Engineering and Technology Journal
Journal homepage: https://etj.uotechnology.edu.iq

A Proposed Channel Estimation Based on Enhanced Sub-carrier Index Modulation and Packet-Discrete Wavelet Transform to Minimize Bit Error Rate

Ansam S. Jabbar*

Electrical Engineering Department., University of Technology-Iraq, Alsina'a street, 10066 Baghdad, Iraq.
*Corresponding author Email: 30173@uotechnology.edu.iq

HIGHLIGHTS

- Complexity Reduction based on a Packet-Discrete Wavelet Transform (P-DWT) for channel estimation in wireless OFDM instead of the fast Fourier transform (FFT).
- Cost reduction of DWT by recognizing the Packet Wavelet Transform (PWT) coefficients and local points.
- Enhancement the estimation accuracy, while computing cost is reduced.

ARTICLE INFO

Handling editor: Ivan A. Hashim
Keywords:
OFDM
Channel estimation
LMS
MMSE
PSO
Packet wavelet

ABSTRACT

For Orthogonal Frequency Division Multiplexing (OFDM) and other communication systems, many estimating approaches have been developed to estimate the channel state information and lower the Bit Error Rate (BER). These estimating methods, however, are still subject to the influence of large peak powers compared to average powers. Reduced computational complexity is one of the most significant factors to consider while developing a new estimate algorithm. This study aims to provide a novel design of the Packet-Discrete Wavelet Transform (P-DWT) algorithm for channel estimation in wireless OFDM instead of the fast Fourier transform (FFT). It is presented to retrieve the code of a spread spectrum signal and transmitted data bits, and it is compared to particle swarm optimization PSO and least mean square (LMS) optimization. The suggested approach reduces the computing cost of DWT by recognizing the Packet Wavelet Transform (PWT) coefficients and local points, findings utilizing P-DWT channels generated from both models and measurements show that the proposed technique outperforms pilot-based channel estimation in terms of bit error rate under sparseness conditions BER. Moreover, as compared to typical semi-blind approaches, the estimation accuracy is enhanced while computing cost is reduced.

1. Introduction

Because OFDM is one of the strong multiplexing techniques wireless technologies of the future, it has recently been adopted as a modulation scheme to address the increasing demand for high data rate transmission in wireless communications. As a result, channel estimation becomes an important aspect of communication systems in order to reach the communicated information with high precision, and telecommunication researchers and engineers are paying close attention to this area [1]. As a result, effective channel estimates and verification are critical for accurate acquisition in an OFDM system. Blind and training-based channel estimates are the two types of channel estimation for OFDM systems. A known-to-the-receiver value pilot sequence is included in the signal block and broadcast over the channel by used in training-based estimation. The signal received and the known sequence training are used to compute the channel at the receiver. High accuracy and relative simplicity are two advantages of training-based estimates [2]. The training sequence was not transmitted efficiently, and the mean square error was high, a training-based estimate has a reduced bandwidth efficiency. Blind estimate, on the other hand, requires no training and channel estimated entirely based on the received signal. To calculate a channel estimate, statistical features of the received signal and channel structure are used [3].

According to the review, numerous strategies for channel estimate have been used, the majority of them are based on the processing of real-world system behavior [4]. The filter was used in [5] for both channel estimation and symbol detection. [6] also offered a per-survivor strategy that used a bank of Kalman filters for channel estimation. The ideal training sequence for the linear channel estimator that minimizes the channel estimation MMSE is demonstrated to be of length per transmit antenna in [7]. Methods for blind/semi-blind channel estimation can be studied however, they require large data samples and have a high

http://doi.org/10.30684/etj.v39i10.2206
Received 02 June 2021; Accepted 31 July 2021; Available online 25 October 2021

level of complexity [8]. Furthermore, modifications to the PSO approach have been developed in order to reach the most optimal solution, including Single Solution, Constraint Optimization, and PSO Dynamic Environment [9]. To change continuous functions, [10] presented a mix of Artificial Bee Colony and PSO algorithms. [11] presented function optimization for niching and without niching parameters utilizing a ring topology of PSO. However, several hurdles must be overcome in order to enhance accuracy and reduce execution time, particularly in large nonlinear systems. Others, according to the reviews. To increase the Bit error rate (BER), [12] proposed using a feed-forward multilayered perceptron (MLP) neural network nonlinear autoregressive for OFDM channel prediction. In the meantime, [13] proposed the creation of a two-layer neural network model to predict the channel in a MIMO-OFDM system. Another strategy, suggested in [14], uses fuzzy modeling to provide an accurate model for OFDM channel estimates. Then, in [15], a novel technique of online estimate is created that employs an artificial intelligence approach to channel estimation, i.e., a mix of fuzzy and genetic algorithm (GA) that is employed as an inference system.

