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Multiuser Detection in MIMO-OFDM Wireless Communication System Using Hybrid Firefly Algorithm

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ABSTRACT

In recent years, future generation wireless communication technologies are most the prominent fields in which many innovative techniques are used for effective communication. Orthogonal frequency-division multiplexing is one of the important technologies used for communication in future generation technologies. Although it gives efficient results, it has some problems during the implementation in real-time. MIMO and OFDM are integrated to have both their benefits. But, noise and interference are the major issues in the MIMO OFDM systems. To overcome these issues multiuser detection method is used in MIMO OFDM. Several algorithms and mathematical formulations have been presented for solving multiuser detection problem in MIMO OFDM systems. The algorithms such as genetic simulated annealing algorithm, hybrid ant colony optimization algorithm are used for multiuser detection problem in previous studies. But, due to the limitations of those optimization algorithms, the results obtained are not significant. In this research, to overcome the noise and interference problems, hybrid firefly optimization algorithm based on the evolutionary algorithm is proposed. The proposed algorithm is compared with the existing multiuser detection algorithm such as particle swarm optimization, CEFM-GADA [complementary error function mutation (CEFM) and a differential algorithm (DA) genetic algorithm (GA)] and Hybrid firefly optimization algorithm based on evolutionary algorithm. The simulation results shows that performance of the proposed algorithm is better than the existing algorithm and it provides a satisfactory trade-off between computational complexity and detection performance

Keywords--- Multiple input multiple output, orthogonal frequency division multiplexing, firefly algorithm, genetic algorithm, particle swam optimization

I. INTRODUCTION

In recent years, wireless communication becomes the most promising field because of recent innovative techniques and it is considered a prominent field for future communication consumer products [1].To achieve future efficient communication, innovative techniques are needed for various applications and make sure that the correct architecture is used for applications which are going to be used by the users in future. The wireless communication has tremendous challenges in utilizing the resources effectively and to overcome these challenges many methods are introduced. Among the existing air-interface techniques, OFDM systems have recently attracted great interest.

The main reason for using orthogonal frequency division multiplexing is low complexity is achieved during the implementation because of the subcarriers are transmitted through the multiple channel and ease of equalization. In Europe, video or audio is broadcasted using OFDM and wireless networks such as IEEE802.11a. Mostly the OFDM is used for single users in order to gain efficient communication. In OFDM multiple input multiple output is used for multiuser system and it contains multiple transmission antenna, multiple receive antennas [3, 4].

In different users transmitted signals from different antennas to the base station and it is separated in base station based on their unique, user specific spatial signature. The separated signals are constituted by their element vector channel transfer function between user's single transmit antenna and multi user receiver antenna by considering the flat fading channel conditions in each subcarriers [5]. Many Multiuser detection algorithms are used by various authors for separating the users at the base station on per subcarrier basis. Some of the algorithms are minimum mean squared error, maximum likelihood used for multiuser detection. Both of the algorithms have some problems such as high computation complexity during the multiuser detection. To overcome these problems the author in [6] used Forward Error Correction (FEC) schemes such as Turbo Trellis Coded Modulation (TTCM) for achieving some better performance.

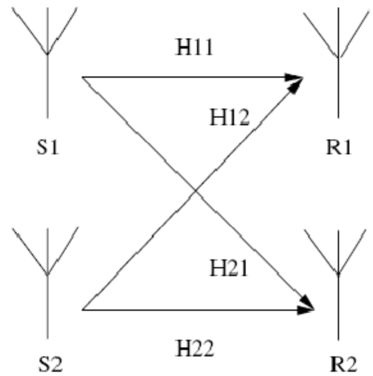

Figure 1: MIMO OFDM system with Nt = Nr = 2.

In this research the hybrid optimization algorithm is used for performing the multiuser detection in MIMO OFDM systems. The separation of noise and interference from the signal is carried out as same as other algorithms and it achieves the significant performance compared to the other methods.

