted signal CSI of current time slot and previous time slot. The signal received at source-l during an arbitrary time slot 't' for $(t \geq 2)$ is given by

$$\begin{aligned} \bar{y}_{\bar{l}}^{(t)} =& C_{r,l}^{(t)} R^{(t)} C_{\bar{l},r}^{(t-1)} \\ &+ C_{r,l}^{(t)} R^{(t)} \sum_{i=0}^{t-2} \Big[\prod_{j=1}^{t-1-i} \\ &(\Delta_{r,r}^{(t-j)} R^{(t-j)}) (C_{l,r}^{(i)} S_l^{(i)} + C_{\bar{l},r}^{(i)} S_{\bar{l}}^{(i)} \\ &+ n_r^{(i)}) \Big] C_{r,l}^{(t)} R^{(t)} n_r^{(t-1)} + \Delta_{l,l}^{(t)} S_l^{(t)} + n_l^{(t)}. \end{aligned} \tag{6}$$

For multiple-relay scenarios, equation (6) can be reformulated by considering all channel matrices between the relays and those between each relay and source nodes. Based on the aforementioned model an optimization problem of relay selection is addressed, out of which a novel methodology in JBF design is proposed to carry BF over selected relay(s).

3. Single-objective optimization problem for multiple-relay selection

The proposed JBF system investigates the problem of unwanted power outages at relay nodes. A novel optimization solution is formulated to select the best relay out of 'N' relays available between the source and destination nodes. The selected relay is responsible for forming a beam with an optimum power to transmit the message to the destination node. The multiple-relay environments offer more diversity than single-relay scenario. The heavy traffic imposed on selected single relay leads to degradation in system throughput and signal may not reach at the destination node within the stipulated time. For a multiple relay facilitating long-distance wireless communication, the heavy load is redistributed among the selected relays. However BF becomes complicated. Let $C_{1,r_i}^{(t)}$ be the CSI from source node S_1 to i^{th} relay and $C_{r_i,2}^{(t)}$ be the CSI from i^{th} relay to the receiver node S_2. In a multi-relay cooperative communication system, in the first step, the transmitter sends $\sqrt{P}I$ to the i^{th} relay, where I is the information transmitted. Average power transmitted becomes P when I is normalized, $E|I|^2$=1. In the subsequent step the received signal at i^{th} relay is modified, so that its transmission power becomes $a_i^2 P_i$ and forwards it to the receiver. When i^{th} relay takes part in the BF a_i=1, otherwise a_i=0.

The i^{th} relay received signal can be written as

$$y_r^{(t)} = |C_{1,r_i}^{(t)}| \sqrt{P} I + w_i. \tag{7}$$

It is assumed that the relays are perfectly synchronized and transmit at the same time. Hence we have considered only the magnitude of CSI value and not the phase. The signal received by the receiver is given by

$$\begin{aligned} y_l^{(t)} =& \sqrt{P}\sum\nolimits_{i=1}^{N} \frac{a_i|(C_{1,r_i}^{(t)})(C_{r_i,2}^{(t)})|\sqrt{P_i}}{\sqrt{1+|C_{1,r_i}^{(t)}|^2 P}} I \\ &+ \sum\nolimits_{i=1}^{N} \frac{a_i|C_{r_i,2}^{(t)}|\sqrt{P_i}}{\sqrt{1+|C_{1,r_i}^{(t)}|^2 P}} u_i + w \end{aligned} \tag{8}$$

where w is the AWGN at the source node, which may be considered as destination at any point of time, $u_i = w_i e^{-jarg(C_{1,r_i}^{(t)})}$ and w_i is the AWGN at the selected and cooperating i^{th} relay. Note that the term u_i considers the phase of CSI value along with instantaneous magnitude in order to realize the effective noise level. At some point of time, AWGN at the selected relay will be negligible due to destructive interference and phase cancellation. Hence, the effective noise at the selected relay node depends on CSI magnitude and phase relative to all other nodes. The receiver and relay noises are assumed to be complex Gaussian functions with zero mean and unit variance. The average SNR, β_{av}, can be calculated as

$$\begin{aligned} \beta_{av} =& P\left(\sum\nolimits_{i=1}^{N} \frac{a_i|(C_{1,r_i}^{(t)})(C_{r_i,2}^{(t)})|\sqrt{P_i}}{\sqrt{1+|C_{1,r_i}^{(t)}|^2 P}}\right)^2 \\ &\bigg/ \left(1 + \sum\nolimits_{i=1}^{N} \frac{a_i^2 |C_{r_i,2}^{(t)}|^2 P_i}{1+|C_{1,r_i}^{(t)}|^2 P}\right). \end{aligned} \tag{9}$$

The average SNR in equation (9) is obtained by finding the ratio of signal power, which is proportional to average of square of the signal term, and noise power, which is proportional to the average of square of the noise term mentioned in (8). The addressed multi-relay selection optimization problem has a single objective for maximizing SNR and is given by

$$\max_{a_1,a_2,\ldots,a_N} \beta_{av} \quad \text{st} \quad a_i \in (0,1). \tag{10}$$

Relay selection is facilitated in order to address the problem of energy consumption in future generation networks. The total transmission power of the system is given by

$$P_T = P + \sum_{i=1}^{N} a_i^2 P_i. \tag{11}$$

P_T increases with the number of cooperating relays N_r given by

$$N_r = \sum_{i=1}^{N} a_i. \tag{12}$$

The power efficiency of the system is proportional to the network capacity C, and inversely proportional to total transmission power P_T. The objective of optimization in BF is to maximize the power efficiency and hence the problem is re-stated as

$$\max_{a_1,a_2,\ldots,a_N} \frac{C}{P_T} = \frac{\log_2(1+\beta_{av})}{P + \sum_{i=1}^{N} a_i^2 P_i}. \tag{13}$$

Every relay unit available in the environment has two decisions—whether to co-operate with BF or not. Hence optimization can be '0-1' programming problem. It is a nonlinear programming problem that makes use of exhaustive search algorithm for optimal solution. As the number of relays in the communication scenario increases, the problem complexity rises exponentially. Whenever a relay R_i is available and selected for cooperative BF, it utilizes its full power allotted to the terminal. In fact, for the proposed BF a power constraint is imposed in such a way that a relay participating in BF will not use a power greater than P_r allotted specifically to it. Hence, to deliver the desired information to the destination node, if the selected relay is intended to use transmission power greater than P_r (the maximum permissible value), it results in excessive power consumption. This issue is resolved using a uniform power constraint at all selected relays, i.e. as soon as a relay node becomes active it participates in BF and transmits RF signal with power $P_i = P_r$ (for all values of selected index i). If input signal power mismatches with the power constraint of the relay, suitable amplification matrices are used at relay node for adjusting the power to be uniform at P_r. In this work, MCSO algorithm is used to solve the single-objective multi-relay selection optimization problem. The best possible combinations of cooperating relays are selected to achieve maximum power efficiency.

