

Incremental gradient algorithm for multiuser detection in multi-carrier DS-CDMA system under modulation schemes

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Abstract

Nowadays, Multicarrier Direct sequence code division multiple access (MC DS-CDMA) systems are used in mobile communication. Performance of these systems are limited by multiple access interference (MAI) created by spread-spectrum users in the channel as well as background channel noise. This paper proposes an incremental gradient descent (IGD) multi-user detection (MUD) for MC DS-CDMA system that can achieve near-optimum performance while the number of users is linear in its implementation complexity. The IGD algorithm make an effort to perform optimum MUD by updating one user's bit decision each iteration in the best way. This algorithm accelerates the gradient algorithm convergence by averaging. When a minimum mean square error (MMSE) MUD is employed to initialize the proposed algorithm, in all cases tested the gradient search converges to a solution with optimum performance. Further, the iterative tests denote that the proposed IGD algorithm provides significant performance for cases where other suboptimum algorithms perform poorly. Simulation compares the proposed IGD algorithm with the conventional detectors.

Keywords: *gradient descent; interference; MS DS/CDMA; multiple-access; multi user detection.*

1. Introduction

A multiple channel access method known as CDMA is used by the technologies of radio communication. The telecommunication and navigation system are majorly CDMA based and it can be recognized based on the nature of the spread spectrum [1]. In CDMA many transistors simultaneously send information along a single communication channel as well as frequency bands are shared by multiple users. This accessing method is used in mobile phones standards such as IS-95, IS-2000, etc. In CDMA, to modulate the signal each user uses different code. For 4G wireless communication, CDMA was not chosen as a main stream multiple access system [2].

DS-CDMA is the popular technique of CDMA in which the transmitter multiplies the signal of each user by using different code waveform. It reduces the complexity in the Beam forming network by means of parallel signal processing [3]. DS-CDMA system capacity is based on the reverse link and it can be limited by the interference that are received at the base station (BS). Multicarrier DS-CDMA (MC DS-CDMA) uses direct-sequence (DS) spreading in each subcarrier which employs degree-of-freedom for high flexibility design and configuration. MC DS-CDMA is a digital modulation and multicarrier technique; it can be implemented using orthogonal frequency division multiplexing (OFDM) and DS-CDMA. The MC DS-CDMA becomes significant multicarrier communication system for fourth generation (4G) system. This system is processed depending on the spreading code of the time domain or the spreading codes of combination of time and frequency domain. That is, the input serial data stream is transformed to parallel and it can be spread using the time domain spreading code,

then each subcarrier is modulated differently with each of the data stream.

Performance and capacity of the multicarrier DS-CDMA are limited due to the interference known as MAI. The near-far problem occurs when a weak signal from a faraway mobile station is swapped out by the strong signal from a mobile station which is closer to the BS. The channel can introduce the fading channel leading to the same effect, even if the mobile stations are at the same distance from the BS. This noise based issue increases the bit error rate (BER) and leads to interference. The interference occurs between the direct sequences users. In the reverse link, each signal reaches at the BS through the different propagation path [4].

Some techniques have been used to resolve the interference issues. Among them one is multi user detection (MUD). Multi user detection is used to eliminate the interference. It copes well with multi access interference [5]. It mainly focuses on the return link in satellite communication, which is the link from the terminals of the user to the gateway, also includes some centralized techniques to apply at the gateway [6]. It is used for downlink communication [7].

Some of the conventional detectors that are used are de-correlating detector, MMSE detector, Maximum likely-hood detection (ML), least square (LS) and the zero forcing algorithm (ZF). The de-correlating detector is used to resist the multiple access interference [8]. This detector applies the inverse of the user spreading code correlation matrix to the output. The de-correlating detector is done at the base station. The base station contains all the available information. But the limitation is that it increases the noise and the matrix inversion is hard to carry out in real time.

MMSE is the detector used in Multicarrier DS-CDMA. It is a decision feedback (DF) receiver, and it employs low complexity and

successive cancellation [9]. It utilized the received signal power to decrease mean square error (MSE). The requirement of received amplitude estimation is the limitation. The maximum likely-hood detection improves the performance of the multi-user detector [10]. Probability of obtaining the particular set of data is likelihood of data. It contains unknown parameters and the parameter value maximizes the sample likelihood. The Zero forcing algorithm is a detector used in communication systems which reduces the interference signal.