II. RELATED WORKS

The blind source algorithm is used for blind multiuser detection and channel estimation method for MIMO OFDM system by Luciano in [7]. In MIMO OFDM systems, the multiple antennas are used for both in transmitter and receiver. The author used blind source separation along with multiple antennas for solving the problems of multiuser detection and linear instantaneous in OFDM. The author used BSS in each subcarrier in order to obtain the efficient output by detecting the user signals. The problems in BSS such as source order and scaling indeterminacies are overcome by calculating the subcarrier cross correlation using convolution encoding. The main advantage of the BSS method used for channel estimation and multiuser detection using cross correlation calculation between the subcarriers is enhancement of the performance of the MIMO OFDM network. The main disadvantage of the BSS method is slow convergence.

Yang et al used hybrid evolutionary algorithm such as genetic simulated annealing algorithm for solving the multiuser detection problem. In previously used systems the rank deficient problem is one of the major issues in multiuser detection system. It has some of the problems such as number of supported users exceeds the number of receiver antennas. It is explained in [8]. The author used genetic simulated annealing algorithm for solving the rank deficient problems. Because of the energy problems the performance of the algorithm used in this paper is not efficient one.

The author used minimum bit error rate for solving the multi user detection in [9] and it is mainly designed for space division multiple access(SDMA) based OFDM systems. The MBER is used for solving the multiuser detection by minimizing the bit error rate. The author compared MBER with the MMSE detector which is used in previous studies for solving the multiuser detection.

In the aforementioned research, minimum bit error rate is used for solving the multiuser detection problem in MIMO-OFDM by minimizing the BER cost function. To overcome the some problems in MBER during the multiuser detection the author used genetic algorithm for calculating the optimal weight vector of MBER. The result obtained from the improved MBER method is better than the results obtained from the aforementioned MBER.

The efficient metaheursitcs algorithms are used in [11] by for solving the multiuser detection. The metaheuristics algorithms are mainly based on the artificial bee colony and particle swarm optimization. It is used by the author in turbo trellis coded modulation based Space Division Multiple Access (SDMA) Orthogonal Frequency Division Multiplexing (OFDM) system. The method used by the author in this system is not like a method used by previous studies. The metaheuristics algorithm is used to make sure the objective function without the solution being trapped into local optima. The author used these methods in MIMO systems in order to achieve the performance in the so called overloaded system. The results are compared with the existing system such as genetic based multiuser detection, minimum MSE.

The existing systems such as minimum mean square error, successive interference cancellation based ones, maximum likelihood are some of the multiuser detection systems. Since the existing systems have the complexity of detection and the complexity is inversely proportional to the users and constellation size. Every time the users and constellation size are increased then automatically the increase complexity of the existing algorithms. To overcome these problems the author introduced the low complexity of MLD scheme using the sensitive bit algorithms in [12, 13]. The main advantage of these methods is low computational complexity when compared with the other existing algorithms.

III. METHODS AND MATERIALS

The proposed Hybrid firefly algorithm based on evolutionary algorithm is used for detecting the original signal without interference and noise.

3.1. Hybrid Evolutionary Firefly Algorithm (HEFA) Method

The hybrid evolutionary firefly algorithm *(HEFA) is a method used for solving the optimization problems and it is the combination FA [14] and DE [15]. The initial population in the algorithm represents the solution for optimizing the problems within specified searching space. The i^th^ solution X_i is represented as follows

$$X_{i(t)} = \{x_{i1(t)}, x_{i2(t)}, \ldots, x_{id(t)}\} \quad (1)$$

where x_{ik} is the vector with $k = 1, 2, 3, \ldots d$, , and t is the time step. Initially, the fitness value of each solution was evaluated. The solution that produced the best fitness value would be chosen as the current best solution in the population. Then, a sorting operation was performed. The newly founded solutions in these algorithms are used for solving the ranked based fitness and it is classified into two groups. The first group is formed using the fitness values. The fitness value of i and j population is compared with each other. If the fitness value of the neighboring solution was better, the distance between every solution would then be calculated using the standard Euclidean distance measure. The distance was used to compute the attractiveness, β:

$$\beta = \beta_0 e^{-\gamma r_{ij}^2} \quad (2)$$

where β_0, γ and r_{ij} , are represented as a predefined attractiveness, light absorption coefficient, and distance between i^th^ solution and its j^th^ neighboring solution, respectively [14]. The new attractiveness value was used to update the position of the solution, as follows:

$$x_{id} = x_{id} + \beta(x_{jd} - x_{id}) + \alpha\left(\delta - \frac{1}{2}\right) \quad (3)$$

where α and δ are uniformly distributed random values between 0 to 1. Based on the new update positions, the solutions that produced best fitness value are obtained [14].

The second group consists of the population based on the less significant fitness values and these solutions obtained from these populations are evaluated using the DE methods. The evolutionary operations such as mutation operation performed by original counterparts and crossover operations performed by original existing population are used in firefly algorithms for better and efficient results. The i^th^ trivial solution, V_i, was generated based on the following equation:

$$V_{i(t)} = \{v_{i1(t)}, v_{i2(t)}, \ldots v_{id(t)}\} \quad (4)$$

$$v_{i(t)} = x_{best(t)} + F.(x_{r1(t)} - x_{r2(t)}) \quad (5)$$

where $x_{best(t)}$ is the vector of current best solution, F is the mutation factor, x_{r1} and x_{r2} are randomly chosen vectors from the neighboring solutions [15]. The vectors of the i^th^ offspring solution, Y_i, were created as follows:

$$Y_{i(t)} = \{y_{i1(t)}, y_{i2(t),}, \ldots, y_{id(t),}\} \quad (6)$$

$$y_{i(t)} = \begin{cases} v_{i(t)} if\ R<CR \\ x_{i(t)} otherwise \end{cases}$$

where R is a uniformly distributed random value between 0 to 1 and CR is the predefined crossover constant [15]. As the population of the offspring solution was produced, a selection operation was required to keep the population size constant. The operation was performed as follows:

$$X_{i(t+1)} = \begin{cases} Y_{i(t)}\ if\ f(Y_{i(t)}) \le f(X_{i(t)}) \\ X_{i(t)} if\ f(Y_{i(t)}) > f(X_{i(t)}) \end{cases} \quad (7)$$

The fitness value of the new solutions which is produced during the crossover and mutation operation are better than the original solution then the original values are replaced by offspring values or else the original solutions will be initial population for next iteration. The pseudo code of the algorithm is explained in the algorithm1.

Hybrid Evolutionary Firefly Algorithm (HEFA)

Input: Randomly initialized position of d dimension problem: X_i

Output: Position of the approximate global optima: X_G

```
Begin
  Initialize population; Evaluate fitness value;
  X_G →Select current best solution;
   For t ← 1 to max
     Sort population based on the fitness value;
   X_good ← first_half(X); X_worst ← secondhalf(X);
     For i ← 0 to number of X_good solutions

For j ← 0 to number of X_good solutions
            if (f(X_i) > f(X_j)) then
     Calculate distance and attractiveness
               Update position;
             End If
           End For
         End For

For i ← 0 to number of X_worst solutions
         Create trivial solution, V_i(t);
         Perform crossover, Y_i(t);
         Perform selection, X_i(t);
       End For
       X ← combine(X_good, X_worst)
     X_G ← Select current best solution
               t ← t + 1;
     End For
End Begin
```

3.2. Multiuser Detection Using Hybrid Evolutionary Firefly Algorithm

In MIMO OFDM system, the k[th] signal is represented in the mathematical formulation as

$$r_k(t) = a_k e^{j\varphi_k} x_k(t) \tag{8}$$

Where, a_k and φ_k are the amplitude of the signal and its carrier phase, and $x_k(t)$ is given by

$$x_k(t) = \sum_{i=0}^{N-1} x_k[i] g(t - iT - \tau_k) \tag{9}$$

In MIMO OFDM systems, inverse FFT and FFT is used for data transmission at the transmitter and receiver side. The data are divided into the blocks and it is separated by guard interval and the guard bit is used for eliminating the inter block interference. The cyclic prefix consists of redundant symbols which are transmitted along with the data at the beginning [16].

