INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume3, Issue3)
Available online at www.ijariit.com

Mimo Channel Estimation Using Fast Converging Evolutionary Optimization Algorithm

Monika
L. R Institute of Engineering & Technology, Himachal Pradesh
16monikagautam@gmail.com

Mahendra Tyagi
L. R Institute of Engineering & Technology, Himachal Pradesh
mahendra.tyagi9@gmail.com

***Abstract:** In this paper, a new method using fast converging particle swarm optimization for channel estimation in transmit diversity has been proposed. Also, various estimation techniques for improving the accuracy of channel estimation, comparing the LS estimator with Adaptive Least Square estimator receiver which includes a feedback of output and improves the BER performance of the system, close to the ideal channel performance, have been studied. In the channel, it is required to transmit the data from a transmitter to receiver but sometimes noise is added to the data that has to be transmitted and that noise is called the interference. To improve the estimation process, an evolutionary algorithm like optimization techniques can be utilized for the estimation of the channel. Therefore, a method can be developed based on Particle Swarm Optimization based Least Square estimator for transmit diversity case in OFDM. The results have been shown in support of the proposed method.*

***Keywords:** MIMO, OFDM, LS, FCPSO.*

I. INTRODUCTION

In any communication system, the channel is to be estimated. This estimation of the channel is required for decoding of the message which is transmitted, thus it can be said that channel estimation is the most significant part in any communication systems. Channel estimation provides maximum capacity and diversity gain with multiple inputs and multiple output (MIMO) channels. Estimation of the channel is also necessary for optimization problems like joint detection, power adaptation and much more. Hence estimation of channel plays a vital role in designing and implementation of the communication system. In the real world, there will some changes in the communication system which will move the transmitter and receiver which affects the channel and cause frequency selective in the channel. Hence, the channel is estimated by an appropriate method such as channel reciprocity, channel feedback, prediction methods etc. at both ends (transmitter and receiver end). In the channel, it is required to transmit the data from a transmitter to receiver but sometimes noise is added to the data that has to be transmitted and that noise is called the interference. To reduce the computational complexity, used the latest channel estimate to approximate the IAI (inter-antenna interference) effect, exploited the correlation of channel parameters at adjacent subcarriers to remove IAI. In, the standard LS method was applied to obtain the new channel estimates from IAI canceled data. So, the purpose is to reduce the interference by estimating the channel. The channel can be estimated by the different techniques like LS, MMSE etc. These are the equalizers use to balance the ISI. In the **Least Square (LS)** algorithm, proposed by Widow and Hoff, is a popular method for system identification. Its applications include and so forth. Although there exist algorithms with faster rates of convergence like LMS methods are popular because of its ease of implementation, low computational costs, and robustness. In **MMSE, the goal of the equalizer** design is to minimize the average mean square error (MSE) between the transmitted symbol and its estimate at the output of the equalizer.

A. *MIMO SYSTEM*

MIMO system can significantly enhance the performance of wireless systems through multiplexing or diversity gain. For a given transmit energy per bit, multiplexing gain provides a higher data rate whereas diversity gain provides a lower BER in fading. The advantage of MIMO system is higher capacity, better transmission quality, and increased coverage. The MIMO system is utilized with multiple antennas at both ends of the link, all transmit and receive antenna pairs can be represented by the MIMO channel. In the MIMO system, a binary data stream is supplied to a basic transmitting block. This block involves the effectiveness of error control coding and mapping to complex modulation symbols. After supplying binary data stream to transmitting block, a spate symbol stream has been generated that is a collection of the independent and fully redundant stream. Afterward, each signal is mapped onto one of the multiple transmitter antennas and then the signals are transferred to the wireless channel following upward frequency conversion, filtering, and amplification. Then, the signals are received by multiple receiver antennas and demodulation and mapping operations are executed to recover the message. There are four types of MIMO systems: spatial division multiplexing (SDM), space division multiple access (SDMA), space-time block coding (STBC), beamforming.