2. System model

The system is a multicarrier DS-CDMA system. This system works with L number of users on the same channel with A_r receive antennas and A_t transmit antennas. Codes are assigned separately to the users in order to differentiate the signal with length N. Each user's signal is multiplied by a code and it can be modulated by using the modulation schemes known as BPSK [11], QPSK [12] and QAM [13]. The process of changing some carrier wave characteristics in proportion to the signal to be transmitted is defined as modulation. Fig. 1 shows the model for MC DS-CDMA transmitter.

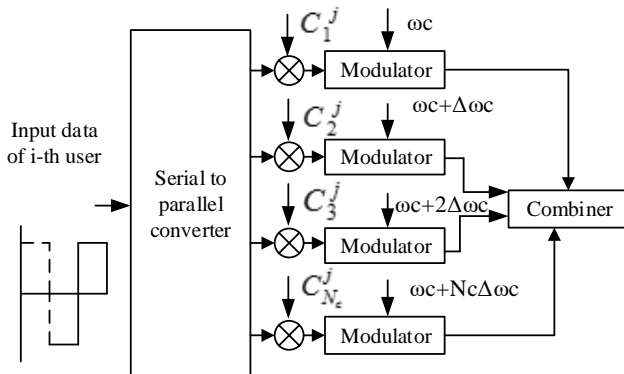


Fig. 1: MC DS-CDMA Transmitter model

A sine wave equation for BPSK modulation is,

$$b(t) = B_c \sin(2\pi f_c t + P) \quad (1)$$

Where $b(t)$ denotes the sine wave amplitude at a time t , B_c denotes the peak amplitude, f_c denotes the frequency of the wave in hertz, t denotes the time in seconds and P denotes the phase. The sine wave can be changed based on the amplitude, the frequency, and the phase. A carrier containing more frequency components after it is modulated and it requires proper channel to carry all the frequency of this modulated signal. BPSK uses phase shift keying (PSK) modulation technique. The carrier differs based on binary inputs by keeping the amplitude and frequency constant.

The QPSK modulation signals are defined as,

$$s_j(t) = C \cos(2\pi f_c t + \phi_j) \quad (2)$$

Where $j = 1, 2, 3, 4$, $\phi_j = \frac{(2j-1)\pi}{4}$, f_c denotes the carrier frequency.

In QPSK, the signals are formed by grouping together the bits. By modulating the signal using QAM, the signal is in the form of,

$$s(t) = R[I(t) + Q(t)]e^{j2\pi f_c t} \quad (3)$$

Where $I(t)$ and $Q(t)$ are the modulating signals, f_c denotes carrier frequency, and R indicates real part.

Then the modulated serial signal is transmitted to the IFFT. Parallel output of IFFT is then converted into serial and passed through the channel (Rayleigh fading channel and AWGN) where the noise are present by adding the remaining data streams. The received signal at k th receiving antenna is,

$$r_q(t) = \sum_{m=1}^M \sum_{a=1}^{A_t} \sum_{l=1}^L c_{a,q} b_{l,a} s_l + n_q(t) \quad (4)$$

Where $c_{a,q}$ is the fading coefficient of a th transmitting terminal and q th receiving terminal, $b_{l,a}$ is the amplitude of l^{th} user from a th transmit antenna. $s_l = s_l(t - mT_s - \tau_{a,q})$ is the l^{th} user signature sequence. T_s is the duration of the symbol, $\tau_{a,q}$ is the time delay between the a th transmitting and q th receiving antenna. M is the size of the frame and $n_q(t)$ is the AWGN noise.

The received signal with the noise term is,

$$r(t) = \sum_{k=1}^K r_q(t) + n(t) \quad (5)$$

Where $n(t)$ is the Gaussian noise that will undergo a filtering process at the receiver.

3. Conventional detectors

3.1. De-correlating detector (DD)

The DD de-correlates the filter output and the inverse of the user spreading code correlation matrix is applied to the output. The de-correlating detector [14] is done at the BS. The base station contains all the available information. The matched filter output can be given as,

$$y = RBc + n \quad (6)$$

The soft estimate of the de-correlating detector is,

$$c_{dec} = R^{-1}y \quad (7)$$

The k^{th} component is free from the interference which is caused by other users, but the interference is caused by the background noise.