The identical independent distribution (i.i.d.) and unit variance are encoded to the data $d_u(n)$ using the convolutional encoder along with the real valued impulse response $c(n)$ and length F to the obtain the encoded signal for transmit antenna u

$$s_u(n) = \sum_{l=0}^{F-1} c(l) d_u(n - l) \tag{10}$$

The encoded signal is then transmitted in blocks $s_u(i) = [s_u(iN), s_u(iN + 1), \cdot\cdot\cdot, s_u(iN + N - 1)]^T$ where i is the block index and the block length N corresponds to the number of subcarriers. The frequency selective channel is converted into flat fading channel using the cyclic prefix and it is occurred in each subcarrier [16].

Considering N_t transmit antennas and N_r receive antennas we can build blocks of received signals per subcarrier k $for\ k = 0, 1, \cdot\cdot\cdot, (N - 1)$: $r(k) = [r_1(iN + k), r_2(iN + k), \cdot\cdot\cdot, r_{N_r}(iN + k)]T$ where $r_v(\cdot)$ is the signal from receive antenna v. After the signal is converted into the blocks, the total received signal is represented as a

$$r(k) = H(k)s(k) + n(k) \tag{11}$$

With

$$H(k) = \begin{pmatrix} H_{11}(k) & \dots & H_{1N_t}(k) \\ H_{21}(k) & \dots & H_{2N_t}(k) \\ \vdots & \ddots & \vdots \\ H_{N_r1}(k) & \dots & H_{N_rN_t}(k) \end{pmatrix}$$

where $H_{vu}(k)$ is represented as a k[th] DFT coefficient of the channel between transmit antenna u and receive antenna v. The signal transmitted per subcarrier $k\ is\ s(k) = [s_1(iN + k), s_2(iN + k), \cdot\cdot\cdot, s_{N_t}(iN + k)]^T$ where $s_u(\cdot)$ is the signal transmitted by transmit antenna u and $n(k) = [n_1(iN + k), n_2(iN + k), \cdot\cdot\cdot, n_{N_r}(iN + k)]^T$ is the additive white gaussian noise (AWGN) vector with zero mean and variance N_0.

IV. PROPOSED METHODOLOGY

As mentioned in MIMO OFDM system, the, transmitted signal is received in receiver side antenna and multi user detection technique is used for detecting the noise and interference in the signal.

In this method, initial population represents original transmitted signals with interference and noise. The initial population is represented as a

$$Y(k) = [y_1(iN + k), y_2(iN + k), \cdot\cdot\cdot, y_{N_t}(iN + k)]^T \tag{12}$$

and it is the signal transmitted per subcarrier in the network. Initially the fitness value of the received signal is calculated. In this method, delay estimation and initial phase estimation is considered as a fitness values of the signal. The fitness value calculation is explained briefly in the following paragraph

4.1. Fitness value calculation

4.1.1. Delay estimation

After the signals are received in the receiver, the signals are subjected to various evaluation for eliminating the interference and noise. During that process the asynchronous character of the signals are not modified but considered for further operation. The delay estimation of each calculation is based on the signal correlation pilot symbol calculation. The delay estimation can be calculated as

$$\hat{\tau}_k = \arg\max\left(\left|\sum_{i=1}^{N_s \times N_p} Re(y_k(i).P_k(i)^*)\right| + \left|\sum_{i=1}^{N_s \times N_p} Im(y_k(i).P_k(i)^*)\right|\right) \tag{13}$$

Where $\hat{\tau}_k$ is represented as delay estimation, $Re(.)$ and $Im(.)$ represents the real part and imaginary part of the complex numbers, $(.)^*$ represents the conjugate operator of that specific complex number aforementioned. N is the pilot symbols number.

