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Frequency Offset Estimation for UWB-OFDM System using Weight and Exhaustiveness based Monarch Butterfly Optimization Approach



Abstract: -The performance of an OFDM system has limitation because the carrier frequency offset (CFO) and sampling frequency offset (SFO) is not estimated correctly. Current methods propose the way of obtaining frequency estimation by using the evolutionary algorithm, but the evolution algorithm suffers from the premature convergence problem. In order to provide efficient frequency offset estimation, this paper proposed weight and exhaustiveness based monarch butterfly optimization approach. First, on the transmitter block, for modulating an input symbol, the Hybrid-Quadrature Phase-Shift Keying modulation scheme is used. Brunn's IFFT is done at each transmitter for symbol mapping and then in each transmitter block cyclic prefix is inserted. After that, WE-MBO algorithm estimates the frequency offset. On receiver side, the inverse operation of the transmitter is performed. After comparison of proposed system with the existing system, the proposed system gave better performance.

Keywords: Hybrid-Quadrature Phase-Shift Keying (H-QPSK), Weight and Exhaustiveness based Monarch Butterfly Optimization (WE-MBO).

I. INTRODUCTION

The current trend is to use high-speed wireless personal area networks (WPANs) for the wireless networking for the homes and offices to provide the high-speed applications as well as broadband communications [1, 2]. UWB technology provides high spectrum efficiency, reliability, and remarkable performance under different circumstances [5, 6].

UWB-OFDM technique has attracted more research and has been standardized for the high data rate, [7] where the frequency is divided in to various bands and the transmission carried out in each band with time-frequency code (TFC) in a harmonious manner.

OFDM is used in broadcasting domain for high data rates transmission and it is also adopted in numerous standards such as ultra-wideband and 802.11 WLAN [8]. The inter-symbol interference suffers less from OFDM, so the elimination of ISI is possible by adding zero-suffix. The cyclic delay diversity (CDD) scheme avoids inter-carrier interference and inter-symbol interference. The CDD is one of low-complexity diversity technique for OFDM transmitter.

II. RELATEDWORKS

Yong-An Jung and Young-Hwan [16] demonstrated a joint estimation technique for sampling frequency and carrier frequency offsets in multiple input-multiple output-OFDM. By proper choosing of a pilot subset, the SFO and CFO estimation scheme were improved and a bias is eliminated. When compared to conventional estimation scheme, joint estimation scheme proven as minimum affected by number of frequency offset from the pilot subset.

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BenudharSaho [19] proposed improved residual frequency estimation for OFDM based WLAN systems. The approach entails two steps: estimation of residual frequency error for OFDM symbol and correction. In the estimation system, the variance of the residual and frequency offset estimation error became relatively small.

Zhibin Yang [20] suggested applying frequency offset estimation to OFDM systems using index modulation. To improve the accuracy of carrier frequency offset estimation, specific inactive data tones were used. The finding reveals that the model demonstrated higher precision in CFO prediction.

Chun-chyunchen and meng-linku[21] introduced a OFDM based CFO estimation for single relay networks with multiple channels. The two hops were added together so as to produce a composite parameter for the modeling of the flat fading channels. The first-order Taylor series expansion was utilized for a calculation the inverse of the covariance matrix. The CRB modified, which is MCRB, is the system parameter used for the estimation of the CFO. The operations in CFO estimation error also used the system to calculate the operating signal-to-noise ratio (SNR).

III. PROPOSED FREQUENCY OFFSET ESTIMATION METHODOLOGY

The UWB-OFDM system is enhanced by introducing a frequency offset estimation approach based on both weight and monarch butterfly optimization method. First, on the transmitter block, for modulating an input symbol, the Hybrid-Quadrature Phase-Shift Keying modulation scheme is used. Brunn's IFFT is done at each transmitter for symbol mapping and then in each transmitter block cyclic prefix is inserted. Then transmit the symbols with adding AWGN noise over the Multipath channel. Before adding AWGN noise, the frequency offset is estimated using the Weight and Exhaustiveness based Monarch Butterfly Optimization (WE-MBO) algorithm. Followed by the Brunn's FFT computation, the frequency offset estimation is done at the receiver place. To eliminate the computing power and achieve the fast synchronization, the computation of the FFT will be done in a preliminary stage. Figure 1 illustrates the block diagram detailing the proposed model.

3.1 Transmitter Side (Tx)

3.1.1 Input data

Initially, the input data (packets) are sent to the receiver side and the data have different data rates. The initial data set is expressed as follows,

$$S_s = \{s_1, s_2, s_3, \dots, s_n\} \tag{1}$$

Where, S_s denotes the data set (packets) and s_n represents the n-number of data.