4. MCSO algorithm for relay selection

As the relay and mobile environment are fast and dynamically changing, it is necessary to select the best relay(s) using a faster convergent optimization algorithm. Studies of [23] proved that CSO has characteristics of the global optimizer with ability for converging to the true global optimum. On the other hand the theoretical studies of PSO showed that this algorithm looses a diversity of population very fast, i.e. all the solutions become similar to the current best solution. In other words, all solutions are crowded around the current best solution in a small region of search space. In such situations, the PSO algorithm converges prematurely and hence the global optimum cannot be found. Typically this phenomenon can be detected by multi-modal optimization, where the PSO algorithm converges fast to the local optimum, while the CSO can find a way to the global optimum.

CSO approach is used to select the best relay out of finite relays available in the scenario so as to maximize the fitness function. This is analogous to a cuckoo's behaviour of searching a nest to lay eggs to satisfy its own comfort. After selecting the optimum relay that maximizes a function, it is very much necessary that other test relays shall update their new position towards the position of selected relay so as to enable the chance that they get selected in future. This procedure is analogous to the swarm movement of birds towards a location where one of the birds in the group has found the food and intimated others.

The positive features of PSO nd CSO are utilized in our investigation. The unselected and non-optimum relays will update their own positions to be the same as the current best relay so that any available mobile nodes present in the same location can utilize the rejected relays with new update. In order to see the merits of PSO and CSO, we hybridized the two algorithms to utilize MCSO in a better way. A hybrid combination of PSO and CSO is used in MCSO algorithm that selects the best relay or a fixed number of relays for BF that maximizes the fitness function. All other relays that are not participating in beam formation enter into sleeping mode, where the transmission power is set to zero watts and hence restrained from BF. The modified Levy flights of CSO algorithm and velocity update of PSO techniques are incorporated in the proposed algorithm and hence it is a hybrid combination of CSO and PSO. The estimated fitness result of CSO is reconstructed utilizing Levy flight activities of mobile nodes. Levy flight is modified on Gaussian distribution. The velocity update of Levy flight of each particle is carried out using PSO. This hybrid combination of CSO and PSO results in fast convergence of MCSO. Hence it is best suitable for a dynamically changing environment to address the fast changing positions of mobile nodes and relay nodes. The quality solutions are combined and graded to ascertain the current best solution. Thus, the selected relay nodes in the scenario are ranked and arranged in an order in such a way that the best relay (for single-relay scenario) or combination of relays (multiple-relay scenario for long-distance coverage) that closely satisfies the fitness function is ranked first.

