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Improving The Channel Estimation In OFDM System Using Fuzzy Logic And ANN In Parallel

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Abstract

This paper introduces a method for developing the detection in OFDM system using Estimation channel by FL (Fuzzy Logic) and ANN (Artificial Neural Network) in Parallel. OFDM system and OFDM with FL-ANN (OFDM-FL-ANN) are explained in details and are modeled using matlab Simulink. BER (Bit Error Rate) is calculated to comparing among OFDM and OFDM-FL-ANN performance. Detection is improved by estimation channel using FL-ANN. The ANN part estimates the noise of channel to cancel the noise. While the fuzzy logic part estimates channel state of information. OFDM-FL-ANN has better performance. BER is founded for improved OFDM system with FL-ANN and OFDM to compare. The results indicate that proposed method improves detection in OFDM system, where the average of enhancement rate for BER is 40.011 and 0.55 Mbps for both BER, throughput. Finally, as implementation case, "Queen Elizabeth's" image is sent and received using OFDM and OFDM-FL-ANN models in MatLab Simulink. The average of enhancement 10.8291 in MSE for OFDM-FL-ANN over the basic OFDM model.

Keywords: Obile Communication System; Detection; Four Generation Communication; Neural Networks; Ofdm System; Fuzzy Logic, Complexity.

تحسين تخمين القناة في نظام OFDM باستخدام المنطق العائم والشبكات العصبونية الصنعية على التوازي

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الملخص

تقدم هذه الورقة البحثية طريقة لتطوير عملية الكشف في نظام OFDM عن طريق تخمين القناة بواسطة المنطق العائم والشبكات العصبونية الصنعية على التوازي. تم توضيح وشرح نظام OFDM ونظام OFDM المطور باستخدام المنطق العائم والشبكات العصبونية الصنعية OFDM-FL-ANN بالتفصيل ونمذجتهما باستخدام بيئة المحاكاة MatLab-Simulink. طُورت عملية الكشف بتخمين القناة باستخدام المنطق العائم والشبكات العصبونية الصنعية، بحيث تقوم الشبكة العصبونية بتخمين ضجيج القناة لإلغاء الضجيج. بينما المنطق العائم يخمن حالة معلومات القناة. تم حساب معدل الخطأ في الخانة لمقارنة أداء نظامي OFDM وOFDM-FL-ANN. فأعطى نظام OFDM-FL-ANN، (OFDM المطور بالمنطق العائم والشبكات العصبونية الصنعية على التوازي)، أداء أفضل عند مقارنة معدلات الخطأ للخانة فيه مع مثيلاتها في نظام OFDM، حيث اثبتت النتائج أن الطريقة المقترحة حسنت عملية الكشف في نظام OFDM. وكان معدل التحسين 40.011 في معدل خطأ الخانة و0.55 Mbps في تدفق البيانات. أخيراً تمت عملية إرسال واستقبال صورة الملكة اليزابث كحالة دراسية تطبيقية بواسطة نموذجي OFDM وOFDM-FL-ANN المطور في بيئة محاكاة Mat Lab وحساب متوسط مربع الخطأ بين الصورة الأصلية والمستقبلة فكان مقدار التحسين 10.8291 لنموذج OFDM-FL-ANN عن نموذج OFDM الأساسي.

الكلمات المفتاحية: نظام اتصالات المتنقلة، الكشف، جيل الاتصالات الرابع، شبكات عصبونية، نظام OFDM، المنطق العائم، تعقيد.

1-Introduction

In mobile communications, orthogonal frequency-division multiplexing (OFDM) is a kind of digital sending by encoding digital data on multiple carrier frequencies. OFDM is considered as a popular system for wideband digital communication and is used in many applications such as wireless networks, and 4G mobile communications. OFDM is a method of data transmission where a single information stream is split among several closely spaced narrowband sub channel frequencies instead of a single wideband channel frequency and it is one of the most used scheme that provides large system capacity without additional power or bandwidth consumption for high speed wireless communication systems. Therefore, this research aims to propose a new method to estimate channel based on fuzzy logic and artificial neural network in parallel (FL-ANN) for OFDM systems. In our proposal, the FL-ANN is designed to estimate the noise of channel using ANN part and to estimate the channel state information using fuzzy part, then is used as a channel estimator. To evaluate performance of proposal FL – ANN – OFDM, its Results was compared to basic OFDM system using Matlab Simulink. The importance of proposal shows in the field of 4 G communication, make OFDM is more resilient to electromagnetic interference, and enables more efficient use of total available bandwidth. It is also make OFDM is more resistant to interference. The aim of this paper is to simulate the OFDM and OFDM-FL – ANN systems performance, which analyzed the BER and SER in AWGN channel and Rayleigh fading channel.