The advantage is that the received amplitude knowledge is not required. Computational complexity of Decorrelating detector is lower than the ML detector. But it also has the limitation that it increases the noise and the matrix inversion was hard to resist in real time and user's signature waveform must be known.

3.2. MMSE detector

MMSE is a detector which takes the noise of the background and utilized the received signal power knowledge. It decreases the mean sequential error $E[|c - Ly|^2]$.

$$L_{MMSE} = [R + \sigma^2 B^{-2}]^{-1} \quad (8)$$

MMSE [14] implements the correlation matrix inverse. That is, the modification is directly proportional to the noise of the background. It provides better error probability performance as well as eliminates MAI. But the limitations are, received amplitude estimation was required and the performance of MMSE was based on the interfering user power.

3.3. Maximum likely-hood detection (ML)

The ML detector [14] provide the most likely sequence 's' which increases the probability, 's' was transmitted and r(t) received the sequence. The advantages of ML are that it provide good performance and also gains the capacity. But the limitation was high cost as well as received phase and amplitude knowledge was required.

3.4. Zero-forcing algorithm (ZF)

The zero forcing algorithm [14] performs two operations as linear operation and subtractive interference cancellation operation (SIC). The linear operation de-correlates the users partially and SIC subtracts the interference from the user. It is based on the white noise channel, and it can be defined as,

$$y_w = FBs + z_w \quad (9)$$

Where Z_w denotes the noise co-variance matrix.

It eliminates MAI and increases the SNR. Limitations of ZF are received and the performance was worse than the de-correlating detector.

4. Incremental Gradient descent (IGD) based MMSE MUD

4.1. Basic Gradient descent

Gradient descent is an optimization algorithm used to find the minimum function. The steps are taken proportional to the gradient negative to find the local minimum function. The other name of gradient descent is the steepest descent. A bank of matched filter is denoted as,

$$z = RBc + n \quad (10)$$

Where R denotes the matrix of cross correlation, B denotes the diagonal matrix, c denotes the transmitted bits and n represents the noise.

Even though it solves the optimization problem, it has computational complexity and channel selection problem. So, the incremental gradient descent (IGD) based MMSE MUD is used to overcome all the problems.

4.2. Incremental gradient descent multi user detector

The MMSE detection scheme is improved and the IGD based MMSE MUD will reduced the MAI. The general objective of IGD MMSE is defined as,

$$\theta = \theta - \mu \nabla_{\theta} E[I(\theta)] \quad (11)$$

Where μ denotes the learning rate, ∇_{θ} is the vector which contains the coefficients and θ contains the training set.

The incremental gradient MMSE approach decreases the error with respect to the coefficients. The coefficients can be upgraded based on the step size multiplier. In IGD the parameters and the learning rate can be selected initially. Consider $(c - c^* y)$ is the detector to minimize the mean square error.

$$\nabla MMSE = E[(c - c^* y)^2] \quad (12)$$

The incremental gradient descent technique searches the real vector y, which is orthogonal to the real and imaginary vectors forming the vector c to reduce the interference signal effects and n defines the equivalent noise. It can be indicated as,

$$(c^* + y)^T x = c^{*T} cd + (c^* + y)^T n \quad (13)$$

An objective is to search the vector to satisfy the constraints and to reduce the interference and noise that are in the detected signal. This equalizes the reduction of the total output energy as defined by the cost function.

$$f = [(c^* + y)^T x][(c^* + y)^T x]^* + \beta_1 y^T c + \beta_2 y^T c^* \quad (14)$$

Where β_1 and β_2 are the multipliers of the Lagrangian to make certain the constraint. Differentiating the above equation by means of the vector element y,

$$\text{grad}(f) = [(c^* + y)^T x]x^* + [(c^* + y)^T x]^* x + \beta_1 c + \beta_2 c^* \quad (15)$$

The incremental gradient descent rule is given by,

$$y(i) = y(i-1) - \mu \text{grad}(f) \quad (16)$$

Where μ denotes the step control multiplier, and y(0) is an initial value for the vector y. By considering $mn^* + m^*n = 2R(mn^*)$, then the incremental rule can be altered as,

$$y(i) = y(i-1) - \mu [2R([(n^* + y(i-1))^T x(i)]^* x(i)) + \beta_1 c + \beta_2 c^*] \quad (17)$$