Algorithm 2 Pseudo-code for relay selection using MCSO

Input: 'p' number of source nodes considered as cuckoo and 'N' number of relay nodes considered as nest
Output: optimum relay
Initialization: Obtain a cuckoo randomly say 'p'

```
1: Evaluate the fitness function, F_p of the cuckoo.
2: for q=1 to k do
3:    Calculate fitness function, F_q.
4:    if (F_p > F_q) then
5:       Replace F_q by new solution.
6:    end if
7:    replace F_q as current solution
8: end for
9: Update by modified Levy flights equation.
10: Particle updation by Particle Swarm Optimization (PSO) algorithm
11: Get current best solution
12: If current iteration I_c ≤ Maximum Iteration, go to step 2
13: Find optimum solution after convergence and return output
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The conventional Levy flight update in [20] is modified by employing Gaussian distribution and hence the modified Levy flight update equation is given by

$$X_q^{w+1} = X_q^w + \delta + \sigma \tag{14}$$

where δ is the step size, $\sigma = \sigma_0 e^{-\chi C_g}$ where σ_0 and χ are constants and C_g is the current generation. The velocity matrix is updated using PSO according to [18, 19] as

$$\begin{aligned} V_{id} = & w_0 V_{id}^{(t-1)} + K_1 U_{d1}^{(t)} (P_{id}^{(t)} - X_{id}^{(t-1)}) \\ & + K_2 U_{d2}^{(t)} (g^{(t)} - X_{id}^{(t-1)}) \end{aligned} \tag{15}$$

where 't' and '$t-1$' refer, respectively, to the time index of the current and the previous iterations, U_{d1} and U_{d2} are two uniformly distributed random numbers in the interval [0,1] and these random numbers are different for each 'd' components of the i^{th} particle velocity vector. The parameters K_1 and K_2 are self-confidence and swarm confidence, respectively. The term $g^{(t)}$ represents the swarm's best solution as of time 't'. MCSO algorithm for relay selection works on the basis of pseudo-code discussed in Algorithm 2. After the selection of best relay corresponding to the current position of source nodes, all the unselected intermediate relay nodes will update their current position in favour of source nodes that are active. This will create a possibility that they would get selected for the communication in the next time slot. Equation (14) is the modified Levy flight update equation of CSO according to which the non-cooperating relays in the communication scenario would update their own position. Equation (15) is the velocity update equation using PSO that signifies the rate of change of position coordinates of the non-cooperating relay nodes in a unit time slot to track the recent selected relay and source nodes. This approach would ensure the continuity of signal delivery with frequent switching of relays with respect to mobility nature of communication nodes.

The optimal relay or combination of multiple relays selected using MCSO algorithm are used for beam formation, which is carried out using MMSE algorithm discussed in the following section.

5. MMSE-based JBF design

In this section, MMSE-based JBF design is proposed and the algorithm works over the selected combinations of relays operating between two sources. The optimal relay participates in beam formation and updates BF matrix at the end of optimum time slot $t = \hat{m}$. The non-convex problem of JBF in source–relay–destination nodes is decomposed into subordinate problems and an iteration-based design is developed for relay BF design and receiver BF design.

The signal received at a particular time slot is a function of estimated channel error matrices and signals transmitted in previous time slots. Thus, to compensate the effect of residual SI and to facilitate desired signal transmission, it is necessary to update the BF matrix at each time slot and hence leads to considerable computational complexity and delay. To tackle this problem, the proposed algorithm computes BF matrix based on latest 'm' time slots. It is desirable to find the optimum value of time slot such that MSE is minimized and ASR is maximized. To mitigate the power loss effects in MIMO networks, power constraints are used in BF matrix update at relay nodes. This permits the utilization of optimum power by relay nodes for transmitting the signal to desired destination node. Power requirements depend on the dynamic displacement of source nodes participating in the FD communication. Hence, it can be substantiated that proposed JBF is power–time-optimized design for MIMO networks.

MMSE is implemented jointly at source nodes and selected relay node for BF vector updation and subsequent BF. An MMSE criterion checking is accomplished at the source nodes, which is summarized in the following discussion. Consider that the source S_1 has got a signal intended to S_2 via R_1, which is selected by MCSO approach. A BF vector is initialized for the desired source and destination for the selected relay at the present time slot. The BF vector is to be updated at each time slot following the new relay selection or new positions of mobile nodes. Note that all source nodes know the CSI values with respect to all participating relay nodes and other source nodes. With the knowledge of CSI between $S_1 - R_1$ and $R_1 - S_2$, source S_1 estimates the received signal at S_2 with the assumption that transmission has been done with the estimated and locked CSI of current slot. The estimated received signal and transmitted signal are jointly analysed to calculate MMSE at the current time slot. After updation of new BF vectors, MMSE value is checked for minimization. A finite number of iterations are carried out to achieve minimum MSE, so that BF vectors corresponding to the optimum value are utilized for BF and thereafter signal transmission is carried out subsequently.

To mitigate the effect of SI and facilitate effective signal transmission, the receiver BF matrix $Z_j^{(t)}$ and relay BF matrices $R_i^{(t)}$ for $i \in (1, 2, ..., N)$ and $j \in (1, 2, ..., M)$ are computed based on MMSE criterion subject to a power constraint for transmission imposed at the relay. In case of multiple-relay schemes, power constraint per relay is used for acceptable power consumption. In accordance with the power constraint, optimization problem is formulated as