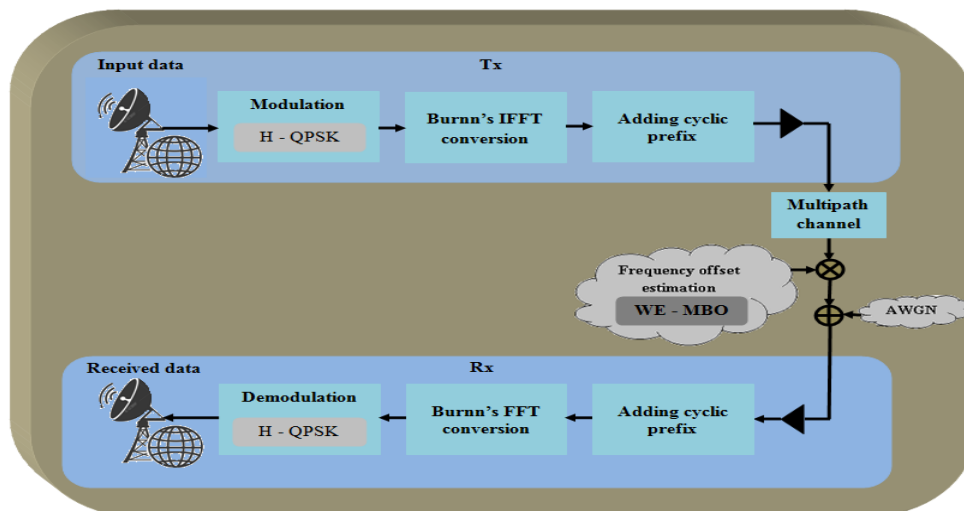


Figure 1 Block Diagram of Proposed Method

3.1.2 Modulation

The input data is modulated using H-QPSK modulation scheme and the output of H-QPSK modulation is given to Brunn’s IFFT converter. Here, the four bits are simultaneously modulated because the data is given to serial-to-parallel converter before modulation. H-QPSK is obtained by combining two sets of QPSK which are generated and orthogonally modulated. The M-QPSK reduces symbol error rate (SER) due to twice the bandwidth efficiency. H-QPSK modulator architecture is shown in Figure 2.

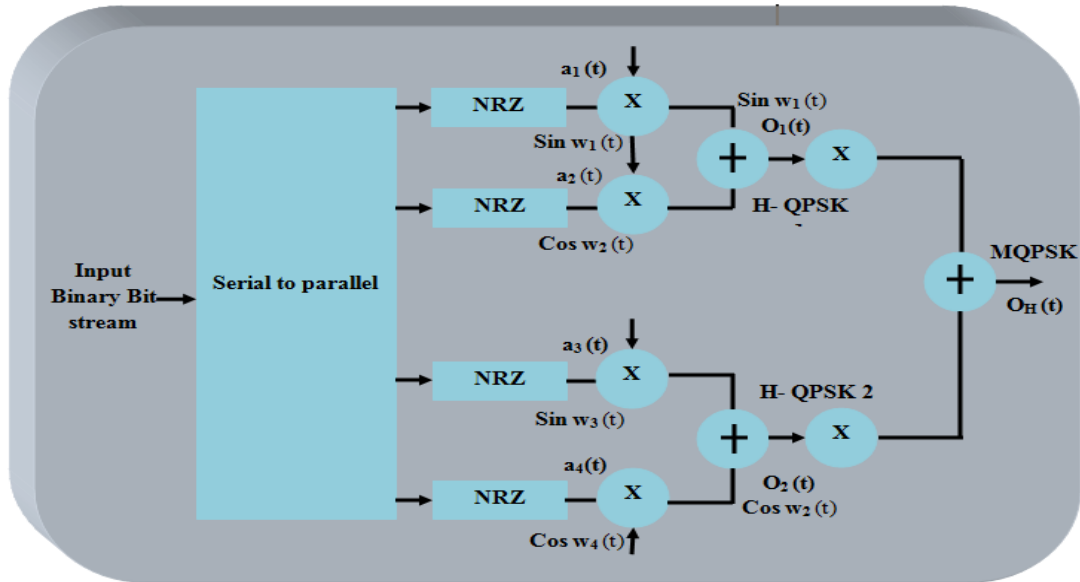


Figure 2 Structure of H-QPSK

Two orthogonally modulated output signals $O_1(t)$ and $O_2(t)$ are the generated out of bit streams $a_1(t), a_2(t), a_3(t)$ and $a_4(t)$. The $O_1(t)$ and $O_2(t)$ are calculated as follows,

$$O_1(t) = a_1(t)\sin w_1(t) + a_2(t)\cos w_2(t)..... \tag{2}$$

$$O_2(t) = a_3(t)\sin w_3(t) + a_4(t)\cos w_4(t)..... \tag{3}$$

H-QPSK modulator output is computed by

$$O_H(t) = O_1(t)\sin w_1(t) + O_2(t)\cos w_2(t)..... \tag{4}$$

Where, $O_H(t)$ denotes the output of the H-QPSK modulation.