Modified y(i) is,

$$y(i) = y(i-1) - \mu [\varphi + \beta_1 c + \beta_2 c^*] \quad (18)$$

Choosing y(0) = 0, the multipliers of the Lagrangian can be found by pre-multiplying the above equation by c^T and c^{*T} also by applying the constraints,

$$c^T \varphi + \beta_1 c^T c + \beta_2 c^T c^* = 0 \quad (19)$$

$$c^{*T} \varphi + \beta_1 c^{*T} c + \beta_2 c^{*T} c^* = 0 \quad (20)$$

By solving β_1 and β_2 ,

$$\beta_1 = \frac{(c^{*T} c^* c^T - c^T c^* c^{*T}) \varphi}{(c^{*T} c)^2 - \|c^T c\|^2} \quad (21)$$

$$\beta_2 = \frac{(c^T c c^{*T} - c^{*T} c c^T) \varphi}{(c^{*T} c)^2 - \|c^T c\|^2} \quad (22)$$

β_1 and β_2 , are the complex conjugates and substitute, it can be obtained as,

$$y(i) = y(i-1) - 2\mu R([(c^* + y(i-1))^T x(i)]^* [x(i) + c\alpha^T x(i) + c^* \alpha^{*T} x(i)]) \quad (23)$$

Where,

$$\alpha^T = \frac{(c^{*T} c^* c^T - c^T c^* c^{*T})}{(c^{*T} c)^2 - \|c^T c\|^2} \quad (24)$$

The step control multiplier μ varies using MMSE. $\mu = \mu_0 / (x^{*T} x)$ determines the most suitable values, where μ differs in simulation based on the frame length and number of users.

Algorithm: Incremental Gradient descent (IGD) based MMSE MUD

Step 1: Initialize the parameters: L no. of users, transmit antenna, receive antenna, cyclic prefix, active users, BER.

Transmitter side:

Step 2: Transmit the input stream to the serial to parallel converter.

Step 3: A code multiplies the user's signals.

Step 4: The converted data streams are modulated using BPSK, QPSK and QAM.

Step 5: Modulation block related to IFFT converts the frequency domain vector signal to the time domain vector signal.

Step 6: Output of IFFT is given to the parallel to serial converter.

Step 7: Cyclic prefix is placed to protect the OFDM signal from interference.

Channel side:

Step 8: AWGN noise and interference occurred through the Rayleigh fading channel.

Step 9: MMSE MUD

Estimate the result by the random variable to minimize the error.

For better optimization IGD based MMSE is used.

Step 10: IGD based MMSE MUD algorithm minimizes the error (noise) and interference.

Initialize learning rate, training set based on the objective function $\theta = \theta - \mu \nabla_{\theta} E[I(\theta)]$

Repeat the iteration until obtain the minimum approximation based on (23).

Minimized result

Receiver side:

Step 11: Remove the cyclic prefix and apply serial to parallel converter to the output of IGD MMSE, to convert the data stream in time sequence.

Step 12: FFT converts the time domain vector signal to the frequency domain vector signal.

Step 13: Demodulates data streams.

Step 14: The output of demodulation is given to the parallel to serial converter.

Step 15: Output

5. Simulation Results

Simulation results are presented using MATLAB to show the success of the proposed method. Table 1 show the system and channel parameter values which are deployed in the incremental gradient descent MMSE-MUD optimization.

Table 1: System and channel parameters

Sr. No.	Parameters	Values
1	Modulation	BPSK, QPSK, 16-QAM
2	Spreading Sequence	Gold Sequence
3	Length of FFT	64
4	Number of subcarrier	52
5	Number of users	20, 100
6	Cyclic prefix	1/4
7	Signal-noise ratio	SNR $\in [-2:15]$ dB
8	Fading Channel	Rayleigh fading
9	Noise	AWGN
10	Active users	6 to 8
11	Time domain spreading factor	N=15
12	Frequency domain spreading factor	M=7