Aside from that, [16] proposes the usage of the PSO method, which employs a sub-model combination approach to fit the sample data optimally. Each of these strategies, however, has its own set of restrictions. The memberships and rules for fuzzy modeling methods, for example, should be carefully chosen. The starting weights, number of hidden layers, and number of cells in each layer should all be considered when building a neural network, especially in big systems. The genetic algorithm, on the other hand, suffers from sluggish convergence and "pre-maturation" in some cases [17]. While PSO has the potential to search in complicated space, the presence of more than one local point may limit the accuracy, particularly in nonlinear systems. There are also some recent developments for wavelet-based OFDM systems discussed in [18]. The reference [19] compares the BER performance of a multi-wavelet-based OFDM system to DFT and Haar-wavelet based on OFDM systems. The proposed and compare the performance of BER for wavelet-based OFDM systems based on Haar, Daubechies, symlets, and coiflets with Doppler shifts of 0.005 and 0.05 Hz [20]. Similarly, that compare [21] investigated the BER of Daubechies wavelet and Alamouti-coded by DFT with OFDM systems at 8, 3, and 2 fading path channels. There has been Comb Pilot-Based MMSE channel estimation, as discussed in reference [22]. The author of [23] discusses the various approaches of channel estimate with the Single-Layer Traveling-Wave.

This work proposes a new method based on the P-DWT algorithm to solve the drawbacks of model estimate approaches for OFDM systems. The range segmentation methodology is always capable of achieving the best initial operating parameter due to its fast convergence. Other stochastic approaches, such as the DWT and P-DWT algorithms, can yield simple and efficient solutions in a faster calculation time and with a steadier convergence characteristic than the P-DWT methodology.

2. Channel Estimation OFDM System

The OFDM technique divides the available spectrum into orthogonal narrowband and a number of overlapping sub-channels, which sends its own data using a sub-carrier. Meanwhile, Figure 1 depicts the block diagram of OFDM system, which was converted from a serial bit stream to a parallel bit stream and mapped according to modulation in a 64-QAM constellation mapper symbol. The OFDM converts a frequency selective channel into a non-frequency selective channel by dividing the available spectrum into a number of overlapping on the other hand orthogonal narrowband sub-channels [24]. Furthermore, ISI is prevented using employing CP that is accomplished thru lengthening an OFDM symbol's tail or head [25]. Because of these major advantages, data is modulated onto orthogonal frequency carriers in OFDM-based systems. These sub-channels frequency responses must be estimated and subtracted from the frequency samples in order to identify the sent data in a coherent manner. Pilot data based on the system model, which is well known to the receiver, is utilized to estimate the channel. In single-carrier communication systems, channel estimate has a long and illustrious antiquity. Many of the single-carrier channel estimating techniques may be used for multi-carrier systems. The unique qualities of multi-carrier transmission, on the other hand, open up fresh possibilities for developing novel techniques to multi-carrier system channel estimate. Figure 1 displays a characteristic OFDM system block diagram with pilot symbols. The binary data is aggregated and 16QAM mapped. After the pilot symbols are introduced, the complex data is modulated on N parallel subcarriers using IDFT. The symbols of the OFDM that produce are [25]:

$$x(n) = IDFT\{X(k)\} = \sum_{k=0}^{N-1} X(k) e^{j\left(\frac{2\pi kn}{N}\right)}, \quad n = 1, 2, \dots \dots N-1 \tag{1}$$

The guard interval is added after the IDFT block to prevent inter-symbol interference. The cyclic prefix is included in the guard interval, and the resultant OFDM symbols are

$$\tilde{x}(n) = \begin{cases} x(N_g + n) & n = -N_g,\ -(1 - N_g), \dots \dots \dots \quad -1 \\ x(n) & n = \ 0,\ 1, \dots \dots \dots \dots \dots \dots \dots \dots \quad N-1 \end{cases} \tag{2}$$