3.1.3 Brunn’s IFFT conversion

The modulated symbols are sent to the Brunn’s IFFT block. The Brunn’s algorithm is a FFT algorithm based on the unusual recursive polynomial factorization scheme. Brunn's algorithm describes the algorithmic framework which can express both itself and the CooleyTukey algorithm, and permits mixtures of two algorithms. The Brunn’s algorithm is obtained from Discrete Fourier Transform is as follows:

$$X_k = \sum_{n=0}^{N-1} (O_H(t))_n e^{-\frac{2\pi^2}{N}nk}, k = 0, \dots, N-1 \tag{5}$$

Where, X_k denotes the direct computation. For convenience, N roots of unity are denoted as,

$$W_N^n \quad (n = 0, \dots, N - 1) \tag{6}$$

$$W_N^n = e^{\frac{-2\pi^2}{N}n} \tag{7}$$

Where, W_N^n represents the twiddle factor, the polynomial $y(z)$ with coefficients y_n is defined as,

$$y(z) = \sum_{n=0}^{N-1} y_n z^n \tag{8}$$

Where, z^n signifies the polynomial factor. By reduction of this polynomial, the DFT can be understood

that is X_k which is given by,

$$X_k = (w_N^k) = y(z) \bmod (z - W_N^k) \tag{9}$$

Here mod refers the polynomial remainder operator.

3.1.4 Adding cyclic prefix

After conversion, cyclic prefix is added as follows to avoid ISI and ICI.

$$D = C_p + X_k \tag{10}$$

Where, D denotes the symbols with cyclic prefix

C_p represents the cyclic prefix.

3.2 Frequency Offset Estimation

The data with cyclic prefix is sent to the receiver through multichannel. AWGN noise is also added in multichannel. Before adding the AWGN noise, WE-MBO algorithm is used by selecting a subband with maximum power and cyclic delay in the UWB-OFDM system. For initial population maximum channel power and cyclic delay are taken as fitness. From the Brunn's equation, channel transfer function power is defined as follows,

$$|X_k|^2 = \left| \sum_{n=0}^{N-1} (O_H(t))_n e^{\frac{2\pi^2}{N}nk} \right| \cdot \left| \sum_{n=0}^{N-1} (O_H(t))_n e^{\frac{2\pi^2}{N}nk} \right| \tag{11}$$

The cyclic delay period is,

$$J_H = \frac{K}{M_\Delta} \tag{12}$$

Where, J_H - should be an integer value,

K - number of fast Fourier transform

M_{Δ} - minimum cyclic delay.

M_{Δ} relates the following condition,

$$\frac{M_f}{J_H} = \frac{M_f M_{\Delta}}{K} = 1 \tag{13}$$

Where, M_f denotes the integer, which is the multiple of periodicity. Frequency band estimation is obtained by,

$$c(\hat{b}) = \arg \min_{c(b)} \left\{ \sum_{i=1}^{K_p} |X_{b(i)}(Z_i)|^2 \right\} \tag{14}$$

Where, $X_{b(i)}$ - frequency bands of input symbol

Z_i - pilot symbols.

The existing evolutionary algorithm based offset estimation encompasses premature convergence problems. To overcome this problem, the proposed methodology considers the Monarch Butterfly Optimization (MBO) algorithm. To give more proper results, the proposed work uses WE-MBO algorithm. The working of MMBO is explained below.

MMBO resembles the migration behavior of the monarch butterfly when the seasons change. First, the population is initialized based on exhaustiveness value which means an additional control parameter that is expressed as follows,

$$u_{i,j} = \psi \cdot (ae_j - be_j) + be_j \tag{15}$$

Where, $u_{i,j}$ denotes the total population, ae_j and be_j denote the lower and upper bounds of parameter j and ψ is the pseudo-random range in the initialization phase. Let the initial populations as OFDM symbols and subcarriers. In MBO according to fitness, population is divided in to sub population1 and sub population2 of size $u_{i,j}$, $u_{(i,j)_1} (\Phi \times u_{i,j})$ and $u_{(i,j)_2} (u_{i,j} - u_{(i,j)_1})$ respectively. Here, Φ is the proportion of subpopulation1 in the entire population and $u_{i,j}$ specifies the total number of the population.