4.1.2. Phase Estimation

The phase estimation of the signals are important process before the decoding the algorithms. The phase estimation of the signals are represented using the given formula

$$\varphi_k = ang\left(\sum_{N_p} y_k(i)\tilde{P}_k(j)^*\right) \tag{14}$$

Where, $\tilde{P}_k$ is a $N_s \times N_p$ length column vector. It is derived from the pilot sequence vector P_k as follows. $\tilde{P}_k = [P_k(1), .., P_k(1), \dots, P_k(N_p), \dots, P_k(N_p)]^T$, with P_k is the vector of k[th] user training sequence which consist of N_p pilot symbols and $ang(\cdot)$ represents the angle of complex number operator.

4.2. The proposed algorithm for multiuser detection

Step1: Input: Initialized population as signals with interference and Gaussian white noise $y(k) = [y_1(iN + k), y_2(iN + k), \cdots, y_{N_t}(iN + k)]^T$ where $s_u(\cdot)$ is the signal transmitted by transmit antenna u and $n(k) = [n_1(iN + k), n_2(iN + k), \cdots, n_{N_r}(iN + k)]^T$ is the additive white gaussian noise (AWGN) vector with zero mean and variance N_0.

Step 2: Initialize population; Evaluate fitness value;

The fitness value calculation is

$$\hat{\tau}_k = \arg\max\left(\left|\sum_{i=1}^{N_s \times N_p} Re(y_k(i) \cdot P_k(i)^*)\right| + \left|\sum_{i=1}^{N_s \times N_p} Im(y_k(i) \cdot P_k(i)^*)\right|\right)$$

and $\varphi_k = ang\left(\sum_{N_p} y_k(j)\tilde{P}_k(i)^*\right)$

After the calculation of the delay and phase for given input signal. If the fitness value of the signal was better, then channel decoding is measured.

Step 3: the obtained signals are sorted using the fitness function based on delay estimation and phase estimation.

$X_{good} \leftarrow first_{half}(X)$ ie., the signals without interference and noise

$X_{worst} \leftarrow secondhalf(X)$; The signals with interference and noise

Step 4: the sorted signal is decoded using the formula given below. The SNR value is used for decoding the signal in this research

$$\widehat{SNR} = \arg\left(\min_{SNR \in [SNR_{min}, SNR_{max}]}(BER)\right)$$

Step 5: if the co channel interference coefficients are calculated first based on the formula

$$\hat{h}_{k,l}^{(n)} = \frac{1}{2 \times N_s(N+1)} \sum_{j=1}^{N_s(N+1)} y_k(j)\, \hat{x}_l^{(n)}(j)$$

Step 6: in this research, light absorption coefficient is considered as interference and it is calculated using the CCI coefficient calculated in the above step and the formula is explained below

$$y_k^{(n)}(j) = y_k(j) - \sum_{k=1}^{k-1} \hat{h}_l^{(n-1)}(k) x_k^{(n)}(j) - \sum_{k=k+1}^{K} \hat{h}_l^{(n-1)}(k) x_k^{(n-1)}(j)$$

Step 7: the worst signals are re-estimated using crossover operation in this research.