In **Spatial division multiplexing (SDM),** this technique is used to maximize the attainable multiplexing gain. In this SDM scheme, the throughput of a single user can be increased when CIR array elements are employed. Also, SDM systems use multiple antennas to increase the throughput of a wireless system in terms of the number of bits per symbol that can be sent by a specific user in a known bandwidth at a given integrity. SDM transmits streams of independent data over different antennas, consequently offering a linear increase in the transmission rate for the same bandwidth, with no additional power expenditure required. In **SDMA**, throughput can be divided between the supported users in order to maximize the number of supported users. The directional angle is used as another dimension in the signal space in space division multiplexing and the direction can be channelized and gives to separate users. Directional antennas are used to perform this task. If directionality is obtained by utilizing an antenna array, the exact angular resolution requires a large array. In **Space-time block coding (STBC) The** main purpose of STBC is to maximize the diversity gain. This STBC technique maintains reliable communication over the air interface and this done by using multiple antennae at both transmitter and receiver end. The transmission of data in this system can be carried out in 2D. The space dimension is extended by multiple transmit antennas while the time dimension is extended by multiple time intervals over which multiple blocks are transmitted. In these systems, ST encoder is employed at the transmitter and an ST decoder employed at the receiver. The ST encoder converts one-dimensional block transmissions into two-dimensional ST transmissions. Various Applications of MIMO system are as follows: 1. MIMO system may be used to overcome the detrimental effects of multi-path and fading while attaining high data throughput in limited-bandwidth channels. 2. These systems are used in modern wireless standards, including in IEEE 802.11n, 3GPP LTE, and mobile WiMAX systems. 3. These systems provide higher data rates. 4. It also provides superior data rate and reliability without any requirement of additional bandwidth and transmits power. 5. MIMO systems create multiple independent channels for sending multiple data streams.

II. RELATED WORK

Sadek, Mirette et al. [1] in this work, the leakage-based preceding approach has been presented. This approach is basically used for downlink multiple users in MIMO channel. The proposed scheme designs the precoders in order to enhance the signal to leakage noise ratio. This paper studied the system performance which is affected by channel estimation error. The proposed method is compared with zero-forcing solutions and it is found that the presented approach will not impose any condition on a number of transmitting and receive antennas but it will eliminate the noise. The results of simulation demonstrate the performance of the proposed scheme. **Tarighat, Alireza** et al. [2] presented beam forming approach which is used for downlink MIMO channels. Beam forming approach depending on maximizing the signal to leakage ratio. This proposed scheme does not impose any limitation on the available transmit antennas. The proposed beamforming scheme is better as compared to another conventional beam forming scheme. **Spencer, Quentin H.** et al. [3] a zero forcing method has been proposed in this paper. Two constrained solution i.e. (block-diagonalization and successive optimization) has also been described in this paper. These two constrained are used to optimize the minimum power at high signal to noise ratio and also used to solve the power minimization problem. Furthermore, an approach for coordinated transmitter-receiver processing has been discussed. **Kaltenberger, Florian** et al. [4] this paper presents the capacity and correlation of measured for MIMO channels. The data which is measured has attained by EMOS. This EMOS can easily perform for multiple channel measurements over multiple users. The result indicates that those multiple user MIMO channels give higher throughput in comparison with single user MIMO channels. But in the outdoor environment, when users get closer than the capacity significantly drops, this is due to the fact that at the transmitter side correlation is high. In this case, single user and multiple user-MIMO channels are comparable. **Chen, Jianwu** et al. [5] In this work, joint carrier frequency offset and channel estimation in MIMO channels has been proposed. The main purpose of this paper is giving smallest MSE; asymptotic Cramer rao has been employed. To reduce the asymptotic Cramer rao, the optimal training sequences has been designed. Channel estimator and CFO have been derived in this paper which is depending on the maximum likelihood. Furthermore, the computational technique has also been proposed which utilizing sampling technique. This computational technique helps to solve multidimensional exhaustive search. The simulation results indicate that the benefits of proposed approach. **Shin, Changyong** et al. [6] this work proposed the blind channel estimation in multiple inputs multiple output system. This proposed method gives an efficient solution for MIMO systems. This proposed scheme is depending on subspace approach. This blind channel approach gets precise channel estimation and fast convergence. If virtual carriers (VCs) are available, the proposed method can work with no or insufficient cyclic prefix (CP), thereby potentially increasing channel utilization. Moreover, this method can also be applied to the MIMO-OFDM system without cyclic prefix but in the presence of virtual carries. Furthermore, it is shown under specific system conditions that the proposed method can be applied to MIMO-OFDM systems without CPs, regardless of the presence of VCs, and obtains an accurate channel estimate with a small number of OFDM symbols. Thus, this method improves the transmission bandwidth efficiency. Simulation results illustrate the mean-square error performance of the proposed method via numerical experiments.