(i) Migration Operator

The position of the subpopulation1 and subpopulation2 is determined by individuals inside the subpopulation. The position of individual k from generation τ to $\tau + 1$ is formulated by Eq.

$$\delta_{q,v}^{\tau+1} = \lambda \cdot \delta_{r1,v}^{\tau} \tag{16}$$

Where, $\delta_{q,v}^{\tau+1}$ indicates the v^{th} element of δ_q at generation $\tau + 1$ which represents the position of the monarch butterfly q and λ represents the weighting parameter which is not considered in the general MBO algorithm. But the proposed methodology considers this weighting parameter for speed convergence. Similarly, $\delta_{r1,v}^{\tau}$ indicates the v^{th} element of δ_{r1} that is the newly generated position of the monarch butterfly $r1$. τ Signifies the current generation number. The monarch butterfly $r1$ is randomly selected from Subpopulation 1. When

$r \leq \Phi$, the element v in the newly generated monarch butterfly is generated by eq. (16). Here, r can be calculated as,

$$r = rand * p_d \tag{17}$$

Here, p_d means the migration period

$rand$ denotes the random number drawn from uniform distribution. When $r > \Phi$, the element w in the newly generated monarch butterfly is generated by,

$$\delta_{q,v}^{\tau+1} = \lambda \cdot \delta_{r2,v}^{\tau} \tag{18}$$

Where, $\delta_{r1,v}^{\tau}$ represents the v^{th} element of δ_{r2} that is the newly generated position of the monarch butterfly $r2$. The monarch butterfly $r2$ is randomly selected from Sub population 2.

(ii) Butterfly Adjusting Operator

The movement of an individual q from generation τ to $\tau + 1$ can be expressed as follows:

$$\delta_{q,v}^{\tau+1} \leftarrow \begin{cases} \lambda \cdot \delta_{best,v}^{\tau} & \text{if } rand \leq \rho \\ \lambda \cdot \delta_{r3,v}^{\tau} & \text{if } rand > \rho \wedge rand \leq BAR \\ \lambda \cdot \delta_{k,v}^{\tau} + \eta \times (dz_w - 0.5) & \text{if } rand > \rho \wedge rand > BAR \end{cases} \tag{19}$$

BAR is a control parameter that decides the butterfly adjusting rate (BAR) and dz can be obtained by using Levy flight which is expressed in eq. (20). The parameter η is the weighting factor that is denoted in eq. (21),

$$dz = Levy(\delta_q^{\tau}) \tag{20}$$

$$\eta = a_{max} / \tau^2 \tag{21}$$

Where, a_{max} denotes the maximum walk step. Figure 3 shows the WE-MBO Pseudo code.

Input: minimum cyclic delay and maximum channel power
Output: CFO and SFO estimation

Begin
Initialize the population such as OFDM symbols and sub-carriers using equation (15), maximum generation Max_{gen} , p_d , Φ , BAR , a_{max} and Generation G
Evaluate fitness function
While ($G \leq Max_{gen}$)
 Sort the population (sub-carriers) in non-ascending order according to their fitness.
 Generate an offspring solution of subpopulation1 using,
 $\delta_{q,v}^{\tau+1} = \psi \cdot \delta_{r1,v}^{\tau}$ And $\delta_{q,v}^{\tau+1} = \delta_{r2,v}^{\tau}$
 Generate an offspring solution of subpopulation2 as eq. (19).
 Recombine the newly-generated subpopulations into one population.
 Find the current best individual.
 Set $G = G + 1$
End while
Find the global best individual
End

Figure 3 WE-MBO Pseudo code

3.3 AWGN Noise

AWGN is a noise model used in communication to represent the effect of random processes. AWGN is added to channel after the frequency offset estimation.

An AWGN channel is expressed as the following

$$Y(n) = T(n)X(n) + J(n) \tag{22}$$

Where

$X(n)$ _ transmitted signal at time n

$Y(n)$ _ received signal at time n .

$T(n)$ - time-varying channel gain, and

$J(n)$ - Gaussian noise at time n , assumed to be independent and identically distributed with variance σ^2 .