$$\begin{aligned} &\min_{Z_j^{(t)}, \alpha^{(t)}, R_i^{(t)}} J(Z_j^{(t)}, \alpha^{(t)}, R_i^{(t)}) \\ &\text{st} \qquad E[||S_r^{(t)}||^2] = N_r P_r \qquad \text{for} \\ &i \in (1, 2, ..., N). \end{aligned} \tag{16}$$

The term $N_r P_r$ corresponds to total power constraints on the entire relay combination, where N_r is the number of cooperating relays and P_r is the maximum permissible power used by a particular relay. Power constraint per relay is imposed to fulfill the regulatory constraints.

The Lagrangian of the optimization problem is defined as

$$\begin{aligned} &L(Z_j^{(t)}, R_i^{(t)}, \alpha^{(t)}, \lambda^{(t)}) \\ &= J(Z_j^{(t)}, \alpha^{(t)}, R_i^{(t)}) \\ &\quad + \lambda^{(t)}(E[||S_r^{(t)}||^2] - N_r P_r) \\ &= (p_1 + p_2) - {\alpha^{(t)}}^{-1} \\ &\quad \left[\operatorname{tr}({W^{(t)}}^H R_i^{(t)}) + \operatorname{tr}(W^{(t)} {R_i^{(t)}}^H)\right] \\ &\quad + {\alpha^{(t)}}^{-2} E[||Z_j^{(t)} \hat{y}_j^{(t)}||^2] \\ &\quad + \lambda^{(t)}(E[||S_r^{(t)}||^2] - N_r P_r) \end{aligned} \tag{17}$$

where p_1 and p_2 are the power used at S_1 and S_2 to establish communication to the respective selected relay node, $\lambda^{(t)}$ is a Lagrangian multiplier in time slot t and

$$W^{(t)} = p_1 C_{r,2}^{(t)^H} Z_j^{(t)} C_{1,r}^{(t-1)^H} + p_2 C_{r,1}^{(t)^H} Z_j^{(t)} C_{2,r}^{(t-1)^H}. \tag{18}$$

To account for a large number of communication nodes considered as destinations at a specific time slot, sum of MSE function, $J(Z_j^{(t)}, \alpha^{(t)}, R_i^{(t)})$, is used rather than typical MSE. The sum of MSE for all available receivers using the same selected relay(s) is defined as

$$\begin{aligned} J(Z_j^{(t)}, \alpha^{(t)}, R_i^{(t)}) &= E\left[\left\|S_2^{(t-1)} - \alpha^{(t)^{-1}} \hat{y}_1^{(t)} \left[\sum_{j=1}^{M} a_i Z_j^{(t)^H}\right]\right\|^2\right] \\ &+ E\left[\left\|S_1^{(t-1)} - \alpha^{(t)^{-1}} \hat{y}_2^{(t)} \left[\sum_{j=1}^{M} a_i Z_j^{(t)^H}\right]\right\|^2\right] \end{aligned} \tag{19}$$

where 'i' is the selected relay index; $a_i = 0$ when the relay is not co-operated with BF, and $a_i = 1$ when the relay is co-operated for the BF. The relay BF matrix $R_i^{(t)}$ is product of two components [21, 22] such that $R_i^{(t)} = \alpha^{(t)} \bar{R}_i^{(t)}$ where $\alpha^{(t)}$ and $\bar{R}_i^{(t)}$ denote power amplification matrix and steering direction vector, respectively. We have

$$R_i^{(t)} = \alpha^{(t)} \bar{R}_i^{(t)}. \tag{20}$$

Using equation (20), the Lagrangian in (17) is reduced to

$$\begin{aligned} L(\bar{R}_i^{(t)}, \alpha^{(t)}, \lambda^{(t)}) &= (p_1 + p_2) - \left[tr(W^{(t)^H} \bar{R}_i^{(t)}) + tr(W^{(t)} \bar{R}_i^{(t)^H})\right] \\ &+ tr(W_1^{(t)} \bar{R}_i^{(t)} G_1^{(t)} \bar{R}_i^{(t)^H}) \\ &+ tr(W_2^{(t)} \bar{R}_i^{(t)} G_2^{(t)} \bar{R}_i^{(t)^H}) \\ &+ \alpha^{(t)^{-2}} W^{(t)} + \lambda^{(t)} \alpha^{(t)^{-2}} \left[tr(\bar{R}_i^{(t)} G_r^{(t)} \bar{R}_i^{(t)^H}) - N_r P_r\right] \end{aligned} \tag{21}$$

where

$$\begin{aligned} G_1^{(t)} &= p_2 C_{2,r}^{(t-1)} C_{2,r}^{(t-1)^H} + \sigma_{n,r}^2 I_{N_r}, \\ G_2^{(t)} &= p_1 C_{1,r}^{(t-1)} C_{1,r}^{(t-1)^H} + \sigma_{n,r}^2 I_{N_r}, \\ G_r^{(t)} &= p_1 C_{1,r}^{(t-1)} C_{1,r}^{(t-1)^H} + p_2 C_{2,r}^{(t-1)} C_{2,r}^{(t-1)^H} \sigma_{n,r}^2 I_{N_r}, \\ W^{(t)} &= (p_1 \sigma_{e,1}^2 + \sigma_{n,1}^2) tr(Z_j^{(t)} Z_j^{(t)^H}) + (p_2 \sigma_{e,2}^2 + \sigma_{n,2}^2) tr(Z_j^{(t)} Z_j^{(t)^H}). \end{aligned} \tag{22}$$

The receive BF matrices at the sources are given by

$$Z_l^{(t)} = \alpha^{(t)} p_{\bar{l}} \left[C_{r,l}^{(t)} R_i^{(t)} G_l^{(t)} R_i^{(t)^H} C_{r,l}^{(t)^H} + \sigma_{n,l}^2 I_{N_s}\right]^{-1} C_{r,l}^{(t)} R_i^{(t)} C_{\bar{l},r}^{(t-1)} \tag{23}$$

where $\bar{l}$ is the index of the other source.

The algorithm to solve the optimization problem of BF is iterative in nature and a JBF design is proposed involving a collaborative work of relay and receiver BF. The relay BF matrix and receiver BF matrices are optimized successively at each time slot until convergence is reached. The proposed iterative algorithm is shown in Algorithm 3. The proposed algorithm performs beam steering via selected relay or combination of relays based on the active source and receiver nodes. The algorithm works for 'M' number of receiver nodes and 'N' number of relay nodes operate concurrently.

Algorithm 3 Algorithm for calculating MMSE function for convergence

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Input: N_r, maximum iteration, selected relay node attribute from Algorithm 2, current position of source nodes and selected relay node

Output: $Z_j^{(t)}, \alpha^{(t)}, R_i^{(t)}$

Initialization: $Z_j^{(t)} = I_{N_r}$ and $R_i^{(t)} = I_{N_s}$ for $i \in (1, 2, 3, \ldots, N)$ and $j \in (1, 2, 3, \ldots, M)$

1. Update steering direction matrix $\bar{R}_i^{(t)}$ using $Z_j^{(t)}$ for $j \in (1, 2, \ldots, M)$ and equations (21) and (22)
2. Update power amplification factor $\alpha^{(t)}$ using $\bar{R}_i^{(t)}$ and equations (21) and (22)
3. Update new BF matrix $R_i^{(t)}$ using $\bar{R}_i^{(t)}$, $\alpha^{(t)}$ and equation (20)
4. Update new receiver matrix using $\bar{R}_i^{(t)}$, $\alpha^{(t)}$ and equation (23)
5. Update $J(R_i^{(t)}, \alpha^{(t)}, Z_j^{(t)})$ using equation (19)
6. Repeat steps 1–5 until iteration converges.