Tu, Chao-Cheng et al. [7] Presented novel channel estimation depending on subspace algorithm. This proposed algorithm is obtained by utilizing the frequency correlation among adjacent subcarrier in MIMO system. This paper generally overcomes the problems of the subspace algorithm. The proposed approach requires a lesser number of samples. The results indicate that the proposed approach performance is better that already proposed a method. **Minn, Hlaing** et al. [8] in this work, various pilot designs for channel estimations of MIMO systems. This design is required very smaller plot overhead that the existing designs and also provides the estimation. The performance analyses and simulation results provide the benefit of proposed design.**Ylioinas, Jari** et al. [9] Presented the iterative detection and decoding by utilizing prior data. A new list has derived which his based on the parallel interference cancellation (PIC) detector. This list is used to estimate the APP algorithm with reduced complexity and minimal losses of performance. Moreover, SAGE channel estimation is optimized by computer simulation. It is also shown that the list PIC detector with good initialization outperforms the *K*-best list sphere detector (LSD) in the case of small list sizes, whereas the complexities of the algorithms are of the same order. **Khojastepour, Mohammad A. Amir** et al. [10] this paper presented a novel approach for channel estimation in MIMO system. Sparse channel estimation refers to estimating the time domain channel impulse response. In this work; the problems are formalized and drive the essential condition on the different number of pilots. Moreover, the suboptimal solution has been presented which is improved OMP of MIMO channel. The work in this paper explained that training overhead can be severely minimized while maintaining the same accuracy as the current state of the art techniques. **Carrascosa, Patricia Ceballos** et al. [11] in this work, adaptive channel estimation has been presented. Data detection for under water acoustic MIMO system has been also proposed. The result illustrated on the experimental data which is recorded is shallow water channels over the 1KM distance. Almost, error-free performance has been viewed for one or more transmitter with BCH (64, 10) encoded quadrature phase-shift keying (QPSK) signals. Improved results have been shown in MIMO configuration. **Mohammed, Saif K., Ahmed Zaki** et al. [12] proposes a low-complexity algorithm in this work. This proposed algorithm is used for detecting high rate, non-orthogonal space-time block coded (STBC) that attains high spectral efficiencies of the order of tens of bps/Hz. in this paper, a training-based iterative channel estimation scheme has been presented for such large STBC MIMO systems. The results indicate that the bit rate has attained by the proposed multistage likelihood ascent search (*M*-LAS) detector. **Knievel, Christopher** et al. [13] Graph-based soft channel estimation has been presented and detection is extended to an OFDM-based air interface, where the channel response varies in two dimensions; time and frequency. Initial channel estimates obtained by training symbols are conveyed by a two-dimensional (2D) factor-graph in time and frequency with only a linear increase in complexity. The required training overhead for the proposed 2D graph-based soft channel estimation scheme may be substantially reduced by taking the redundancy introduced by the channel coding into account. **Dai, Xianhua** et al. [14] in this paper, two step schemes have been adopted to calculate the LTV channel over multiple OFDM symbols. Furthermore, analysis of channel estimation has been proposed and derived a closed-form expression for the channel estimation variances. The result indicates that the performance of channel estimation is increased with limited pilot power. An interference cancellation procedure is introduced to iteratively mitigate the information sequence interference to channel estimation. **Sarmadi, Nima** et al. [15] in this paper, a new blind channel estimation approach for orthogonally coded MIMO-OFDM systems has been presented. The main purpose of this approach is utilizing some properties of OSTBC in order to calculate FIR channel parameter for each subcarrier. By utilizing SDR technique, the problem of estimation of the channel can solve efficiently. The simulations confirm the performance of proposed method is far better than as blind MIMO-OFDM channel estimation methods. **Venkateswaran, Vijay** et al. [16] proposed beamforming in MIMO communications with phase shift networks. The main goal of this paper is to terminate interfering signals in the analog domain, which helps in reducing the required ADC resolution. In order to reduce the MSE between the desired user and its receiver estimate, the optimal analog beamformer has been presented. But on the other hand, analog beamformers develop a quantized number of phase shifts, for such case, the technique is especially proposed in this work. Finally, an online channel estimation technique is introduced to estimate the required statistics of the wireless channel on which the optimal beamformers are based. **Wang, Zhongju** et al. [17] in this work, the problem of optimal uni-modular sequence design has been presented for MMSE channel estimation and conditional mutual information maximization, respectively. Majorization-minimization approach has been proposed in this paper for both issues. The results indicate that the proposed framework is efficient and precise. **Li, Tao, Xiaodong** et al. [18] presented a position aided approach for estimation of the channel. In this approach transmit antenna transmits pilot symbol. The full channel matrix may be calculated by using these pilots together with the position of which is depending on the joint spatial-temporal correlation. The results demonstrate the system throughput with the position-aided channel estimator does not decline substantially as the mobility increases.