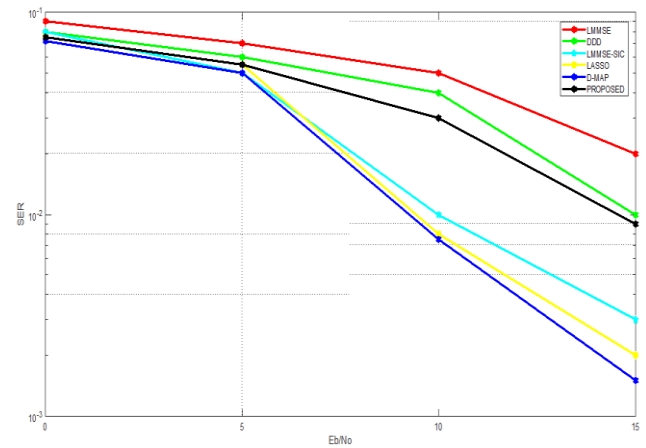


Fig. 2: SER vs. SNR (dB) comparison for 20 users

Fig. 2 shows SER vs SNR (dB) with 20 users. The figure clearly indicates that the proposed IGD based MMSE MUD gives significant performance than some of the other detectors.

The effectiveness of the proposed IGD-MMSE is compared with the D-map [15], LMMSE [15], LASSO [15], DDD [16], SSD [16], and LMMSE-SIC [17] for the symbol error rate (SER).

MAI with MUD that are caused in the star topology machine to machine (M2M) communication is considered. M2M is the internet of things in which it has large number of nodes. It has been assumed that the signals that are transmitted are discrete. The detection problem is coined as the maximum a posteriori (MAP) estimation. The optimization known as the sum of absolute value can be solved by the splitting algorithm and it cannot be solved by the polynomial time. The map that increases the posterior probability is given by,

$$b_{map} = \arg \max_{x \in A^N} p(x | y) \quad (25)$$

Linear minimum mean square error (LMMSE) obtained the near-far receivers in DS-CDMA. It also reduced the MSE between the output and transmitted data. It cannot be implemented in fast fading channels since it depends on the coefficient of the channel. Least absolute shrinkage and selection operator (LASSO) reduces sum of squares concern to the actual value of the coefficients less than a constant. Sub-net selection and ridge regression are the suggested properties for LASSO.

Decision directed detector (DDD) algorithm depends on back substitution to disintegrate the cost of sparse MAP into k sub-cost. Each cost accepting the solution of closed form and each dependent on the variable of a single scalar. Thus it found the minimum after comparing all the cost. Sparse sphere decoder (SSD) algorithm used mainly for the ML demodulation of MIMO transmissions. In SSD, the searches were based on the hyper-solid. It found the unknown vector which reduced the distance metric. Successive interference cancellation (SIC) algorithm with low complexity and the combined LMMSE output was selected and the slicer estimated the transmitted symbol. Due to the symbol that is detected, the signal contribution is reconstructed and cancelled from the received vector. The correct ordering of symbols on the channel state increased the performance of LMMSE-SIC.

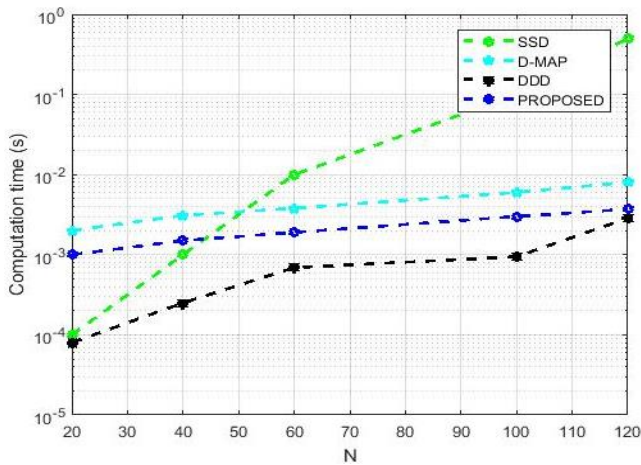


Fig. 3: Comparison of computation time vs. the number of users

Fig. 3 shows the computation time for various algorithms and the proposed system achieves a normal scenario as compared with the existing results. The average elapsed time to approximate an original signal b by the D-MAP detector, DDD, SSD, and proposed algorithm vs. N , has been shown. The computation times of D-MAP and proposed algorithm does not change considerably with number of users N . But, SSD increases exponentially with size of the system. Thus the proposed multi user detection method provides effective performance than the other existing approaches. The IGD-MMSE estimation relaxed with an optimization which solves the problems based on optimization efficiently.