3.4 Receiver side (Rx)

The above operations are performed at the transmitter side. At the receiving side, reverse operations are carried out. First the inserted GI is removed, then GI removed data is converted into FFT, thirdly the data is demodulated using H-QPSK. Finally the data is received at the receiver.

IV. RESULTS AND DISCUSSION

For different data rates, the proposed algorithm is implemented in MATLAB to various channel models and analyzed the performance with existing methods. Parameter values for simulation are shown in table 1.

Table 1 Parameters values for simulation

Parameters	Values
Number of Sub-Bands	3
Bandwidth	528 MHz
data sub carriers	120
pilot sub carriers	16
FFT sample points	132
zeroes prefix samples	40
Normalized frequency offset	40 ppm

Table 2 Data rate of channel model

Channel model	Transmission Data Rate
CM1	480 Mbps
CM2	200 Mbps
CM3	106.7 Mbps
CM4	53.3 Mbps

Table 2 shows the transmission data rate of channel model for the OFDM system. The proposed method takes four-channel models which have different transmission data rate. The channel model 1 has a transmission data rate of 480 Mbps. The channel model 2 has a transmission data rate of 200 Mbps. The channel model 3 has the transmission data rate of 106.7 Mbps, and channel model 4 has the transmission data rate of 53.3 Mbps.

4.1 Performance Analysis

The performance analysis of proposed system using WE-MBO is compared with the existing techniques namely Maximum likelihood estimator, particle swarm optimization (PSO) and improved artificial bee colony (IABC). The parameters BER, MSE, SNR and NMSE are considered for performance analysis.

(a) BER

BER is measured from the following equation.

$$BER = \frac{1}{2} \operatorname{erfc} \left(\sqrt{\frac{X_{eb}}{Y_{ns}}} \right) \tag{23}$$

Where X_{eb} - energy per bit, Y_{ns} - noise power spectral density ratio.

(b) SNR

SNR is measured in decibels.

$$SNR = \frac{X_{eb}}{Y_{ns}} \tag{24}$$

(c) MSE

MSE is expressed as

$$MSE = E \left[\left(X'_{eo} - X_{rs} \right)^2 \right] \tag{25}$$

Where, E - the error which is difference between expected output X'_{eo} and received symbol X_{rs} .

(d) NMSE

NMSE is expressed as

$$NMSE = \frac{1}{N} \sum \left(\frac{X'_{pv} - Y'_{mv}}{\bar{X}_p \bar{Y}_m} \right)^2 \tag{26}$$

Where,

$$\bar{X}_p = \frac{1}{N} \sum X'_{pv} \tag{27}$$

$$\bar{Y}_m = \frac{1}{N} \sum Y'_{mv} \tag{28}$$

Where X'_{pv} represents the predicted values and Y'_{mv} denotes the measured values of an estimator

and \bar{X}_p and \bar{Y}_m indicates the mean over the sampling points.

The proposed system takes four-channel model values for performance analysis.

Table 3 Performance analysis of four channel models based on SNR

SNR	Channel Model-1	Channel Model-2	Channel Model-3	Channel Model-4
10	0.06	0.082	0.071	0.09
12	0.057	0.078	0.064	0.084
14	0.05	0.07	0.06	0.08
16	0.046	0.067	0.053	0.076
18	0.04	0.06	0.05	0.07
20	0.034	0.057	0.042	0.065
22	0.03	0.051	0.04	0.06
24	0.023	0.048	0.33	0.055
26	0.02	0.04	0.03	0.05
28	0.016	0.037	0.023	0.046
30	0.01	0.031	0.02	0.04

The table 3 shows the performance analysis of the bit error rate for four-channel models based on SNR. Channel model-1 has a less BER of 0.06 % for SNR 10 dB and also channel model-1 has low BER of 0.01% for SNR 30 dB.

Table 4 Performance analysis of NMSE for proposed method based on SNR

SNR	Proposed WE-MBO	Maximum likelihood estimator	PSO	IABC
4	0.3	0.73	0.69	0.45
4.5	0.39	0.69	0.61	0.39
5	0.26	0.6	0.58	0.3
5.5	0.24	0.41	0.38	0.24
6	0.15	0.35	0.29	0.15
6.5	0.01	0.3	0.21	0.08
7	0	0.23	0.19	0
7.5	0	0.16	0.02	0
8	0	0.09	0	0

The table 4 shows the performance analysis of NMSE based on the SNR. The proposed method achieves less NMSE that is 0.3 % for SNR 4 dB and also the method achieves 0 % NMSE for higher SNR 8 dB. But the existing approaches namely maximum likelihood estimator, PSO, and IABC have the NMSE of 0.73 %, 0.69 %, and 0.45 %. From this, the proposed WE-MBO is better than existing methods for various SNR values.