III. PROPOSED METHODOLOGY

Particle swarm optimization (PSO) is a population-based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation.

In proposed Fast Converging PSO (FCPSO), the potential solutions, called particles, fly through the problem space by following the current optimum particles. Each particle keeps track of its coordinates in the problem space which is associated with the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called *best*. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbors of the particle. This location is called *lbest*. When a particle takes all the population as its topological neighbors, the best value is a global best and is called *gbest*. The particle swarm optimization concept consists of, at each time step, changing the velocity of (accelerating) each particle toward its p*best* and *lbest* locations (local version of PSO). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward *pbest* and *lbest* locations.

In past several years, FCPSO has been successfully applied in many research and application areas. It is demonstrated that FCPSO gets better results in a faster, cheaper way compared with other methods. Another reason that FCPSO is attractive is that there are few parameters to adjust. One version, with slight variations, works well in a wide variety of applications. Particle swarm optimization has been used for approaches that can be used across a wide range of applications, as well as for specific applications focused on a specific requirement. It is an evolutionary algorithm inspired by the food search methodology of a swarm of insects. The position of each insect represents a candidate solution, which is updated as the swarm of insect flies in a multi-dimensional search space. The movement of each insect is governed by the efficacy of their own previous position and that of their neighbors.

Each insect can be described by two parameters- position (x_i) and velocity (v_i), which is updated by the following rule as in equation below:

$$v_i(t+dt) = w * v_i(t) + c_1 * r_1 * \left(pbest_i(t) - x_i(t)\right) + c_2 * r_2\left(gbest(t) - x_i(t)\right) \quad (1)$$

$$x_i(t+dt) = x_i(t) + v_i(t)dt \quad (2)$$

Here, $pbest_i$ is the best position obtained by *ith* particle and *gbest* is the best position obtained by any particle till current iteration. c_1, c_2 are known as acceleration vectors whereas r_1, r_2 are two random vectors uniformly distributed between '0' and '1' and *w* denotes inertial weight.

IV. RESULTS

The proposed algorithm is implemented in MATLAB. It is assumed that transmitter has perfect channel knowledge of fading channels are Rayleigh, Rician and Flat fading channel. The channel estimation of the MIMO-OFDM system is measured by applying a Fast Converging Particle Swarm Optimization (FCPSO) algorithm to estimate the channel in different fading. In evaluating the results are changing the number of iterations. The performances of our proposed channel estimator are compared to Adaptive LS and LS with FCPSO algorithms. Initially, we see the best result obtained at each stage for a number of iterations: 40, Inertia weight: 0.01, Acceleration constants: 0.9. Three channels are considered for this experimental analysis namely Rayleigh, Rician and Flat fading channel.

The results for the proposed methodology in comparison with the existing is presented below. The comparison is made on two parameters, Mean Square Error (MSE) and Bit Error rate (BER). The fig.1 shows the Mean Squared Error (MSE) and Signal to Noise Ratio (SNR) curve for the Flat fading channel. Graph comprises of x-axis SNR which is measured in d Band Y-axis is MSE. SNR is used to compare the level of the desired signal to the level of background noise.
For Rician fading channel, the fig. 2 is shown. It also shows the graph between MSE and SNR value of the channel. Channel estimation increases with the increase in SNR value of the channel.
For Rayleigh fading channel the fig. 3 is shown. It also shows the graph between MSE and SNR value of the channel. Channel estimation increases with the increase in SNR value of the channel.