The number of samples in the guard interval is N_g. The signal is then routed to a frequency-selective time-varying fading channel. The signal that is received is provided by

$$\tilde{y}(n) = [y(n) \otimes h(n)] + W(n) \tag{3}$$

where is $W(n)$ Additive White Gaussian Noise ($AWGN$) and $h(n)$ is the impulse response of a channel, the channel response is as:

$$H(k) = DFT\{h(n)\} = \frac{1}{N} \sum_{n=0}^{N-1} h_i\, e^{j\left(\frac{2\pi kn}{N}\right)} \delta(\lambda - \tau_i), k = 0,1, \dots. \quad \dots., N-1 \tag{4}$$

The total number of paths for propagation is N, and h_i is the amplitude impulse response of the ith path which is Gaussian, T is the sample period, is the ith path delay regularized by the sampling time, and $\delta(t)$ is the delta function, and is the ith path delay normalized by the sampling time. f_{Di} is the ith path Doppler frequency shift, λ is the delay extent index. After removing the guard interval from $y_g(n)$, a DFT on the resultant sequence is performed at the receiver as $y(n)$:

$$Y(k) = DFT\{y(n)\} = \frac{1}{N}\sum_{n=0}^{N-1} y(n)\, e^{j\left(\frac{2\pi kn}{N}\right)},\ k = 0,1,\ldots.\quad \ldots.,N-1 \tag{5}$$

After that, in the channel estimation block, the pilot symbols are recovered and the channel transfer function is $H\ (k)$ estimated. The transmitted signal can be approximated using the following formula:

$$\tilde{r}(k) = \frac{x(k)}{H_{p-wt}(k)} \tag{6}$$

Where $H_{p\text{-}wt}(k)$ is a P-DWT estimate of $H\ (k)$. The binary information data are retrieved at the receiver output after signal demapping.

3. Wavelet and Packet- Wavelet Transform

The underlying premise of FFT is to decompose the conversion of length N sequence into lesser discrete Fourier transforms DFTs of the odd and even sections. Wavelet packet decomposition replaces the odd-even parting in the wavelet scheme. The WT is based on the Fourier transform. Functions for WT are spatially localized, but Fourier cosine and sine, there are no functions. WT analysis is the process of breaking a signal addicted to scaled and shifted replicas of a certain wavelet. Perfect reconstruction is a significant property analysis of wavelet, which allows us to precisely rebuild the transmitted signal at the receiver [26] gives the DWT of $L(n)$.

$$\mathrm{L(m,k)} = \sum_{\mathrm{k=0}}^{\mathrm{n}} \mathrm{l(n)}\ \Psi(2^{\mathrm{m}}\mathrm{n}-\mathrm{k})2^{\mathrm{m}/2} \tag{7}$$

And the IDWT of equation 8 is

$$\mathrm{l(n)} = \sum_{\mathrm{m}=-\infty}^{\infty}\sum_{\mathrm{k}=-\infty}^{\infty} \mathrm{L(m,k)}\ \Psi(2^{\mathrm{m}}\mathrm{n}-\mathrm{k})2^{\mathrm{m}/2} \tag{8}$$

Where $\Psi(m,k)$ is the mother WT function, m is scale translation. The WT is a signal filtering technique that combines high pass filtering (HPF) and low pass filtering (LPF). The HPF generates detailed information at each level, though the LPF related to the scaling function generates stiff guesstimate information. The decimation process and filtering are repeated until the desired output level is achieved. The number of levels is determined by the length of the signal. Synthesizing into wavelet coefficients is the term for signal processing using the inverse wavelet transform, while analyzing starting the coefficients of wavelet is the term for the converse operation. The estimated at each level are up sampled by two, and then processed through HPF and LPF synthesis before being additional, because reconstruction is the inverse of decomposition. This method has the same number of levels as the decomposition procedure in order to obtain the original signal. In DWT decomposition, the path of decomposition is always towards LPF branches, i.e., the 2-channel filter bank iteration sequence is always low pass filters. The low frequencies portion of the decomposition contains fewer coefficients at the end, resulting in a narrow bandwidth. Because the high frequencies section has a larger number of coefficients, it has a wider bandwidth. PWT on the other hand, decomposes the iteration of a two-channel filter bank on both sides, which is to say on the HPF and LPF branches. The PWT has an evenly spaced frequency resolution and a like bandwidth size. The filter bank structure is expanded into a complete binary tree in PWT. The level that corresponds to the depth of a node in the tree structure is specified by l, and p the position at the current node is indicated by $\gamma_{\mathrm{l}}^{\mathrm{p}}$. The PWT divides each parent node into two orthogonal subspaces, $\mathrm{W}_{\mathrm{l}}^{\mathrm{p}}$, It is given as and is situated at the following recursive level [27];

$$\mathrm{W}_{\mathrm{l}}^{\mathrm{p}} = \mathrm{W}_{\mathrm{l}}^{\mathrm{p}/2} \oplus \mathrm{W}_{\mathrm{l}}^{\mathrm{p}/2} \tag{9}$$