The sum of MSE $J_m^{(t)} = J(Z_i^{(t)}, \alpha^{(t)}, R_i^{(t)})$ depends on 'm' and 't'. The value $m = \infty$ implies that JBF converges at an unpredictable time slot. The proposed JBF at $m = \infty$ gives acceptable results on ASR and MSE values but time delay is severe for future generation networks. In the conventional JBF, beam steering takes place at $m = \infty$ and this causes $J_m^{(t)}$ either to increase or remain constant with increase in t. On the other hand, for the proposed JBF, beam steering takes place at optimum time slot $m = \hat{m}$. At $m = \hat{m}$ the MSE function $J_m^{(t)}$ increases or remains constant as t increases provided $t \leq m + 1$, whereas the MSE function $J_m^{(t)}$ decreases as t increases only if $t \geq m + 2$. This is because the relay BF matrix at previous time slot is replaced by the current BF matrix. In other words, the MSE function becomes unstable after time slot $m + 2$. Based on this issue Algorithm 3 is proposed to determine optimum value of time slot 'm', which is denoted by $\hat{m}$. For example, if $J_{m=2}^{(3)} \leq J_{m=2}^{(4)}$, then $\hat{m}$ is set as 2. The proposed algorithm works well and BF matrix is updated at the end of optimum time slot 'm', which is a finite value. Rather than considering infinite time duration, minimum MSE and maximum ASR are achieved and hence it alleviates the problem of numerical complexity. The proposed JBF imposes power constraints at relay nodes and utilizes optimum power for communication. Thus, a hybrid optimization is achieved for the design and made acceptable for future wireless generation networks.

Algorithm 4 Algorithm for calculating optimum time slot for beam formation

Input: T, $Z_j^{(t)}, \alpha^{(t)}, R_i^{(t)}$
Output: optimum time $\hat{m}$
Initialization: Times slot $i = 0$
Evaluate the MMSE function J
for $i = 1$ to T **do**
  Calculate the MMSE function J
  if $J_{m=i}^{i+1} \leq J_{m=i}^{i+2}$ **then**
    Assign $\hat{m} = i$
  end if
end for
Return the value of $\hat{m}$.
Use the present values of $Z_j^{(t)}, \alpha^{(t)}, R_i^{(t)}$ at $t = \hat{m}$ to perform beam steering

6. Numerical results

The performance of proposed JBF algorithm is evaluated in terms of some important performance metrics like SNR, power consumption, power efficiency, ASR and sum of MSE. Sum of MSE and ASR analysis is adopted to account for path loss analysis in the transmission process. The novelty of proposed JBF design lies on the fact that optimum power utilization takes place by proper relay selection along with the effective beam formation. The BF vector update is carried out at optimum time slot with minimum MSE, maximum ASR and power efficiency. The performance comparison of our proposed work is done in two phases. For relay selection, the proposed MCSO is compared to conventional PSO and CSO. For JBF analysis, the proposed JBF with time and power optimization cases is compared to proposed JBF without time optimization ($m = \infty$) and conventional JBF without time optimization and power constraints. The sub-problem (19) is solved using proposed JBF Algorithms 3 and 4 with inputs of selected relays from Algorithm 2. Instead of directly giving the relay attributes as input to Algorithms 3 and 4, these algorithms work with selected relay set at the respective time slot via Algorithm 2. The corresponding relay combination varies with time slot and mobility of communication nodes. Hence, due to lack of identical simulation parameters, similar input arguments, architecture differences, etc., the proposed work lacks comparison to existing works in BF phase; however we have come up with a comparison of relay selection scheme with numerical results of reference [2], which is incorporated in Table 1. In all, 15 relays were deployed in the communication environment. We got appreciable results with a maximum selection of 6 relays for specific channel conditions, which will be discussed in this section. The CSI matrices $C_{1,r}^{(t)}, C_{r,1}^{(t)}, C_{r,2}^{(t)}, C_{2,r}^{(t)}$ follow Rayleigh fading, i.e. the elements of each channel matrix are independent complex Gaussian random variables with zero mean and unit variance. The channel estimation error matrices $\Delta_{i,i}^{(t)}$ for $i \in (1, 2, r)$ also follow the characteristics of Rayleigh fading channel, i.e. the elements of each channel matrix are independent complex Gaussian random variables with zero mean and variance $\sigma_{e,i}^2$. The noise variance and the loop-back channel estimation error variance at each node are defined as follows: $\sigma_{n,1}^2 = \sigma_{n,2}^2 = \sigma_{n,r}^2 = \sigma_n^2$ and $\sigma_{e,1}^2 = \sigma_{e,2}^2 = \sigma_{e,r}^2 = \sigma_e^2$. SNR is defined by $p/(\sigma_n^2 + \sigma_e^2)$ where p is the power transmitted by the selected node. For relay selection phase, MCSO makes use of a population size of 20 samples and maximum iteration is set to 100. For JBF convergence analysis also, maximum iterations is limited to 100. Inputs to proposed JBF algorithm are the optimum selected relay(s) and the associated coordinate vector matrices.

Figure 2 shows the SNR and power consumption as a function of transmitter power. Incorporating Levy flight update and velocity updation of PSO in CSO yield better results in terms of maximum SNR for a large transmitter power. It is substantiated that the low power consumption at relay nodes is accomplished using MCSO algorithm compared with conventional CSO approach. MCSO facilitates a better selection of relay(s) that closely satisfies the fitness function and outperforms the conventional CSO.

Table 1. Performance comparison of relay selection scheme.

Transmitted power (W)	Number of selected relays	SNR (dB) [2]	SNR (dB) (proposed work)
25	6	11	27
50	13	13	50

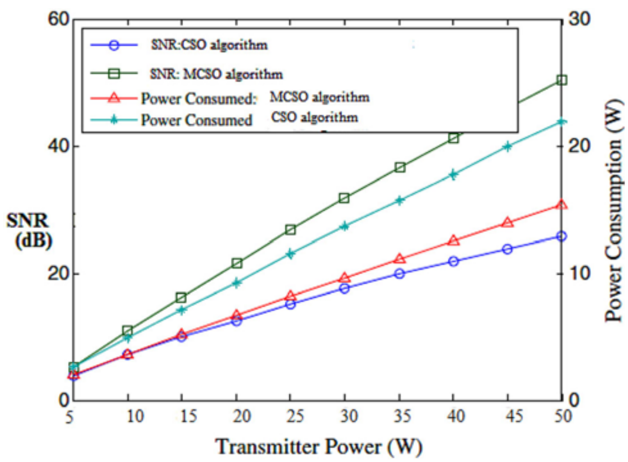

Figure 2. SNR and power consumption as a function of transmitted power. The variation of SNR and power consumption at selected relay(s) is analysed for CSO and MCSO algorithms for different values of input transmission power from 5 to 50 W.

The input transmitter power is fixed by considering coverage range for the signal to reach the destination node. Though power consumption for long-distance communication is more, still considerable wastage can be minimized using the proposed MCSO algorithm. Table 2 shows the precise values of SNR in dB and power consumption in watts for 25 and 50 W transmission power. This proves that the proposed MCSO is a better solution of optimum relay selection compared with the conventional PSO and CSO.