Table 2: The Total Calculations

Detection methods	Each iteration Order	Total order
D-MAP	$O(N(M + L))$	
LASSO	$O(NM)$	
LMMSE		$O(NM)$
DDD		$O(N^2)$
SSD		Exponential into N
LMMSE-SIC		$O(N^2M)$
GPR		$O(n^3)$
Proposed	$O(N^2(M + L))$	

In D-MAP, N represents no. of users, M represents filters and L represents the cardinality of the finite set of the candidate of symbols. In LASSO, LMMSE and LMMSE-SIC, where N is the no. of users and M represents the filters. In DDD, SSD, N denotes the no. of users. In GPR, n represents training points and in the proposed approach, N represents the no. of users, M represents the learning rate and L denotes the finite set of the candidate symbol.

As shown in the Table 2, the numbers of iterations are required to compare the total amounts of calculation of iterative algorithms with those of non-iterative algorithms. The algorithm converges to a solution of the optimization problem, if that problem is convex [15]. Thus proposed MUD method provides effective performance than the other existing approaches. The IGD-MMSE estimation relaxed with an optimization which solves the problems based on optimization efficiently.

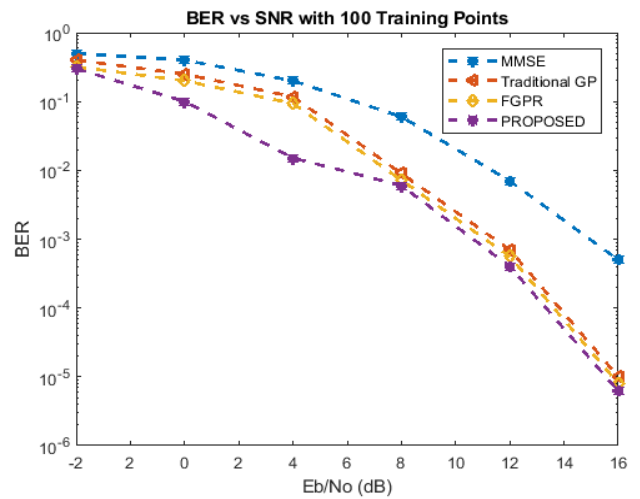


Fig. 4: BER vs. SNR (dB) with 100 training points

Fig. 4 indicates that when comparing the BER of the proposed method with MMSE, GP and FGPR for 100 training points, the proposed gives efficient BER performance. Even though the performance of the other systems came close together, the IGD gives better performance. The Gaussian technique [18] efficiently solves the issues of MUD in CDMA systems. The fast Gaussian process regression reduced the complexity by maintaining the accuracy. That is, this technique dealt with the communication system challenges and provides better performance. The Gaussian process (GP) [19] was used as a detector for the CDMA communication system. It computes the parameters easily and the cross-validation was not required, also computational complexity for implementation is low.

The interference related to block-based and symbol-based detector is suppressed by Minimum mean squared error (MMSE) [20]. It gives high performance with increased robustness. The symbol based can be designed as a parameter vector which can be operated with a symbol length of received data. The block based was designed as a matrix, which deals with a block length received data per time.

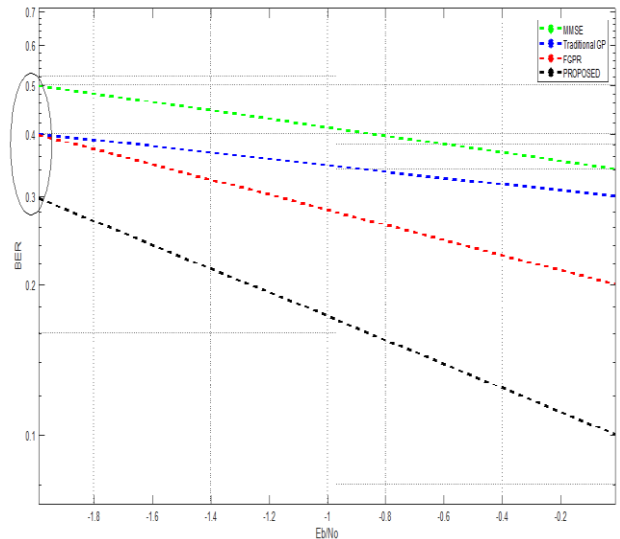


Fig. 5: BER vs. SNR (dB)