Where, $\mathrm{W}_{\mathrm{l}}^{\mathrm{p}/2}$ as the following equation

$$\mathrm{W}_{\mathrm{l}}^{\frac{\mathrm{p}}{2}}(\mathrm{t}) = \{\mathrm{Span}\ \mathrm{P}^{\frac{\mathrm{l}}{2}}\ \left((2^{\mathrm{l}})\mathrm{t}-\beta\right)\}' \tag{10}$$

The scaling PWT coefficients are denoted as $\gamma_{\mathrm{l}}^{2\mathrm{p}}$ and PWT wavelet coefficients are labeled as $\gamma_{\mathrm{l}}^{2\mathrm{p}+1}$, as shown in the expressions below [28],

$$\gamma_{\mathrm{l}}^{\mathrm{p}}(\beta) = \sum_{\mathrm{m}} \mathrm{h}(\mathrm{m}-2\beta)\ \gamma_{\mathrm{l}}^{\mathrm{p}/2}(\mathrm{m}) \tag{11}$$

The 2-channel filter bank's number of iterations increases exponentially as the level's number increases in PWT. As a result, PWT has a higher computational complexity than DWT. PWT overcomes this constraint by analyzing the detailed information of the signal in the high-frequency range. Each sub-band covers one-sixteenth of the signal frequency spectrum, resulting in a total of 16 sub-bands with a four-level PWT. PWT is an appealing method for detecting and classifying high-frequency transients due to its improved signal decomposition capacity [28].

4. Proposed P-DWT Method

Based on the pilot channel estimate, the OFDM system was developed as shows in Figure 1. In the 64-QAM modulator, the input binary data is first grouped and planned according to the modulation. Data is sent to an Inverse Discrete WT after pilots are injected into all sub-carriers for a predetermined period (IDWT). It converts the signal $X(k)$ from the frequency domain to the time domain signal $x(n)$, as well as providing orthogonality to sub-carriers. The proposed method divides the DWT group into a number of elements searching groups, which can be thought of as parts. Each part is an evolutionary process for reaching the global point, particularly when there are multiple local points, as shown in Figure 2. In order to achieve the best initial operating particles, the range segmentation algorithm is always given a faster convergence. The main objectives of this study were to characterize the turbulent atmospheric channel's behavior and to eliminate turbulence-induced signal loss. The signal variation was found linked to climatic factors like temperature and wind speed to carry out the research experimentally. Using the fractional spline wavelet transform approach, we can calculate pressure and humidity. By investigating signal losses at high and low frequency. Methods to reduce perturbation-induced degradation of the received signal were investigated using a WT fractional slice. The local optimal points for each coefficient are shown in Figure 2, with point 3 being the optimum local point. To obtain the optimal coefficient, the best individual location of the particle and the best position of the entire wavelet must be adjusted, and equations 11 and 12 can be updated as follows:

$$W_l^p(t+1) = W_l^p(t) + \beta\left(\gamma_l^{2p}(t) - W_l^{2p}(t)\right) + \beta\left(\gamma_l^{2p+1} - W_l^{2p+1}(t)\right) \quad (12)$$

$$\gamma_l^p(t+1) = \beta h(t) + \gamma_l^p(t) \quad (13)$$

Here after

$$Optimal\ Coefficients = optimal\ W_l^p \mp Loc.\gamma_l^{2p} \quad (14)$$

The channel estimate block diagram employing P-DWT algorithm is shown in Figure 3. Channel transfer function estimation is $H_{p-wt}(k)$ strength, which is adjusted by P-DWT.