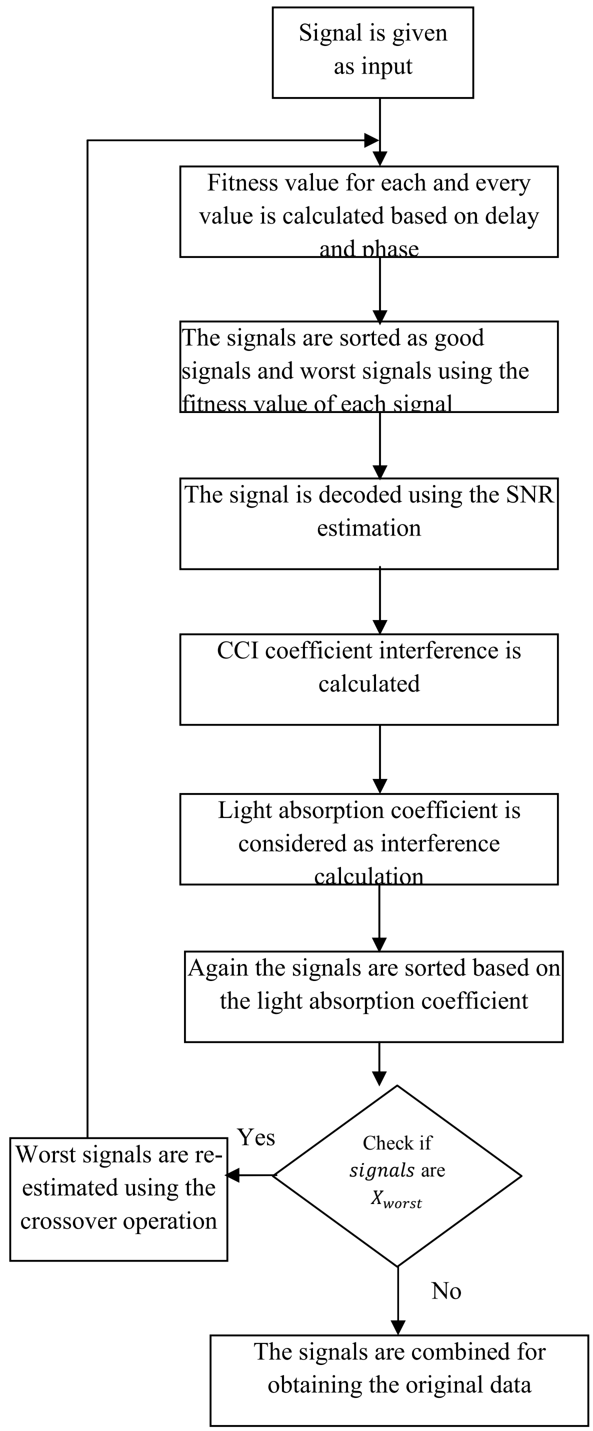

Figure 2: Flow chart for proposed multiuser detection system using hybrid optimization algorithm

By the Two-point crossover operation, we can select two encoding bit points randomly as the cross-points for each pair of the crossover parents and exchange the intermediate part of the two points. Finally, selecting an individual and its two encoding bit points randomly, reversing the intermediate part of the two points as the mutate manipulation.

Step 8: obtained signals are combines to form an original data signal with noise and interference

V. EXPERIMENTAL RESULTS

The signal along with the interference and noises are considered as an input in the experimental results. The signals are transmitted into blocks and it is transmitted using the N_T transmitter antenna. The signal is converted into the block before transmitting the data and it is transmitted along with the cyclic prefix. In receiver side the received signal fitness function is calculated. The proposed calculation is compared with the existing algorithm such as GSAA. The input users taken into account for evaluation are [1, 0.5], [1, 0.5, 0.5, 0.5], and [1, 0.5, 0.5, 0.5, 0.5, 0.5, 0.5, 0.5]. Iteration times are 10, try-number is 3, crowd factor δ is 0.8, the Step is 2, and the Visual is 10. With above parameters the MUD results of different users are calculated.

Table 1: Simulation Parameters

Parameter	Specifications
Total Bandwidth (B)	1MHZ
Modulation Technique	QAM
Number of sub-carriers(N)	128,256
Number of transmitter antenna(N_t)	2,4
Number of receiver antennas(N_r)	2,4
Number of users(K)	50,100,500
FFT Size	2048
Channel	Rayleigh Fading with different maximum Doppler shift