4.2 Comparative Analysis

The performance is analyzed based on BER, SNR, MSE, NMSE. Firstly, the four-channel models of bit error rate are compared with the existing method based on SNR values. This is diagrammatically represented in Figure 4.

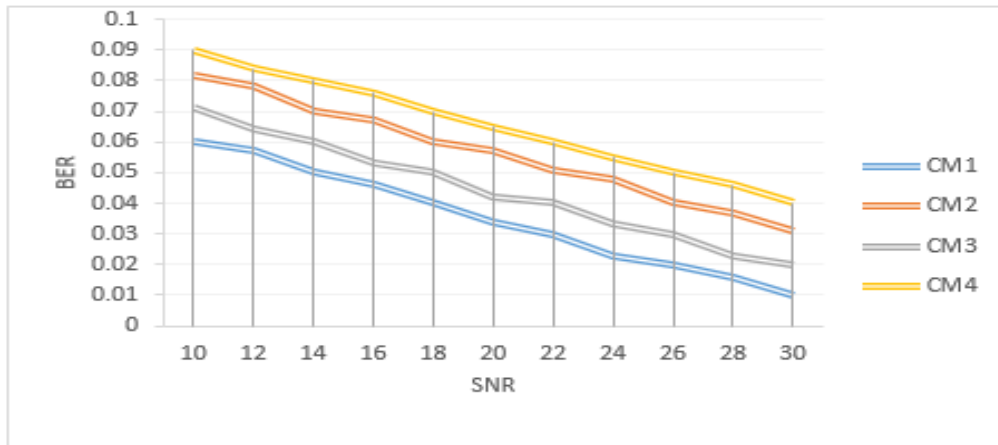


Figure 4 Comparative analysis of four-channel model BER based on SNR values.

Figure 4 shows the comparative analysis of the bit error rate of four-channel models based on various SNR values. The existing methods have a high bit error rate than the proposed approaches. As a result, it summarizes that the performance capability of proposed method is better than the existing methods.

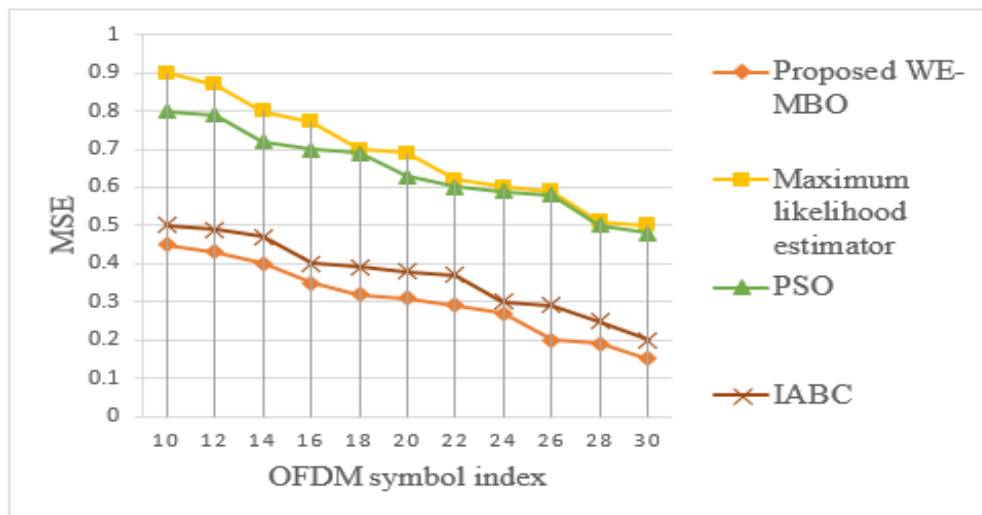


Figure 5 Comparison of MSE of proposed WE-MBO method based on symbol index for channel model-1

The MSE of our proposed WE-MBO is illustrated in Figure 5 where we compare it with the well-known MLE, PSO and IABC methods. In channel model-1, the proposed WE-MBO achieves less MSE of 0.45 % for symbol index 10. But the existing approaches like maximum likelihood estimator, PSO, and IABC have 0.9 %, 0.8 %, and 0.5 %. Then, for various OFDM symbol indexes from 10 to 30, the maximum likelihood estimator has MSE of 0.5 % but the proposed method achieves less MSE of 0.15 % for symbol index of 30.