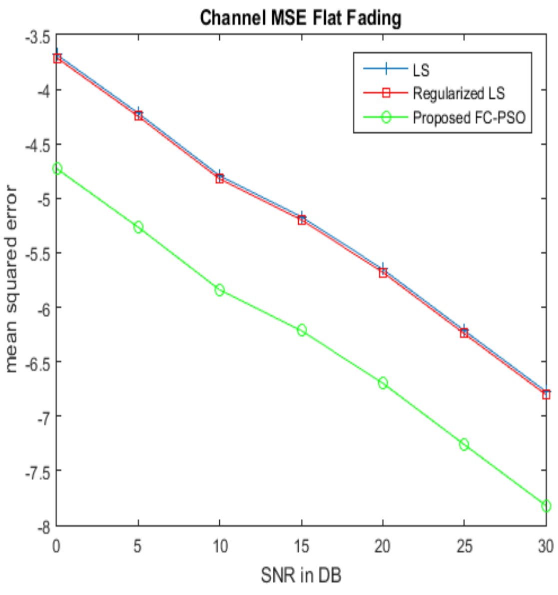

Fig.1 MSE vs SNR for Flat Fading Channel

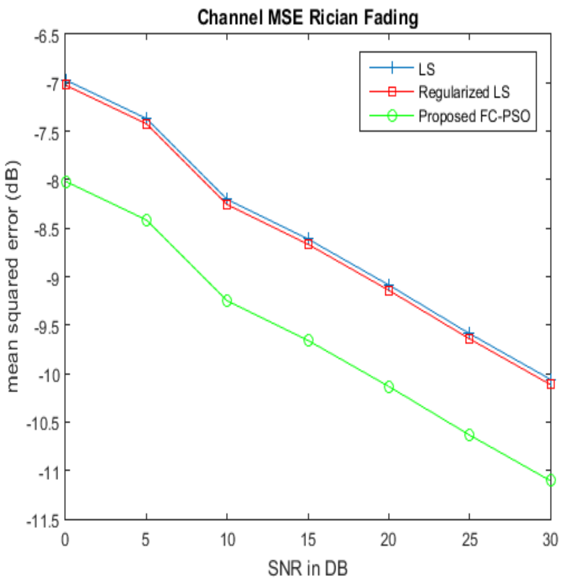

Fig 2. MSE vs SNR for Rician Fading Channel

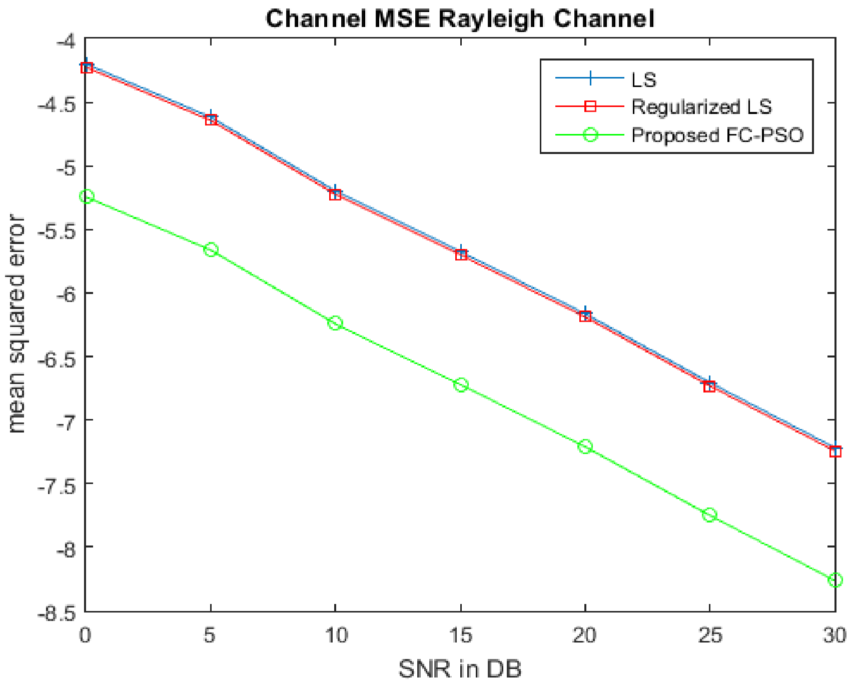

Fig 3. MSE vs SNR for Rayleigh Fading Channel

BER response with respect to Eb/No (Energy per Bit/ Noise) for Flat fading channel, Rician fading channel and Rayleigh fading channel has been depicted in the figures. BER is defined as the rate at which errors occurs in the transmission system.