5.1. The Analysis of the Performance

The proposed Hybrid firefly optimization algorithm is compared with the existing multiuser detection algorithm such as particle swarm optimization, Complementary error function mutation (CEFM) and a differential algorithm (DA) genetic algorithm (CEFM-GA-DA) and GSAA. The conventional approaches are compared with the proposed algorithm in time domain, the proposed algorithm provides low computational complexity per stream solution. In other words, proposed algorithm has time synchronization and low interference suppression for each transmitted data stream. The proposed algorithm requires much lower design and much smaller size. HEFA can provide robust multiuser detection performance, with the increase of user number, the HEFA detection performance is better than other three algorithms such as PSO, GSAA, and CEFM-GA DA performance. The parameter of the multiuser detection is chooses based on the objective function and precision of optimization. The performance evaluation of the proposed algorithm is based on BER and the propagation of delay estimation error. Figure 3 clearly shows the SNR vs BER graphical representation. The bit error rate is the ratio of error data to the total number of data transferred from the transmitter. It is clearly observed from the figure that the proposed HEFA provides lesser BER when compared with the other existing algorithms considered. It is observed that the error rate during the transmission of the data for proposed algorithm is lesser than the existing algorithms.

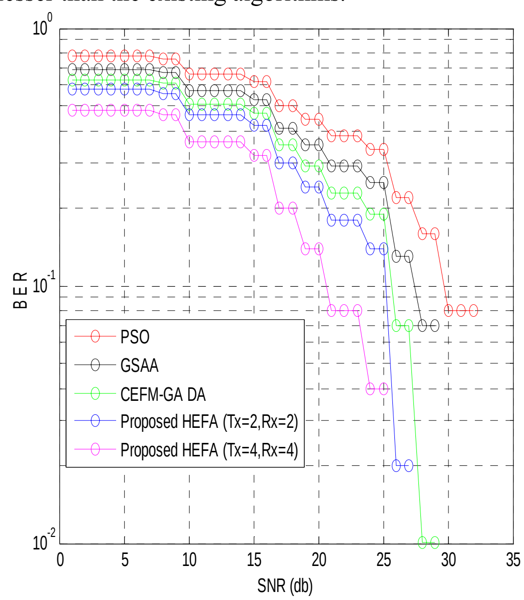

Figure 3: Comparison of BER performance for proposed system and genetic simulated annealing multiuser detection in MIMO-OFDM

The delay estimation is used as fitness value for the calculation of interference and noise in the original signal. The proposed algorithm has less error during the delay estimation when it is compared with the existing algorithm. The figure shows that the graphical representation of comparison of propagation of delay error estimation for proposed hybrid firefly algorithm and genetic simulated annealing algorithm.

From the figure 4, it can be shown that the proposed algorithm gives better performance with low delay estimation error when compared with other existing algorithm.

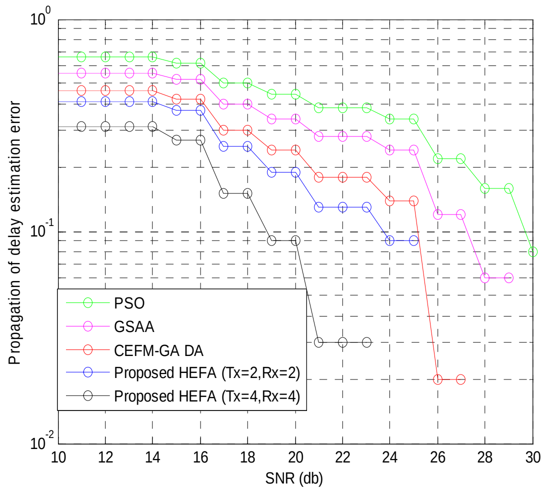

Figure 4: Comparison of delay estimation error for proposed system and genetic simulated annealing multiuser detection in MIMO-OFDM

VI. CONCLUSION

Multiuser detection in MIMO OFDM has become one of the active research areas in the communication. From the literature review, it is observed that, swarm intelligence algorithm provides good results for multi user detection. Genetic algorithm has been observed to produce good results. But, genetic algorithm converges in the local optimal solution so it cannot provide significant optimal result. This paper uses hybrid firefly algorithm based on evolutionary algorithm for better optimization results. The proposed algorithm is used for solving the noise and interference problems in original data. The crossover and mutation operations are used in hybrid firefly algorithm. The simulation results are shows that the proposed algorithm is better than the existing algorithm. The bit error rate and propagation delay estimation error are taken as the performance metrics to evaluate the performance of the proposed algorithm.

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