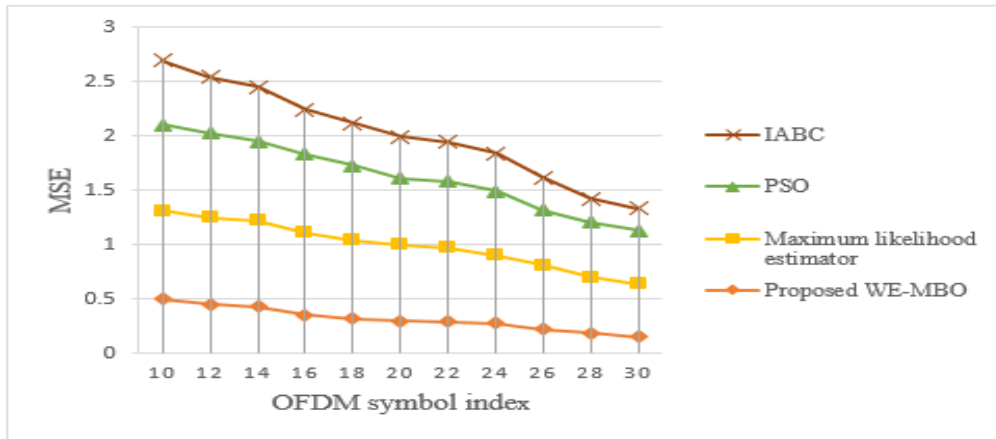


Figure 6: Comparison of MSE of proposed WE-MBO method based on symbol index for channel model-2

Figure 6 illustrates MSE of the proposed WE-MBO that is compared with the existing approaches using the channel model-2 symbol index. The MSE of proposed method is 0.5 % for symbol index 10. But the existing methods namely maximum likelihood estimator, PSO, and IABC have the MSE of 0.81 % 0.79 % and 0.59 %. Then, for various OFDM symbol index from 10 to 30, the existing method maximum likelihood estimator and PSO have the same MSE that is 0.49 %. But the proposed method achieves less MSE of 0.15 for symbol index of 30.

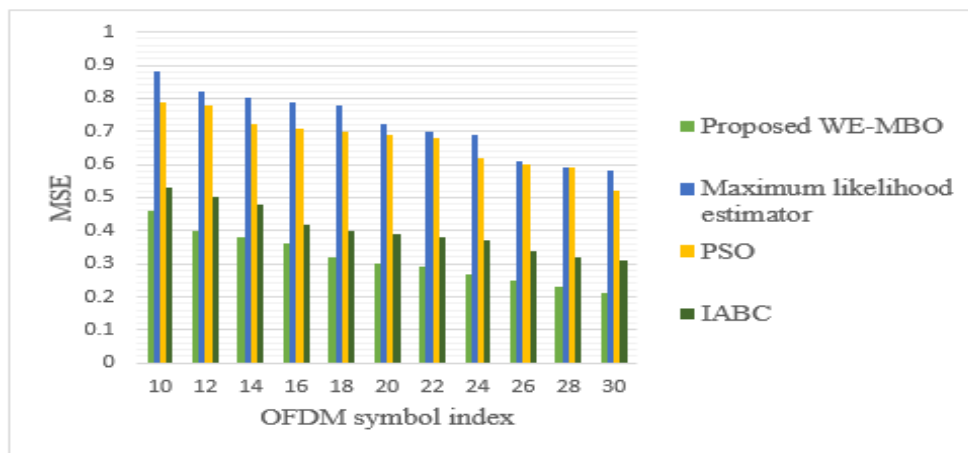


Figure 7: Comparison analysis of MSE of the proposed WE-MBO method based on the symbol index for channel model-3

The figure 7 illustrates the MSE comparison of the proposed WE-MBO method based on symbol index and the existing techniques. In channel model-4, the proposed method achieves less MSE of 0.46 % for symbol index 10. But the existing approaches namely maximum likelihood estimator, PSO, and IABC have MSE of 0.88 %, 0.79 %, and 0.53 %. Then, for various OFDM symbol index values from 10 to 30, the existing approaches have higher MSE than the existing methodologies.