2-Related works

In the literatures, many researchers studied channel estimation in OFDM using artificial intelligence, classical algorithms or heuristic approaches; one of them suggested a channel estimator based on an ANFIS for the purpose of estimating channel frequency responses in orthogonal frequency division multiplexing-interleave division multiple access (OFDM-IDMA) systems (TASPINAR and Shimshis, 2017). In (Seyman and Taspinar, 2012), a new channel estimation algorithm based on adaptive neuro-fuzzy inference system (ANFIS) for MIMO-OFDM systems was proposed by utilizing the learning capability of ANFIS, the correct channel state information is used to train ANFIS that is used as a channel estimator. In (Türk and Kaya, 2009), and in (Liang et al., 2005), LMS and LS channel estimation schemes were described for OFDM systems based on pilot. For channel estimation MIMO wireless communication system a tree layered artificial neural network with feedback was offered in (Zhang and Zhang X, 2007). A kind of neural network based on least mean error algorithm called radial basis function network were applied to get CSIs of SISO-OFDM (Seyman and Taspinar, 2008), (Taspinar and Seyman, 2010). Besides, in (Seyman and Taspinar, 2008) adaptive neuro-fuzzy inference system was suggested to estimate channel in SISO OFDM systems. Takagi-Sugeno-Kang fuzzy model was used for channel estimation in MIMO-OFDM systems in (Zhang et al., 2007). In (Zeeshan and Zainul Abdin, 2017) the two channel equalizers, NN based and ANFIS based are compared on MIMO-OFDM system over Rayleigh fading channel. The application of Neural Network in channel estimation has been tested. Channel's information H is estimated by (Seyman and Taspinar, 2012) using ANFIS also, and tested through COST 207 TU channel type. The fuzzy part has seven rules for both real and image part of signals.

Some paper suggests to design intelligent reflecting surface (IRS)-assisted millimeter Wave (mmWave) orthogonal frequency division multiplexing (OFDM) systems (Zheng and others, 2022). Many models is designed to improve estimation channel in OFDM like liner model. MSE (Mean Square Error) and BER (bit Error Rate) are used to measure enhancement for OFDM system (Asharjabi and others, 2022). Other studies centroid on complexity. least-squares (LS) method is used in OFDM system to estimate the channel frequency responses without need to know the statistical properties of the channel or insert extra pilots (An Kao and Feng Wu, 2022).

A new hybrid network structure is named CAGAN (concrete autoencoder conditional generative adversarial) is used as channel estimation method In MIMO-OFDM systems. This method has good robustness to environmental noise (Kang and others, 2022).

Not only intelligent method are used to improve channel estimation but a method based on two dimensional linear interpolation, which is easy to implement, is proposed for OFDM and in other hand two dimensional Discrete Fourier Transform interpolation (2D-DFTI) is apply to support high speed movement in OFDM system (Hou and other, 2022). Based on the flexibility and high efficiency that OFDM system enjoys and its importance, it has been studied from several aspects; some studies concentrate on transformation techniques like Fourier Transform (FT), lapped transform (LT), cosine transform (CT) and others (Nerma, 2021). Other papers study different distribution conditions for OFDM with Rayleigh channel and 64-QAM modulation (Al-Asady and others, 2021).

All studies estimate information channel H. In this, paper H and N noise of channel will be estimated using FL and ANN in parallel, fuzzy part will estimate H and ANN part will estimate N using neural structure to get the best estimator totally.

3-Materials and working methods

This research was achieved in three steps as follows:

1- Studying OFDM system and analysis.

2- Proposal structure for FL-ANN developing OFDM system is explained in details.