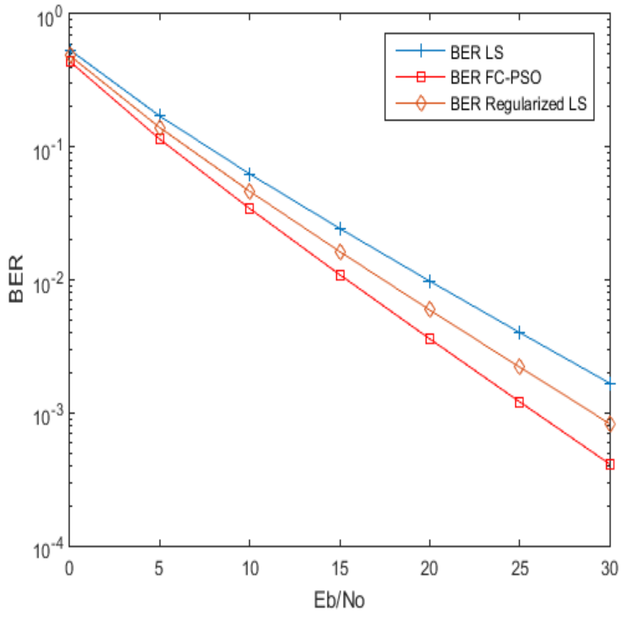

Fig. 4 BER vs Eb/No. for Flat Fading Channel

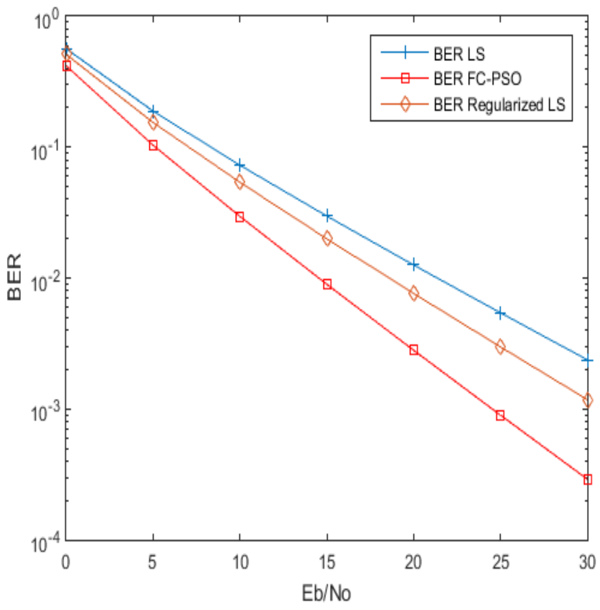

Fig. 5 BER vs Eb/No. for Rician Fading Channel

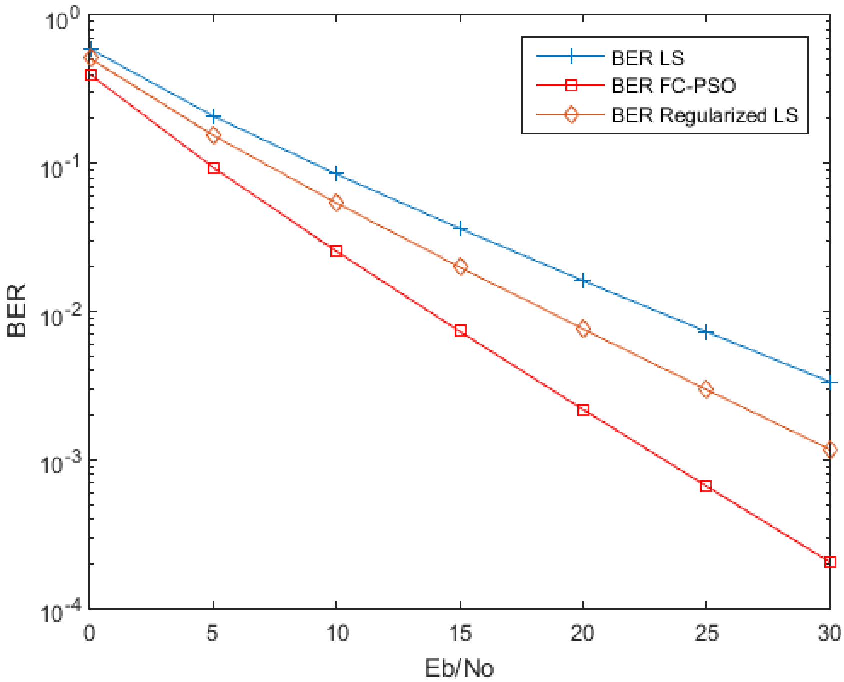

Fig. 6 BER vs Eb/No. for Rayleigh Fading Channel

Table 1 Comparison of Previous and Proposed Algorithm for MSE (Mean Square Error)

CHANNEL	TECHNIQUES USED		
	LS	Adaptive LS	FCPSO
FLAT	1.93e-07	1.7876e-07	1.570e-07
RICIAN	6.619e-11	5.849e-11	5.362e-11
RAYLEIGH	6.498e-08	6.1338e-08	5.264e-08

CONCLUSION

In this work, the various channel estimation techniques for MIMO-OFDM are studied and a new Channel estimation technique based on Fast Converging Particle Swarm Optimization (FCPSO) has been proposed in order to optimize the estimation in Transmit Diversity case in Decision Directed Channel Estimation**.** Channel estimation algorithms have been compared and results show that least square algorithm is the simplest amongst all but has low performance. The adaptively regularized method improves upon the existing LS technique in flat fading and implements a slightly complex method. Also, the regularized method has low performance in Rayleigh and Rician channels. The proposed system in turns has similar complexity as that of the adaptively regularized method but has performed better than both the methods. Hence the proposed method can be considered for practical implementation. Further, a BER comparison of the method is also shown for all the three methods and it can be concluded that the proposed method has performed slightly better in comparison to other methods.