The power efficiency is a very significant optimization function, which is maximized for selecting optimum relay(s). Figure 3 shows the comparison of MCSO-based relay selection with respect to CSO and conventional PSO. For each value of input transmission power used, the power efficiency at selected combination of relays using MCSO algorithm is larger than those of conventional CSO and PSO. Though efficiency is bounded by the value 1 theoretically, the use of power amplification matrix in the relays leads to more signal power at the receiver node than transmitted signal power at the source node for a given power fed to the transmitter terminals. There can be situations where the source nodes are close enough such that they require less transmission power at the antenna terminals. However, the statistical signal processing algorithm implemented in smart antennas leads to imparting a power amplification factor at the relay terminals that leads to more output power for the signal at destination. Note that the need of power amplification factor is to compensate for the losses on account of distantly spaced source nodes and relay nodes. For 1 W transmitter power, power efficiency is more than 1 as the mobile nodes are very much closer such that they select minimum number of relays for transmission and account for the least transmission losses. The relay and receiver amplification matrix yields better signal quality and leads to maximum power efficiency. To facilitate long-distance communication, input transmitter power is increased and it leads to multiple-relay selection, increase of power loss and reduction in power efficiency. Table 2 shows the precise values of power efficiency in percentage for selected relay(s) at 25 and 50 W input powers. This proves that the proposed work is successful in selecting best relay for BF that maximizes the power efficiency.

Performance analysis of proposed JBF is analysed in terms of convergence rate of the algorithm, acceptable ASR and MSE values at optimum time slot of BF vector finalization. Figure 4 depicts the cost minimization results of conventional and proposed algorithms for different SNR regimes. For all three methods, maximum number of iterations is set to 100. A clear comparison of convergence is noted for all SNR regimes (positive, negative and 0 dB) between conventional and proposed designs. It is obvious that MSE value for negative SNR case is high and minimum for positive SNR. Now it is clearly seen that conventional JBF (without time optimality) and proposed JBF for $m = \infty$ case have been able to find the global minimum at about 20, 40 and 65 iterations, respectively, at –5, 0 and 5 dB SNR as depicted in Figure 4. The proposed JBF algorithm achieved convergence at 6^{th} iteration as shown in Figure 5.

Figure 6 shows the variation of ASR with respect to SNR values. The performance of JBF where BF update is carried out at $m = \infty$ is compared to that of proposed JBF with time optimization at $m = \hat{m}$. Here, for analysis, the proposed JBF at $m = 6$ and $m = \infty$ is depicted in Figure 6. It is seen that ASR value for proposed JBF algorithm is better than the conventional. All the three different schemes are compared for different numbers of selected relays N_r= 2, 4 and 6. It is obvious that increased number of selected relay nodes for transmission leads to faithful reproduction of signals at the destination, leading to high ASR value. ASR

Table 2. Parameter analysis of relay selection phase in terms of power efficiency, power consumption and SNR for given transmitter power.

TP	PSO			CSO			MCSO		
(in watts)	PE	SNR	PC	PE	SNR	PC	PE	SNR	PC
25	30	8	18	44	15	11	50	27	9
50	22	12	30	28	25	22	32	50	15

TP: Transmission power in watts, **PC**: Power consumed in watts, **PE**: Power Eciency in percentage, **SNR**: Signal to Noise Ratio in dB

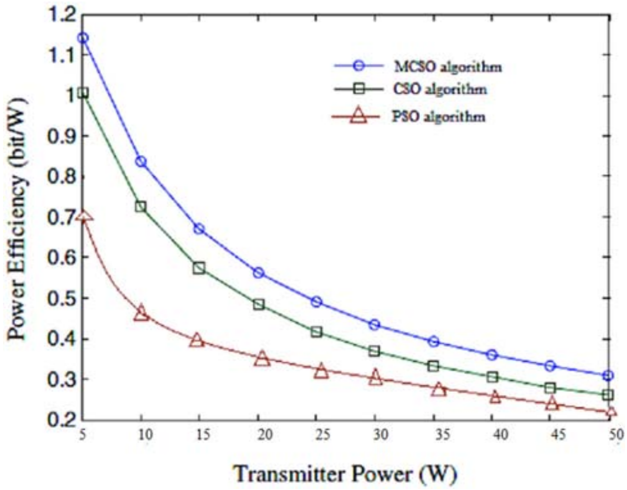

Figure 3. Performance comparison in terms of power efficiency as a function of transmitter power. The power efficiency at selected relay(s) is analysed by varying input transmitter power from 5 to 50 W and performance is compared for conventional PSO, CSO with proposed MCSO.

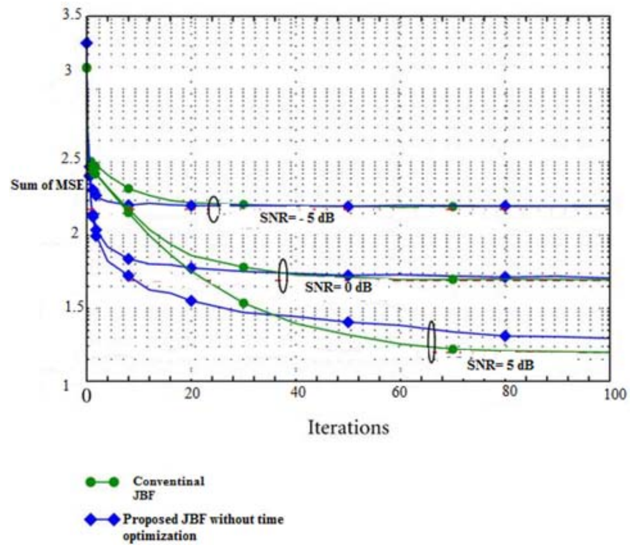

Figure 4. Convergence comparison. Convergence rate of MSE cost function is depicted for conventional MMSE-JBF without power constraints and proposed MMSE-JBF without time optimality ($m = \infty$ case).

values at $m = \infty$ and $m = 6$ are the same, leading to the conclusion that BF matrix at optimum time slot gives acceptable ASR. Hence the proposed JBF scheme can be used for matrix update with less computational delay and faster convergence. It is not mandatory to wait till the end of the observation interval for beam steering. We come across with the acceptable and same ASR value at optimum time slot.

The proposed JBF deals with multiple-relay selection scenario and if the destination nodes are more than one, it is desirable to consider multiple receive BF matrices $Z_j^{(t)}$ for higher values of j rather than $j = 1$. Hence it is desirable to analyse the sum of MSE rather than MSE. MSE has typically low value in noiseless (high SNR) environment. In Figure 7, proposed JBF for maximum number of selected relay units ($N_r = 6$) has minimum sum of MSE. The MSE values are almost same for $m = 6$ and $m = \infty$, which means that proposed JBF algorithm derives better results at optimum time slot $\hat{m}$ rather than updating the matrix at unpredictable time slot $m = \infty$. Acceptable and minimum MSE is achieved even at $m = 6$ and it is not mandatory to wait till the end of the observation interval for beam steering to take place. Thus, the proposed design reduces computational delay and simultaneously guarantees optimum power and minimum MSE.