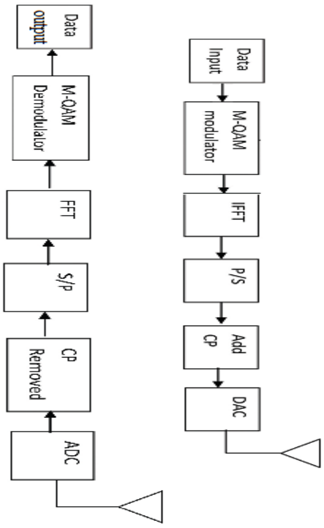
3- Simulation classic OFDM system and OFDM-FL-ANN using Matlab and compare using BER (Bit Error Rate). In addition, signals for images are implemented as cases study.

3.1-The OFDM system

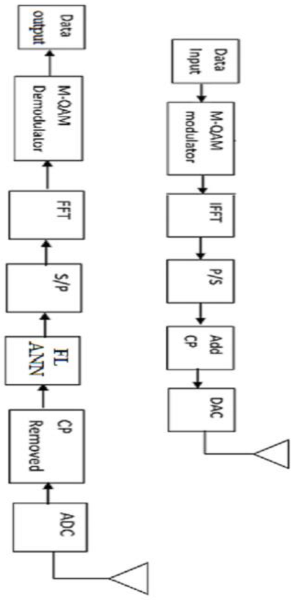
Figure (1-A) shows basic OFDM system diagram. MCM (Multi Carrier Modulation) is dependent in OFDM technique as principle to replace using modeling subcarrier by using orthogonal frequency division multi-access to transduce high transmitting to low. The basic idea is in division available bandwidth to number of subcarriers to become semi ideal, which means it will have constant response so, in this way, to beat subjected effects that face signal like fading, the signal is transmitted using multi sub channels. Basic principle for work of subcarrier is modulating of every carrier in different way about others ones, so reducing spaces in spectrum of subcarriers can be achieved by being orthogonal subcarriers by conclusion reducing their spectrums interference. Inverse Fast Fourier Transforming (IFFT) can be used to generate OFDM symbols for K subcarriers OFDM signal will be given by relation (1) (Armstrong, 2009), (Modabbes et al., 2015):

$$\mathrm{S(t)} = \frac{1}{\sqrt{T}} \sum_{k=-\frac{K}{2}}^{\frac{K}{2}} s_k \exp\left(j2\pi \frac{k}{T} t\right) \prod \left(\frac{t}{T} - \frac{1}{2}\right) \quad (1)$$

Where k: frequency index for each subcarrier, T: Fourier period and s_k symbols of transmitted data that can be gotten from $S(t)$ OFDM signal, that is transmitted by equation (2) in receiving side using Fourier transform.



A – Basic OFDM



B- OFDM-FL-ANN

Figure (1) The proposed OFDM-FL-ANN and Basic OFDM Schemes

$$s_k = \langle \mathrm{g}_k, s \rangle = \frac{1}{\sqrt{T}} \int_0^T \exp\left(-j2\pi \frac{k}{T} t\right) \mathrm{S(t)} dt \quad (2)$$

Where f_{k}: frequency of subcarrier k and $\mathrm{g_k(t)}$ impulse of shifting at frequency f_{k}, by adding Δ protection interval, impulse of shifting will be given in equation (3) (Modabbes et al., 2015):

$$\mathrm{g}'_k(\mathrm{t}) = \sqrt{\frac{1}{T_s}} \exp\left(j2\pi \frac{k}{T} t\right) \prod \left(\frac{t+\Delta}{T_s} - \frac{1}{2}\right) \quad (3)$$

Where T_s time parallel symbol, so transmitted OFDM signal will become like in equation (4) if Δ protection interval was taken in regard (Modabbes et al., 2015):

$$\mathrm{S(t)} = \frac{1}{\sqrt{T}} \sum_{k=-\frac{K}{2}}^{\frac{K}{2}} s_k \exp\left(j2\pi \frac{k}{T} t\right) \prod \left(\frac{t+\Delta}{T} - \frac{1}{2}\right) (4)$$

A Cyclic Prefix (CP) reduces the effects of ISI and delay spread, which is caused by increasing of the symbol duration in the parallel sub-channels in the OFDM system (Maharmi, 2016).