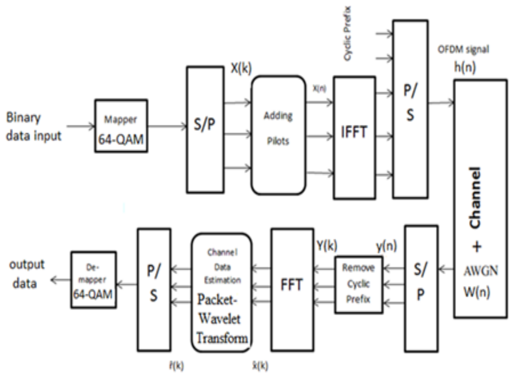


Figure 1: Block Diagram of OFDM Transceiver [11]

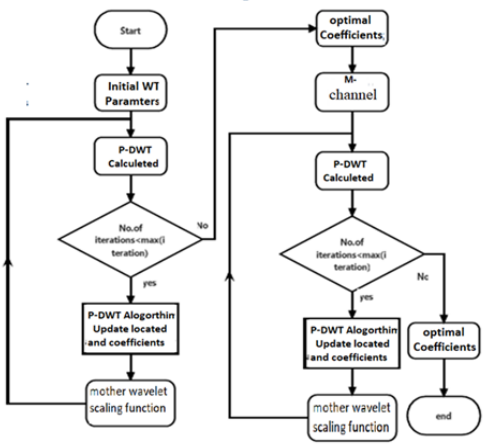


Figure 2: Algorithm of Proposed P-DWT

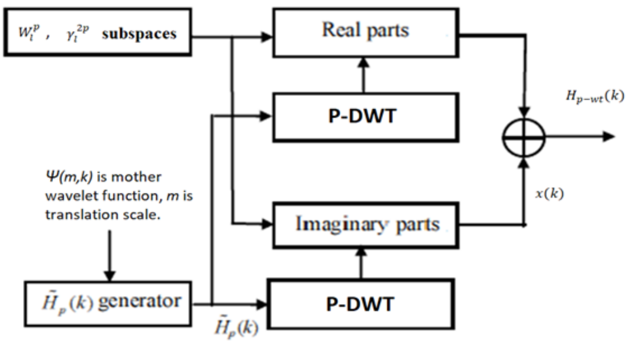
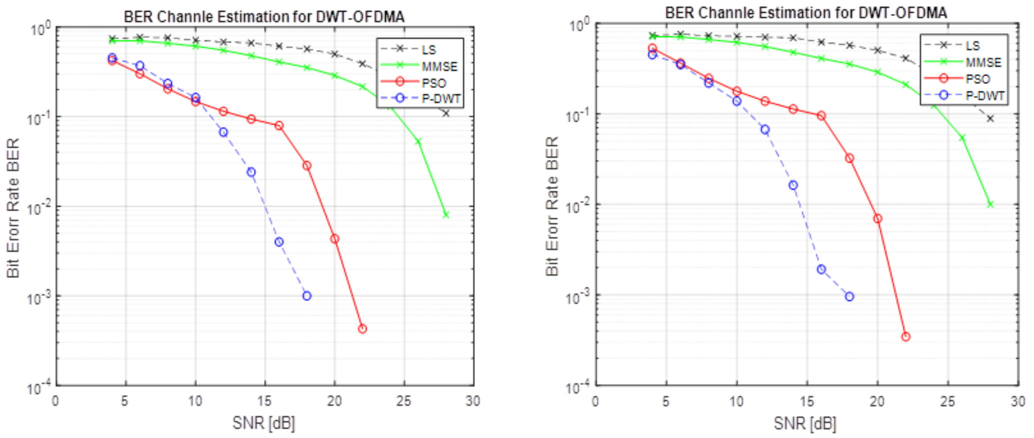


Figure 3: Channel estimation using P-DWT algorithm

Table 1: OFDM system parameters that are used in simulations [11]

Parameter	Value
No. of transmitting bits	10000
Size of FFT	256
No. of subcarrier	256, 512
Modulation	64QAM, 64-PSK
Symbol part duration	24.13 µs
Channel model	AWGN
Number of max trials	300
Orthogonal bases wavelet	P-DWT
Wavelet channel filter bank Level, (L)	1, 2, 3
Pilot numbers (PSO)	32



(a) (b)

Figure 4: OFDM system performance of BER vs. SNR for (a) subcarrier = 256 and (b) subcarrier = 512

5. System Design and Simulation Results

To evaluate the system's performance, computer simulations were used. Simulations in MATLAB were used to conduct the research and make comparisons. In the simulation, we used a total of 512 sub-carriers. The symbol rate in OFDM is 25 Kbps, with a symbol period of 24.13 µ seconds; so, the bit rate is 10000 bits per second. 64-QAM is a subcarrier modulation technique. The following is a comparison of P-DWT with the PSO, MMSE, and LS channel estimation parameters that were used in the optimization: The maximum number of trials is 300, the population size is 60, and the number of pilots is 32 [11]. Table 1 also shows the specifications for the OFDM signals model parameters that were employed.