The computational complexity of the proposed work is measured in terms of time saved in BF vector calculation compared with time spent for the conventional BF. When $m = \infty$ the indefinite time of convergence is taken as the last time slot of the observation period, say $T = 20$, and $m = \hat{m} = 6$ is the estimated optimum time slot for BF vector update for a specific simulation environment; then using the equation $((T - \hat{m})/T)100\%$, it is calculated that 70% of time optimization is done for BF vector update.

Our investigation revealed that a set of relay nodes powered down after a specific time slot are rarely used again or not used till the end of communication time slot. However powering down a relay node is followed by powering up another relay or set of relays, which requires additional time, which is negligible when compared with the time complexity of existing BF matrix update schemes. The proposed BF architecture calculates an optimum time slot for BF matrix update and hence compensates for relay selection time. ASR value and MSE values for the entire SNR regime are very much acceptable for proposed design and outperform well compared with the existing system. Hence, compromising the relay selection time for achieving other metrics seems to be desirable. The relative selection of ideal relay(s) participates in BF with maximum permissible power P_r. Though the proposed realistic energy model consumes little additional energy while powering down and up the relay, the total energy consumed by the selected relay combination for transmission with power constraints is far less than the energy consumed by conventional BF without relay selection. Considering the benefits of proposed energy model, the additional energy used for ON/OFF process of relay units can be compromised. The power efficiency is ideally optimized using MCSO algorithm and compared to those of CSO and PSO.

Table 1 depicts the comparison of performance of proposed relay selection scheme with existing works in reference [2]. It is clear that for long-distance communication, power used at the transmitter node is increased and number of optimum selected relays is also increased. The average

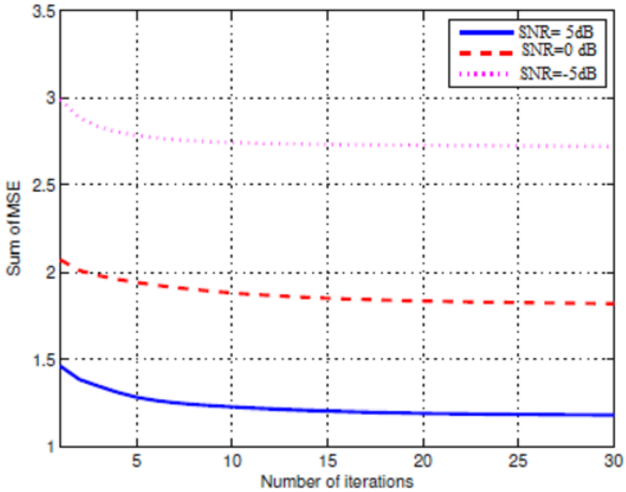

Figure 5. Convergence comparison. Convergence rate of proposed JBF with time optimization ($m = \hat{m}$ case) is depicted for distinct SNR regimes –5, 0 and 5 dB.

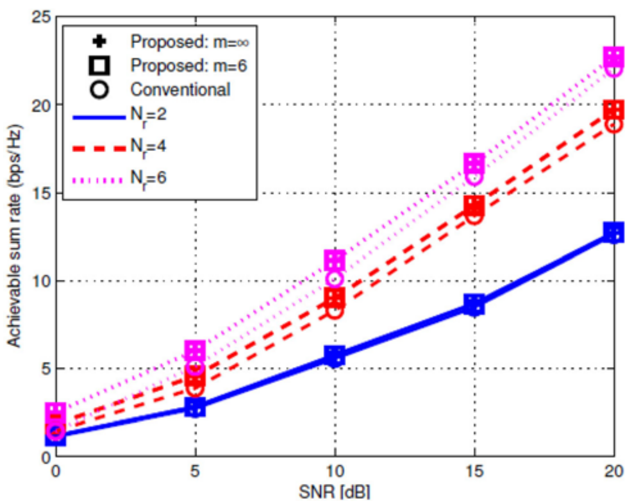

Figure 6. Performance comparison of JBF in terms of ASR as a function of SNR. Here analysis is done for three different numbers of relays selected using MCSO algorithm. Each case of $N_r = 2$, 4 and 6 is compared for three distinct aspects of JBF—conventional, proposed for $m = \infty$ and proposed for $m = \hat{m}$ cases.

SNR at the destination node for proposed work is considerably larger than SNR obtained in [2]. Table 2 shows a consolidated evaluation of performance of relay selection for BF. Three distinct metrics—power consumption, power efficiency and SNR at selected relay(s) for different values of transmitter power input—are mentioned. They are closely compared for PSO, CSO and proposed MCSO algorithms. Table 3 shows a consolidated evaluation of performance of JBF with the selected set of relays. ASR, convergence rate and MSE values are compared for three different cases—conventional JBF without power and time

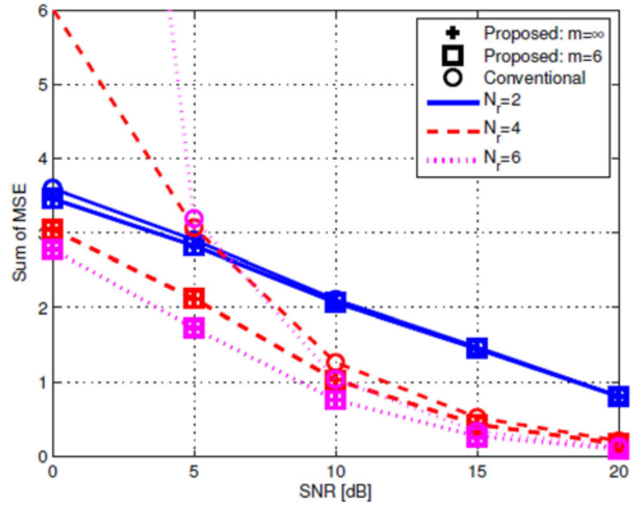

Figure 7. Performance comparison in terms of sum of MSE as a function of SNR. Here analysis is done for 3 different number of relays selected using MCSO algorithm. Each case of N_r= 2, 4 and 6 is compared for 3 distinct aspects of JBF—conventional, proposed for $m = \infty$ and proposed for $m = \hat{m}$ cases.

optimization, proposed JBF without time optimization and proposed JBF with power and time optimization. Table 3 reveals the fact that all essential performance metrics are ideally satisfied at optimum time slot $\hat{m}$ and it is not necessary to wait till $m = \infty$ (an unpredictable time slot) to update the BF vectors. This brings the solution for time delay problem in conventional complex BF matrix update.

These numerical and simulation results show that our proposed work outperforms well in terms of convergence speed, ASR, MSE, power efficiency, power consumption and SNR. The hybrid optimized BF after faithful relay selection adds novelty to our design by alleviating the problem of computational delay for beam steering phase. Thus relay selection phase before beam formation is done in an optimum way, thereby ensuring minimum power wastage by nullifying the unselected relays in the process of beam formation. Thus, a fast-dynamic mobile environment needs precise and frequent relay switching instead of fixed relay selection approach. This would lead to a more complex architecture in which we can utilize our proposed JBF design for fast BF vector update where it compensates for time elapsed in frequent relay ON/OFF.

7. Conclusion

Power-optimized and time-optimized JBF design suitable for relay-based wireless MIMO network is presented in this paper. The investigation leads to a novel architecture that results in optimum relay selection using MCSO algorithm. The selected relays that participate in beam formation lead to enhanced power efficiency and minimum power loss. Time complexity problem in JBF is alleviated by

Table 3. Parameter analysis of JBF with selected relay(s) in terms of ASR and sum of MSE for the obtained value of N_r and given SNR.

Parameters	Conventional	Proposed $m = \infty$	Proposed $m = \hat{m}$
Convergence iteration (at 5 dB SNR)	65	45	6
ASR (at 5 dB SNR and $N_r = 4$)	3	4.5	4.5
Sum of MSE (at 5 dB SNR and $N_r = 4$)	3.2	2.2	2.2

proposing an MMSE-based algorithm to calculate optimum time slot at which BF matrix will be updated, so that MSE is minimized and ASR is maximized. The power constraints in the optimization problem calculate optimum power for beam formation at relay nodes. Hence the proposed hybrid optimization JBF design is suitable for dynamically changing mobile environment and will satisfy the demands of future wireless generation networks. Our future work will focus on multi-user communication over multiple-relay selection to meet the same optimization targets.