3.2-Proposal OFDM-FL-ANN System

Figure (1-B) shows the scheme of the developed OFDM-FL-ANN system. After removing the CP from signals at the receiver antenna FFT is taken and FFT output can be written as:

$$Y_k = H_k s_k + W_k \qquad (5)$$

Where W_k is channel noise and H_k is the channel state information from antenna in transmitting to antenna in receiving. In channel estimation block, H_k is estimated then signals are decoded and demodulated (Seyman and Taspinar, 2012). In our proposal method, Fuzzy Logic and Artificial Neural Network (OFDM-FL-ANN) is used as a filter and estimator. Artificial Neural Network part is used as filter to cancel channel noise W_k in opposite way, that is estimating W_k. In other hand, fuzzy logic part is used as estimator to estimate the channel state information H_k as like shown in figure (2).

In the neural part, the output is W_k given in the following equation:

$$W_k = f_3(W_3 f_2(W_2 f_1(W_1[real\, s_k \quad image\, s_k] + B_1) + B_2) + B_3) \qquad (6)$$

Where: W_1, W_2, W_3 are weight matrixes, B_1, B_2, B_3 are bias matrixes and F_1, F_2, F_3 are activation functions for layer 1, 2 and 3 respectively. The network is trained using Levenberg-Marquardt algorithm (Kafarnawi, 2021). The function of the activation of the output layer neurons F3 is a linear function given by the relation:

$$y = x \qquad (7)$$

The function of activation F1 and F2 are the tansig function that is given by the relation:

$$y = \tan sig(x) = \frac{2}{1+e^{-2x}} - 1 \qquad (8)$$

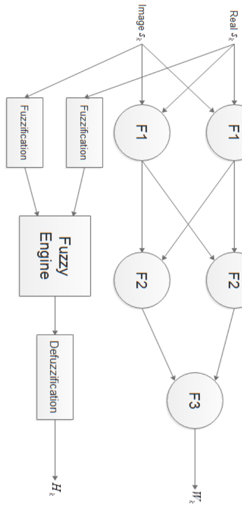


Figure (2) The Structure of proposed FL and ANN in parallel

In the fuzzy part the input real and image part of s_k go to fuzzification, which has three groups Low (L), Medium (M) or High (H), it is Gaussian member function given in the relation:

$$F(Ps_k, \sigma, c) = e^{\frac{-(Ps_k - c)^2}{2\sigma^2}} \qquad (9)$$

Where: Ps_k is real or image part of s_k, σ: variance of Gaussian, and c: is center of Gaussian. The table (1) show rule base for fuzzy engine where the output of fuzzy part H_k has also three defuzzification member function groups Low (L), Medium (M) or High (H). So there are nine rules for example:

$$if\,(real\, s_k is\, L)\, and\, (image\, s_k is\, H)\, then\, (H_k is\, M)$$

Table (1) rules base for fuzzy engine

		Real part of S_k			
		L	**M**	**H**	
Image part of S_k	**L**	**L**	**L**	**M**	H_k
	M	**L**	**M**	**H**	
	H	**M**	**H**	**H**	

4-Results and Discussion

Both OFDM and ODFM-FL-ANN are simulated using Matlab–Simulink as shown in figure (3), similar to OFDM and OFDM-FL-ANN block diagram shown in the figure (1) using the parameters shown in the table (2).

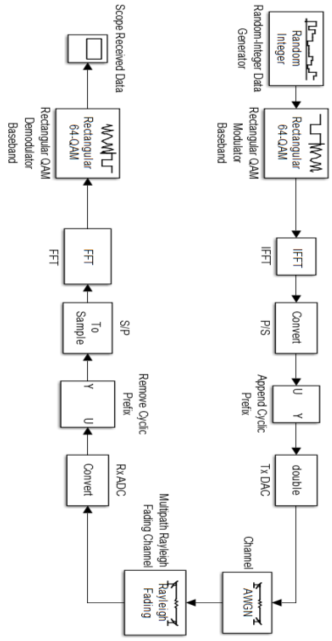
Table (2) OFDM and OFMD-FL-ANN simulation parameters.