As shown in fig. 5 BER measure for all algorithms can be calculated at the initial stage. The % performance deviation of the proposed MUD algorithm is compared with FGPR. As referred in (26) the formula for the percentage of performance deviation.

$$\% \text{ deviation} = \frac{BER(FGPR - Proposed)}{Proposed} \times 100 \quad (26)$$

The proposed IGD MMSE MUD has 33.3% improvement for detecting [23]

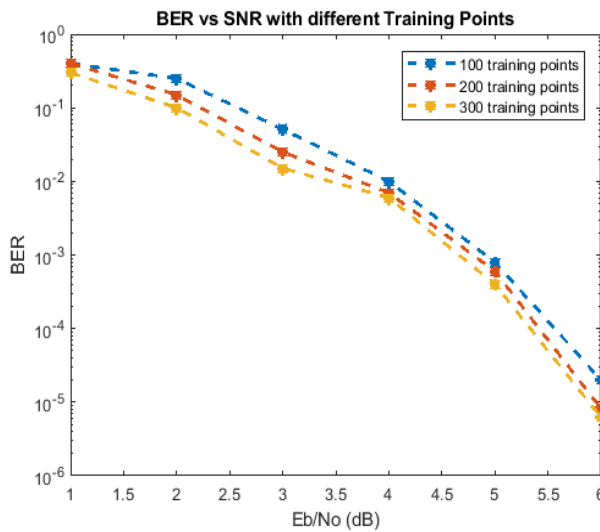


Fig. 6: BER vs. SNR (dB) with different training points

Fig. 6 shows the relationship between BER vs SNR (dB) with the different number of training points as 100, 200 and 300 for the proposed IGD MMSE. It shows clearly that the performance will slightly vary for different training points.

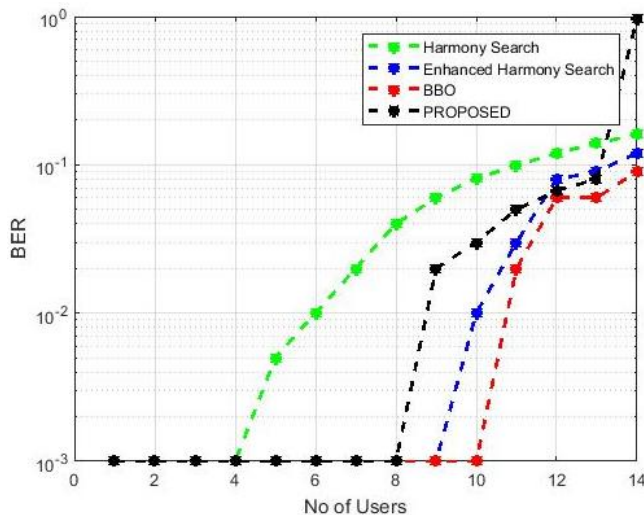


Fig. 7: BER vs. No. of users for various optimization algorithms for MUD

In fig. 7, the BER for different detection techniques has been compared with the proposed with the number of users. CDMA is used for communication and the system performance is affected while transmitting the signal through the fading channel. To overcome the interference, MUD and the channel estimation functions are used. Biogeography base optimization (BBO) [21] is a multi-user detection technique which reduces the transmitted signal error rate. That is, the complexity and interference can be resolved by this technique. The BBO algorithm used set of candidate solutions known as habitats, which is the fitness of the optimization method.

The Harmony search [22] algorithm is used for MUD in DS-CDMA. This algorithm achieved low complexity optimization. In this, the user vectors are legitimated based on the optimum of Bayesian and the rule of the harmony search is used to collect the sufficient number of user vectors.

The enhanced harmony search [23] algorithm is used for MUD in DS-CDMA system. The updating of harmony memory depends on the operation random and mean, and it reduced the complexity, bit error rate and user interference. The enhanced search algorithm calculates both the observed and unobserved node of the marginal distribution. This also improves the efficiency of multiple users as well

as minimized information losses and power corruption of the channel of CDMA. The existing optimization algorithms are lacks at the complexity. The improved efficiency is achieved in our algorithm as well as it is simple. The algorithm performs updates for each training, when the algorithm moves via the training set. Until the convergence of the algorithm, many passes can be made over the training set. To prevent cycles, for each pass the data can be shuffled.