The variance ratio of the energy of the data bit to the SNR was used to determine the BER variation. The BER performance of four impotent Methods channel estimate modulations over the channel is shown in Figure 4. The 64-PSK modulation scheme utilized in this system enhanced the data transmission rate. A number of subcarriers 256, 512 Number of subcarriers taken from Figures 4 (a) and 4 (b) Respectfully, Figures 5 and 6 also illustrate different QAM modulation index 64 with variations in SNR based on BER performance. The improvement in SNR was about 6.7dB and 6.5dB, respectively, for the BER of 10^{-1} for the subcarriers 256 and 512, according to these results. Furthermore, the compatibility of the broadcast original signal with improved received signal across different channels is explained, and the proposed technique outperformed existing methods by roughly 16 percent. Furthermore, the performance of the actual and estimated channels in 10000 OFDM symbols was collected from Table 2 for the specification of the model parameters for OFDM system.

Figures 7 are shown, compared the different Wavelets channel filter bank at the subcarrier 512 with three levels. For the estimated channel P-DWT, performance criterion BER was measured with a signal-to-noise ratio (SNR) specified as dB and compared to the newest research competing to increase performance such as discrete Wavelet, modify local search and MLS-Particle Swarm Optimization. Table 2 shows a comparison of the error rate between the proposed method and the important traditional methods. It shows the effectiveness of the proposed method by reducing the error rate in the same conditions and subcarriers. While, Table 3 includes the specifications of the typical parameters of the OFDM system, P-DWT as well as a comparison with the modern references in reducing the bit error rate, where the DWT method is tagged as well as the PSO and MLS methods, which are important in this field and give a good reduction in the error rate and reduce the complexity. Figure 6 and Table 3 show that the proposed method maintains the center stage with these methods and also gives a new horizon to reach a very significantly reduced error rate.

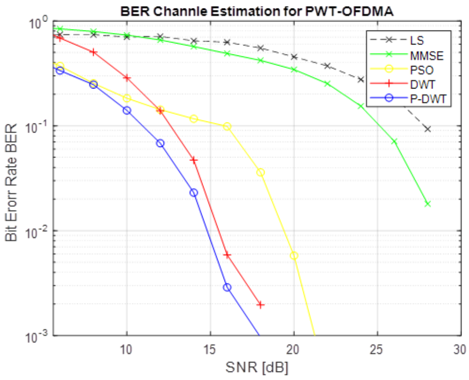


Figure 5: The OFDM system performance of the BER vs. SNR for Number of subcarriers 256, using modulation 64-QAM

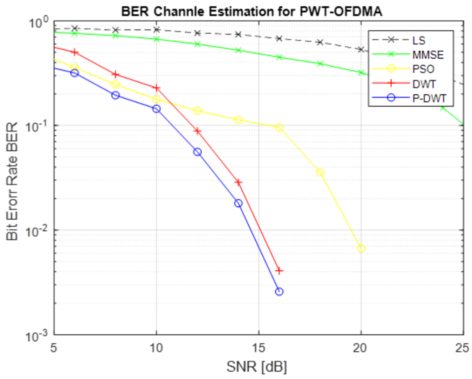


Figure 6: The OFDM system performance of the BER vs. SNR for Number of subcarriers 512, using modulation 64-QAM

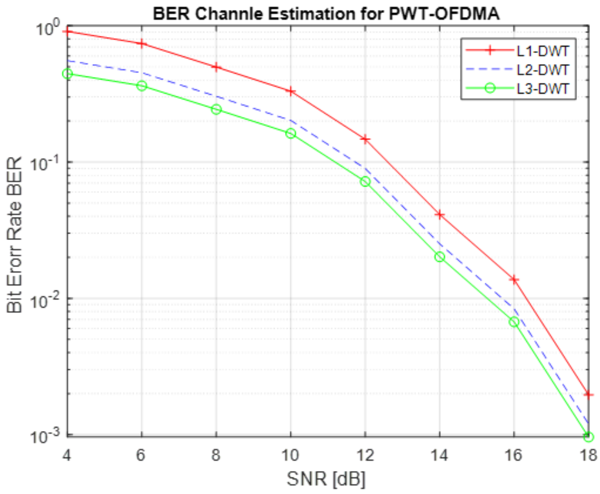


Figure 7: Convergence performance Wavelets three levels channel filter bank at the 64 Modulation index