Parameter	Value
Carrier frequency (f_c)	6 GHz
Sampling frequency (f_s)	8 MHz
FFT size	512
Symbol part duration	$512T_s$ =64 μs
Cyclic prefix duration	T_{FFT} /4= 16 μs
Modulation type	64 QAM
Channel type	AWGN + Rayleigh Fading
mobile speed	120km/h

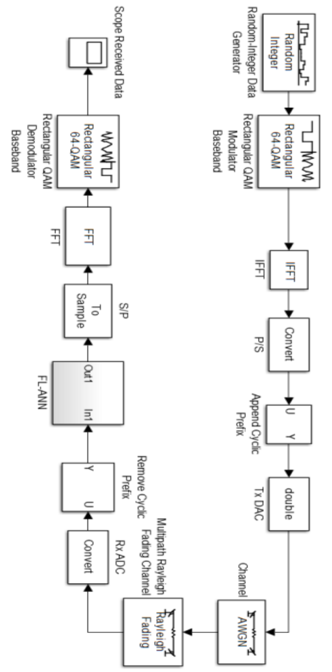
For channels with multiple paths, it could be assign each path a different Doppler spectrum, by entering a vector of doppler objects in the Doppler spectrum field. Because a multipath channel reflects signals at multiple places, a transmitted signal travels to the receiver along several paths, each of which may have differing lengths and associated time delays (Iskander, 2020). The relationship between EsNo and SNR, both expressed in dB, is as relation (10) (Proakis,2013).

$$E_S \,/\, N_o(dB) = 10\log_{10}(T_s \,/ T_{\text{samp}}) + SNR(dB) \quad (10)$$

Where; T_{samp}- sampling time.



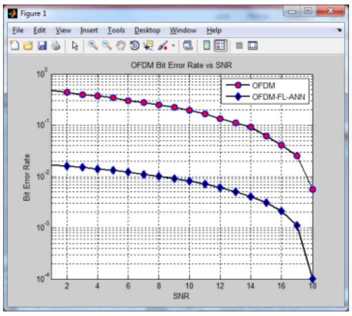
A – Basic OFDM model



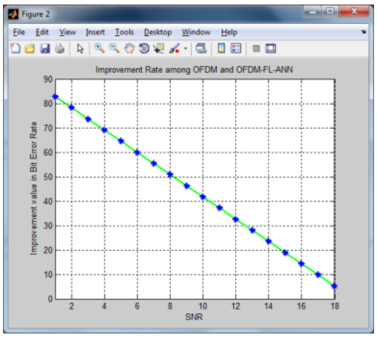
B- OFDM-FL-ANN model

Figure (3) The Simulink models for both OFDM-FL-ANN and Basic OFDM.

To evaluate performance of OFDM – FL-ANN model, BER is calculated for both OFDM and OFDM – FL-ANN as shown in figure (4-A), where all points of curve of BER for OFDM –FL-ANN are under of OFDM one. The rate of enhancement is also calculated as shown in figure (4-B). It is noticed the rate of enhancement is decrease with increase SNR, and average of enhancement for all values of SNR from 1dB to 18 dB is 44.0111.



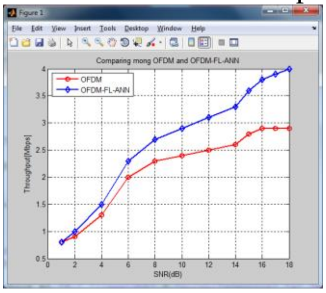
A – The BER



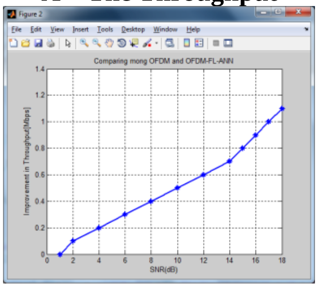
B- Value enhancement

Figure (4) The BER for both OFDM-FL-ANN and Basic OFDM, and rate of enhancement

In the addition above Throughput in founded for both OFDM and OFDM – FL-ANN to evaluate performance of OFDM and OFDM – FL-ANN model, as shown in figure (5-A), where all points of curve of Throughput for OFDM –FL-ANN are above of OFDM one. The value of enhancement is also calculated as shown in figure (5-B). It is noticed the value of enhancement is increased with increase SNR, and average of enhancement for all values of SNR from 1dB to 18 dB is 0.55 Mbps.