The future work may involve the use of such methods which may further reduce the complexity of the algorithm. As can be observed from the results, the BER for both base and the proposed technique is very low, we can now focus on further reduction of complexity. Such a system may be lesser expensive in terms of hardware implementation. Hence, a system can be developed to further improve over the proposed method.

REFERENCES

[1] Sadek, Mirette, A. Tarighat, and A. H. Sayed, “A leakage-based precoding scheme for downlink multi-user MIMO channels” *Wireless Communications, IEEE Transactions on* 6, no. 5, pp. 1711-1721, 2007.

[2] A. Tarighat, Mirette, Sadek, and A. H. Sayed, “A multi-user beamforming scheme for downlink MIMO channels based on maximizing signal-to-leakage ratios” In *Acoustics, Speech, and Signal Processing, Proceedings.(ICASSP'05). IEEE International Conference on*, vol. 3, pp. 1719-1129, IEEE, 2005.

[3] Spencer, H. Quentin, A. L. Swindlehurst and M. Haardt, “Zero-forcing methods for downlink spatial multiplexing in multiuser MIMO channels” *Signal Processing, IEEE Transactions on* 52, no. 2, pp. 461-471, 2004.

[4] Kaltenberger, Florian, D. Gesbert, R. Knopp, and M. Kountouris, "Correlation and capacity of measured multi-user MIMO channels," In *Personal, Indoor and Mobile Radio Communications, PIMRC. IEEE 19th International Symposium on*, pp. 1-5, IEEE, 2008.