Table 2: BER vs. SNR (dB) with various subcarriers based on the OFDM system

Number of subcarriers	LS (dB)	MMSE (dB)	PSO (dB)	DWT (dB)	P-DWT (dB)
256	11.12	10.61	8.12	8.96	6.71
512	12.46	11.76	10.66	9.23	8.42

Table 3: BER at 10^{-3} vs. SNR (dB) based on the OFDM system

Modulation	MLS (Nahar, 2016) [29]	DWT (Sarowa et al., 2020) [30]	MLS-PSO (Jabbar et al., 2018) [15]	P-DWT (Jabbar 2021)
64-QAM	21. 81	21.20	18.33	17.42

6. Conclusion

In this study, OFDM systems, discrete waveform packet switching is utilized instead of FFT switching, which increases bandwidth efficiency by 30% or more and decreases FFT complexity by eliminating the periodic prefix. There is power compression, for the purpose of simulation using the AWGN practical channel. The channel was estimated using the LS, MMSE, MLS, PSO, and DWT channel estimators. The P-DWT rating outperforms the LS rating by 10-14 dB. Wavelet packets outperform other types of packets. Finally, the P-DWT method achieves high flexibility and balanced results compared to DWT, in addition to the ease of achieving quick and good results without complicating PSO method, as well as the traditional methods that no longer meet the progress in the field of wireless communications.

Author contribution

All authors contributed equally to this work.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

References

[1] Van Nee R, Prasad R. OFDM for Wireless Multimedia Communications. Boston, London: Artech House; (2000).

[2] Watanabe, K.; Kojima, S.; Akao, T.; Katsuno, M.; Ahn, C.J. Modified Pilot Selection for Systematic Polar Coded MIMO-OFDM Channel Estimation. In Proceedings of the 2018 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS 2018), Okinawa, Japan, 27–30 November (2018), 237–241.

[3] M. Kumar Gupta, S. Shrivastava, A. S. Raghuvanshi, S. Tiwari. Channel Estimation for Wavelet Based OFDM System , 2011 International Conference on Devices and Communications (ICDeCom), (2011).

[4] Kaur J, Sharma V. A-STBC incorporated power-efficient Radio over Fibre system, Optics Communications, (2019), 84–89.

[5] Mohammadi, M.; Kashani, F.H.; Ghalibafan, J. Backfire-to-endfire scanning capability of a balanced metamaterial structure based on slotted ferrite-filled waveguide. Waves Random Complex Media, (2019).

[6] Zakaria J, Salleh, M. F. M. PAPR reduction scheme: wavelet packet-based PTS with embedded side information data scheme. IET Communications, (2017), 127–135.

[7] Yoon E, Hwang D, Jang C, Kim J, Yun U. Blind Selected Mapping with Side Information Estimation Based on the Received Pilot Signal, Wireless Communications and Mobile Computing. (2018); (5):1–9, DOI: 10.1155/ 2018/8523680

[8] Ahmed M S, Boussakta S, Al-Dweik A, Sharif B, Tsimenidis C C. Efficient Design of Selective Mapping and Partial Transmit Sequence Using T-OFDM. IEEE Transactions on Vehicular Technology, (2020), 2636–2648.

[9] Ganesh RS, Jayakumari J and Akhila IP Channel estimation analysis in MIMO-OFDM wireless systems. International Conference on Signal Processing, Communication, Computing and Networking Technologies, (2011), 399-403.

[10] AM Flashy and GP Ramesh Multi Band Antenna System for Quality Evaluation Application of Apple Fruit Recent Trends and Advances in Artificial Intelligence and Internet of Things, (2020), 199-206.

[11] A. K. Nahar and K. H. Bin Gazali, Local search particle swarm optimization algorithm channel estimation based on MC-CDMA system, ARPN Journal of Engineering and Applied Sciences, 10, (2015), 9659-9766.

[12] S. A. Ghauri, S. Alam, M. F. Sohail, A. Ali and F. Saleem, Implementation of OFDM And Channel Estimation Using LS And MMSE Estimators, International Journal of Computer and Electronics Research, 2, (2013), 41-46.