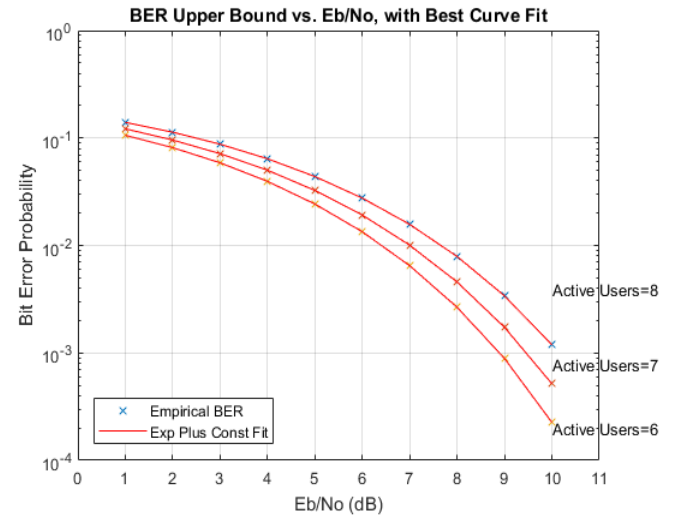


Fig. 8: BER upper bound vs. Eb/N0, with best curve fit

Fig. 8 shows the performance of bit error probability vs. Eb/N0 with different active users, such as 6, 7, and 8 for the proposed IGD MMSE. The performance will vary for the different number of users. More active users in the system increase the BER of the detector. Graph clearly shows that the BER performance with 6 active users gives a better result than with 8 active users.

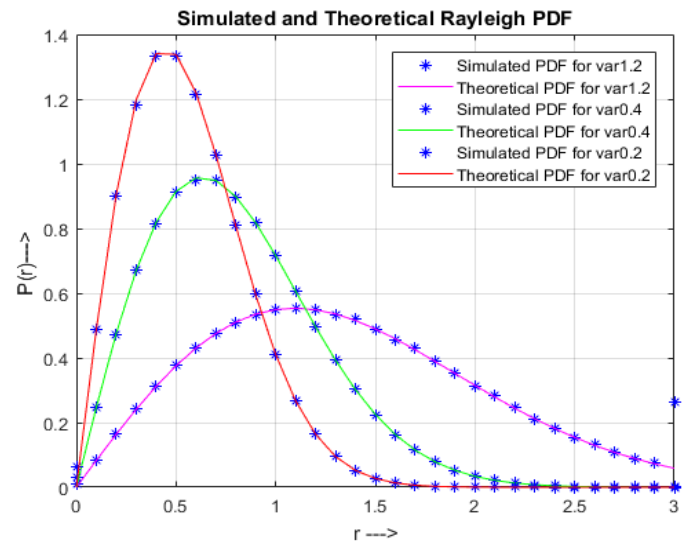


Fig. 9: Simulated and theoretical Rayleigh PDF

Fig. 9 shows that the simulated and theoretical probability density functions of the Rayleigh channel for different values of variance 1.2, 0.4 and 0.2. As the shape parameter increases, the distribution gets wider.

6. Conclusion

The MC DS-CDMA is frequently proposed CDMA system in wireless mobile systems in the third generation. A conventional receiver technique in DS-CDMA is limited by capacity due to the MAI and near- far effects. It degrades the performance of the system substantially. By employing the techniques of MUD with optimum detectors, these problems can be mitigated. Thus, the

paper proposes an IGD-MMSE MUD technique to solve the constraints in the MMSE detector. The existing MMSE technique optimizes the parameter on whole training set, every iteration till convergence. This makes the GD slow. So in the proposed work, IGD based MMSE is used to minimize the error fastly as it is optimizing the parameter on one training example at a time till it converges. In IGD MMSE, the parameters are updated iteratively, and the MMSE can be computed and minimized on the training set. Also set of parameters can be updated in an iterative manner to minimize the error. The computation is faster in IGD MMSE. Even in the large scale system, the proposed IGD MMSE works better and gives the best performance with low complexity. The IGD MMSE algorithm is simple and the system knows active users and spreading codes. The proposed IGD-MMSE technique provides a compromise solution that takes the background noise and the interference of each user. The proposed simulation results are compared with the existing detectors. Our future work is to extend the proposed work by considering other methods for averaging in order to improve the convergence and take into account with other communication systems.

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