[5] Chen, Jianwu, Y.-C. Wu, S. Ma, and T.-S. Ng, "Joint CFO and channel estimation for multiuser MIMO-OFDM systems with optimal training sequences," *Signal Processing, IEEE Transactions on* 56, no. 8 pp. 4008-4019,2008.

[6] Shin, Changyong, R. W. Heath Jr and E. J. Powers, "Blind channel estimation for MIMO-OFDM systems," *Vehicular Technology, IEEE Transactions on* 56, no. 2 pp. 670-685, 2007.

[7] Tu, Chao-Cheng, and B. Champagne, "Subspace-based blind channel estimation for MIMO-OFDM systems with reduced time averaging," *Vehicular Technology, IEEE Transactions on* 59, no. 3, pp. 1539-1544, 2010.

[8] Minn, Hlaing, and D. Munoz, "Pilot designs for channel estimation of MIMO-OFDM systems with frequency-dependent I/Q imbalances." *Communications, IEEE transactions on* 58, no. 8, pp. 2252-2264, 2010.

[9] Ylioinas, Jari, and M. Juntti, "Iterative joint detection, decoding, and channel estimation in turbo-coded MIMO-OFDM," *Vehicular Technology, IEEE Transactions on* 58, no. 4, pp. 1784-1796, 2009.

[10] Khojastepour, M. A. Amir, K. Gomadam and X. Wang, "Pilot-assisted channel estimation for MIMO-OFDM systems using the theory of sparse signal recovery," In *Acoustics, Speech and Signal Processing, IEEE International Conference on*, pp. 2693-2696. IEEE, 2009.

[11] Carrascosa, P. Ceballos, and M. Stojanovic, "Adaptive channel estimation and data detection for underwater acoustic MIMO-OFDM systems," *Oceanic Engineering, IEEE Journal of* 35, no. 3, pp. 635-646, 2010.

[12] M. Saif, A. Zaki, A. Chockalingam and B. S. Rajan, "High-rate space–time coded large-MIMO systems: Low-complexity detection and channel estimation," *Selected Topics in Signal Processing, IEEE Journal of* 3, no. 6, pp. 958-974, 2009.

[13] Knievel, Christopher, Z. Shi, P. A. Hoeher, and G. Auer, "2D graph-based soft channel estimation for MIMO-OFDM," In*Communications (ICC), IEEE International Conference on*, pp. 1-5, IEEE, 2010.

[14] Dai, Xianhua, H. Zhang, and D. Li, "Linearly time-varying channel estimation for MIMO/OFDM systems using superimposed training," *Communications, IEEE Transactions on* 58, no. 2, pp. 681-693, 2010.

[15] Sarmadi, Nima, S. Shahbazpanahi, and A. B. Gershman, "Blind channel estimation in orthogonally coded MIMO-OFDM systems: A semidefinite relaxation approach," *Signal Processing, IEEE Transactions on*57, no. 6, pp. 2354-2364, 2009.

[16] Venkateswaran, Vijay, and A.-J. Veen, "Analog beamforming in MIMO communications with phase shift networks and online channel estimation," *Signal Processing, IEEE Transactions on* 58, no. 8, pp. 4131-4143, 2010.

[17] Wang, Zhongju, P. Babu and D. P. Palomar, "Design of PAR-Constrained Sequences for MIMO Channel Estimation via Majorization-Minimization," *arXiv preprint arXiv: 1602.08877*, 2016.

[18] Li, Tao, X. Wang, P. Fan and T. Riihone, "Position-aided Large-scale MIMO Channel Estimation for High-Speed Railway Communication Systems," *arXiv preprint arXiv: 1603.07541*, 2016.

AUTHOR(S) PROFILE

Monika received B. Tech. in Electronics & Communication Engineering from Himachal Pradesh University, Shimla in 2013. She is currently an M. Tech Candidate in the department of Electronics & Communication Engineering at the Himachal Pradesh Technical University, Hamirpur. Her current research interest includes a Review on Channel Estimation in MIMO-OFDM Wireless System.

Mr. Mahendra Tyagi obtained his B. Tech. (2012) from Madhav Institute of Technology & Science Gwalior (MP) and M.Tech.(2014) NIT Raipur, India. At present, he is working as an Assistant Professor in the department of Electronics and Communication at LRIET, Solan, and Himachal Pradesh, India.