[13] A. K. Nahar, M. M. Ezzaldean, S. A. Gitaffa and H. K. Khleaf, OFDM Channel Estimation Based On Novel Local Search Particle Swarm Optimization Algorithm, Review of Information Engineering and Applications, 3, (2016), 11-21.

[14] Subramani P, Rajendran GB, Sengupta J, Pérez de Prado R and Divakarachari PB 2020 A Block Bi-Diagonalization-Based Pre-Coding for Indoor Multiple-Input-Multiple-Output- Visible Light Communication System Energies, 13, 3466.

[15] A. S. Jabbar, A. K. Nahar, H. K. Khleaf and M. J. Mortada, Modified Local Search Particle Swarm Optimization Algorithm Based on Channel Estimation with VHDL, 2018 Third Scientific Conference of Electrical Engineering (SCEE), (2018), 192-196.

[16] S. Yogeeswaran, S. Parasuraman and A. Manimaran, Channel Estimation of MIMO-OFDM through Wavelet Transform to Improve the Spectral Efficiency and Data Transmission Rate, IOP Conf. Series: Materials Science and Engineering 925, (2020).

[17] D. Khosla, S. Singh, R. Singh, and S. Goyal OFDM Modulation Technique & its applications: A Review Proceedings of the International Conference on Innovations in Computing (ICIC 2017), (2017), 101-105.

[18] H. Sinha, R. Meshram, and G.R. Sinha BER Performance Analysis of MIMO-OFDM over Wireless Channel International Journal of Pure and Applied Mathematics (IJPAM), 118, (2018), 195206.

[19] Fateme Salehi, Mohammad-Hassan Majidi, and Nasser Neda Channel Estimation Based on Learning Automata for OFDM Systems International Journal of Communication Systems, 321, (2018).

[20] Kussum Bhagat and Jyoteesh Malhotra Performance Evaluation of Channel Estimation Techniques in OFDM-based Mobile Wireless System International Journal of Future Generation Communication and Networking (IJFGCN), 8, (2015), 53-60.

[21] Pratima Manhas and M.K Soni OFDM Performance Evaluation under Different Fading Channels using MATLAB Simulink Indonesian Journal of Electrical Engineering and Computer Science, 5, (2017), 260-266.

[22] A. Z. M. Touhidul Islam A Comparative Performance Study of OFDM System with the Implementation of Comb Pilot-Based MMSE Channel Estimation, International Journal on Computational Sciences & Applications (IJCSA), 3, (2013), 45-53.

[23] Alibakhshikenari, M.; Virdee, B.S.; Limiti, E. Compact Single-Layer Traveling-Wave Antenna Design Using Metamaterial Transmission Lines. Radio Sci., (2017), 1510–1521.

[24] Chafii M, Palicot J, Gribonval R, Burr A. G. Power spectral density limitations of the wavelet-OFDM system, Proceedings of the 24th European Signal Processing Conference; Budapest, Hungary, (2016).

[25] Mallat, N.K.; Ishtiaq, M.; Rehman, A.U.; Iqbal, A. Millimeter-Wave in the Face of 5G Communication Potential Applications. IETE J. Res. 3, (2020), 1–9.

[26] 5Awan, W.; Hussain, N.; Naqvi, S.; Iqbal, A.; Striker, R.; Mitra, D.; Braaten, B. A Miniaturized Wideband and Multi-band On-Demand Reconfigurable Antenna for Compact and Portable Devices. AEU Int. J. Electron. Commun. 122, (2020), 153266.

[27] Alibakhshikenari, M.; Virdee, B.S.; See, C.H.; Abdalhameed, R.; Falcone Lanas, F.J.; Limiti, E. High-gain metasurface in polyimide on-chip antenna based on CRLH-TL for sub-terahertz integrated circuits. Sci. Rep.10, (2020), 4298.

[28] I. Nicolae, P. Nicolae, I. Smărăndescu and M. Nicolae, Wavelet packet transform, a reliable and fast method to obtain the fundamental components required for active filtering in power plants, 2016 IEEE International Power Electronics and Motion Control Conference (PEMC), (2016), 918-923.

[29] Ali k. Nahar, Enhanced PAPR Reduction and Channel Estimation Techniques in Multi-Carrier Wireless Communication System, PhD. Thesis for Universiti Malaysia Pahang, September, (2016).

[30] Sarowa S, Kumar N, Agrawal, Balwinder S S. Evolution of PAPR Reduction Techniques: A Wavelet Based OFDM Approach, Wireless Personal Communications, (2020).