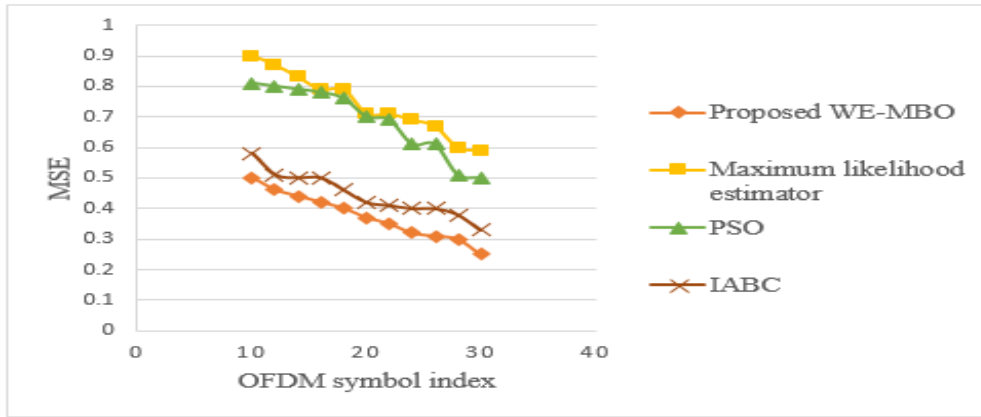


Figure 8: Comparison analysis of MSE of the proposed WE-MBO method based on the symbol index for channel model-4

The figure 8 shows the MSE comparative analysis of the proposed WE-MBO method based on the symbol index for channel model-4. In channel model-4, the proposed method achieves less MSE of 0.5 % for symbol index 10. But the existing approaches such as maximum likelihood estimator, PSO, and IABC have MSE of 0.9 %, 0.81 %, and 0.58 % respectively for OFDM symbol index 10. Typically, for various OFDM symbol index values from 10 to 30, the WE-MBO technique offers better performance than the existing methods.

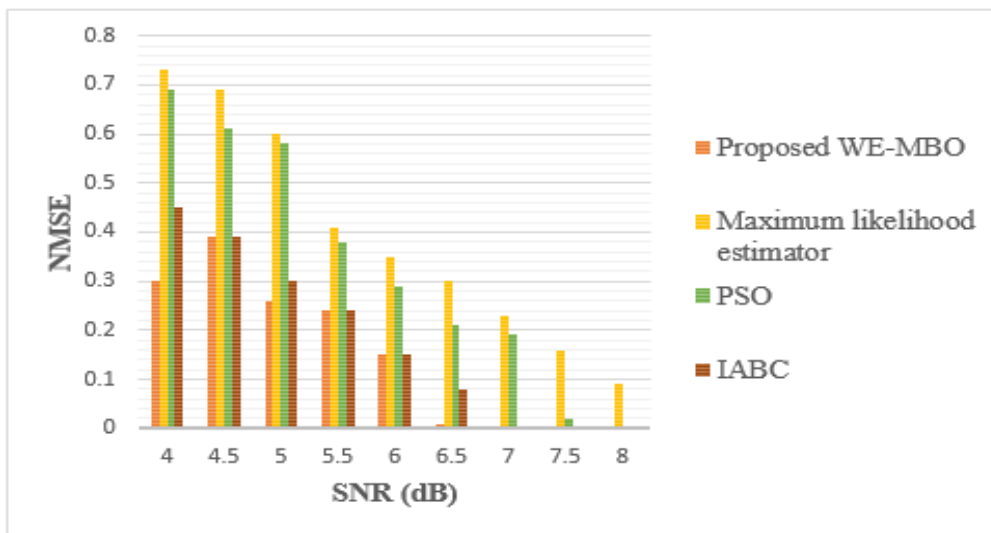


Figure 9: Comparison of NMSE of the proposed WE-MBO method based on various SNR values for channel model-4

Figure 9 shows the comparison of NMSE of the proposed system based on SNR with existing methods. In channel model-4, the exiting IABC method has an NMSE of 0.45 % for SNR 4. But the proposed method achieves less NMSE that is 0.3 % for SNR 4. Then, for various SNR values from 4 to 8, the proposed WE-MBO method has less MSE than existing methods. Consequently, it makes the statement that the WE-MBO method provides an improved performance than other systems.

V. CONCLUSION

The OFDM is one of the most important techniques which are widely used in the transmission of data through wireless networks. The selection of the sampling frequency and carrier frequency fall deviation is among the most important technology in the OFDM system. The suggested method utilizes the WE-MBO algorithm for SFO and CFO estimation with cyclic delay diversity and the maximum channel power. The performance is analyzed based on data packets with four channel models. The proposed system’s performance is compared with existing PSO, maximum likelihood estimator, IABC algorithms based on MSE and NMSE. For channel model-4, the WE-MBO

has 0.3 NMSE at SNR 4 dB but the existing system has higher NMSE. Similarly, for the entire channel model, the proposed system has the lowest MSE. To conclude, WE-MBO approach shows improved performance compared to the other research methods.

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