Notations

S_1, S_2	Source nodes
N	Total number of available relays
$S_1^{(t)}, S_2^{(t)}, S_r^{(t)}$	Signals transmitted by two source and relay nodes in time slot 't'
$n_i^{(t)}, n_r^{(t)}$	Noise interrupting at source and relay nodes in time slot 't'
R_i	i^{th} relay used for beam-forming
$C_{i,r}^{(t)}, C_{r,i}^{(t)}$	CSI matrices between source and relay nodes in time slot 't'
$C_{i,i}^{(t)}, C_{r,r}^{(t)}$	Loop-back channel matrices at source and relay nodes in time slot 't'
$y_r^{(t)}$	Received signal at relay in time slot 't'
$\hat{y}_r^{(t)}$	Received signal at relay in time slot 't' after SI suppression
$\hat{y}_l^{(t)}$	Received signal at l^{th} source node
$\Delta_{i,i}^{(t)}$	Channel estimation error at i^{th} node in time slot 't'
P	Average transmission power
a_i	Scaling factor for power allocation to selected relay
w	AWGN at source nodes
w_i	AWGN at selected relay nodes
β_{av}	Average SNR
P_T	Total transmission power
C	Network capacity
$J_m^{(t)}$	MMSE function at time slot 't'
$\lambda^{(t)}$	Lagrangian multiplier at time't'
$Z_j^{(t)}$	Receiver BF matrix at time 't'
$R_i^{(t)}$	Relay BF matrix at time 't'
$\alpha^{(t)}$	Power amplification matrix
$\bar{R}_i^{(t)}$	Beam steering direction vector
N_r	Selected number of relays
N_s	Number of communication nodes
I_{N_r}	Initialized BF vectors at receiver node
I_{N_s}	Initialized BF vectors at relay node
m	Time slot at which BF matrix update is done
$\hat{m}$	Estimated optimum time slot at which BF matrix update is carried out
l	Source node index
n_r	Noise at relay node
σ_n^2, σ_e^2	Noise variance and loop-back channel estimation error variance
p_l	Power used at the source nodes

References

[1.] Quanzhong Li and Liang Yang 2019 Robust optimization for energy Efficiency in MIMO two-way relay networks with SWIPT. *IEEE Syst. J.* 14: 196–207

[2.] Ala Gouissem, Lutfi Samara, Ridha Hamila, Naofal Al-Dhahir and Sebti Foufou 2019 Multiple relay selection and beamforming in dual-hop amplify-and-forward relay networks. *IEEE Syst. J.* 13: 1534–1545

[3.] Ahmed Alkhateeb, Sam Alex, Paul Varkey, Ying Li, Qi Qu and Djordje Tujkovic 2018 Deep learning wave systems. *IEEE Access* 6: 37328–37348

[4.] Shim Y, Choi W and Park H 2016 Beamforming design for full-duplex two-way amplify-and-forward MIMO relay. *IEEE Trans. Wirel. Commun.* 15: 6705–6715

[5.] Guo T and Wang B 2016 Joint transceiver beamforming design for end-to-end optimization in full-duplex MIMO relay system with self-interference. *IEEE Commun. Lett.* 20: 1733–1736

[6.] Zhong C, Suraweera H A, Zheng G, Krikidis I and Zhang Z 2014 Wireless information and power transfer with full duplex relaying. *IEEE Trans. Commun.* 62: 3447–3461

[7.] Bletsas A, Khisti A, Reed D P and Lippman A 2006 A simple cooperative diversity method based on network path selection. *IEEE J. Sel. Areas Commun.* 24: 659-672

[8.] Liu X, Wen Z, Du N, Fan C and Tang X 2016 Robust source–relay beamforming for full-duplex relay networks with energy harvesting. In: *Proceedings of Globecom Workshops*, IEEE, pp. 1–6

[9.] Chen C, Bai L, Wu B and Choi J 2011 Relay selection and beamforming for cooperative bi-directional transmissions with physical layer network coding. *IET Commun.* 5: 2059-2067

[10.] Prerna Saxena and Kothari A G 2014 Performance analysis of adaptive beamforming algorithms for smart antennas. In: *Proceedings of the International Conference on Future Information Engineering. IERI Procedia* 10: 131–137

[11.] Shu F, Zhou Y, Chen R, Wang J, Li J and Vucetic B 2017 High performance beamformer and low-complexity detector for DF-based full-duplex MIMO relaying networks. *China Commun.* 14: 17–182
[12.] Zhigang Wen, Xiaoqing Liu, Shuangyan Zheng and Wenxia Guo 2018 Joint source and relay design for MIMO two-way relay networks with SWIPT. *IEEE Trans. Veh. Technol.* 67: 1–8
[13.] He Z, Lang Z, Rong Y and Qu S 2014 Joint transceiver optimization for two-way MIMO relay systems with MSE constraints. *IEEE Wirel. Commun. Lett.* 3: 613–616
[14.] Zheng G 2015 Joint beamforming optimization and power control for full duplex MIMO two-way relay channel. *IEEE Trans. Signal Process.* 63: 555–566
[15.] Cui H, Ma M, Song L and Jiao B 2014 Relay selection for two-way full duplex relay networks with amplify-and-forward protocol. *IEEE Trans. Wirel. Commun.* 13: 3768–3777
[16.] Haiyan Guo, Zhen Yang, Yulong Zou and Theodoros Tsiftsis 2019 Secure beamforming for cooperative wireless-powered networks with partial CSI. *IEEE Internet Things J.* 6: 6760–6773
[17.] Quanzhong Li and Liang Yang 2019 Beamforming for cooperative secure transmission in cognitive two-way relay networks. *IEEE Trans. Inf. Forensics Secur.* 15: 130–143
[18.] Khawaldeh Mohammad Kamel and Dia I Abu-Al-Nadi 2012 Design of wideband beamforming using particle swarm optimization. In: *Proc. IEEE Int. Multi-Conf. Syst. Signals Dev. (SSD)*, vol. 2, pp. 25–32
[19.] Khodier M M and Christodoulou C G 2005 Linear array geometry synthesis with minimum side lobe level and null control using particle swarm optimization. *IEEE Trans. Antennas Propag.* 53: 2674–2679
[20.] Garg A and Sahu O P 2015 Cuckoo search based optimal mask generation for noise suppression and enhancement of speech signal. *J. King Saud Univ.-Comput. Inf. Sci.* 27: 269–277
[21.] Choi W C, Choi S, Heo A and Park D J 2014 Joint optimization of source and relay for MIMO two-way relay networks using MSE duality. *IEEE Commun. Lett.* 18: 1246–1249
[22.] Joung J and Sayed A H 2010 Multiuser two-way amplify-and-forward relay processing and power control methods for beamforming systems. *IEEE Trans. Signal Process.* 58: 1833–1846
[23.] Wang F, He X S, Wang Y and Yang S M 2012 Markov model and convergence analysis based on cuckoo search algorithm. *Jisuanji Gongcheng/Comput. Eng.* 38: 180-185