A – The Throughput



B – Value enhancement in The Throughput

Figure (5) The Throughput for both OFDM-FL-ANN and Basic OFDM, and rate of enhancement

Computational Complexity of OFDM and OFDM-FL-ANN is founded as shown in figure (6) using two methods. The first one is Direct Method using the next equations for OFDM (Oppenheim and Schafer,2014), (Srikanth and others, 2019):

$$Cm = 4N^2, Ca = 2N(2N-1) \qquad (11)$$

Where;

N : No. symbols

Cm: The total number of real multiplications

Ca : The total number of additions

For OFDM-FL-ANN, the Computational Complexity is calculated using following equation:

$$\begin{aligned} Cm &= 4N^2 + N * N_{m\_FL\_ANN} \\ Ca &= 2N(2N-1) + N * N_{a\_FL\_ANN} \end{aligned} \qquad (12)$$

Where:

$N_{m\_FL\_ANN}$: The total number of real multiplications in proposed FL and ANN

$N_{a\_FL\_ANN}$: The total number of real additions in proposed FL and ANN

The second one is the total computation count as shown table (3) using the next equations for OFDM (Dimitrov and others, 2014):

$$C = M(4N\log(N) - 6N + 8)/N + 4M\log(M) - 6M + 8 \quad (13)$$

Where the total number of carriers is divided into *M*/*N* resource blocks.

For OFDM-FL-ANN, the Computational Complexity is calculated using following equation:

$$C = M(4N\log(N) - 6N + 8)/N + 4M\log(M) - 6M + 8 + T_{FLANN}$$
(14)

Where:

T_{FLANN}: Time for proposed FL and ANN

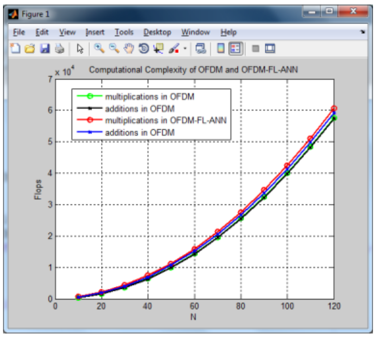


Figure (6) Computational Complexity of OFDM and OFDM-FL-ANN using Direct Method.

Table (3) Computational Complexity of OFDM and OFDM-FL-ANN using total computation count where FFT size= 512.

OFDM	OFDM-FL-ANN
5000ms	5461ms

Queen Elizabeth's image is taken as case study. And it is sent and received using OFDM model in Matlab Simulink for SNR from 1dB to 18 dB like it is shown in figure (7-A). In the same way, Queen Elizabeth's image is sent and received using OFDM –FL-ANN model in Matlab Simulink as shown in figure (7-B). Figure (8-A) shows MSE (Mean Square Error), that is calculated between basic image of "Queen Elizabeth" and received image from both OFDM and OFDM-FL-ANN model using the next equation:

$$MSE = \frac{1}{n \times m}\sum_{x=1}^{n}\sum_{y=1}^{m}\left(f(x,y) - R(x,y)\right)^2 \quad (15)$$

Where:

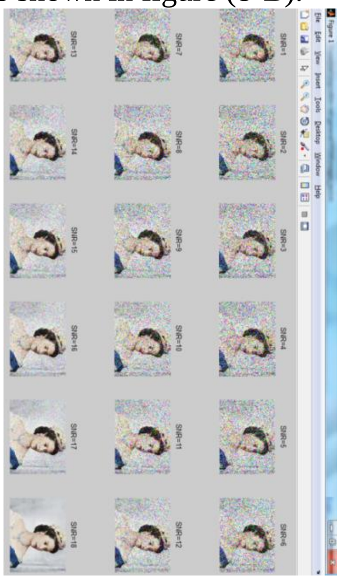
n: No. Rows of image

m: No. columns of image

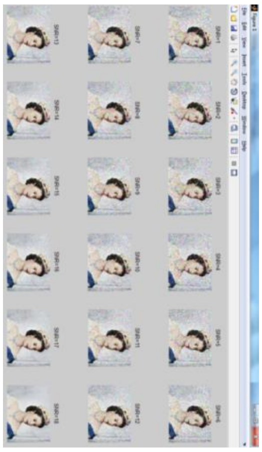
$f(x,y)$: Basic image of "Queen Elizabeth".

$R(x,y)$: received image.

It is noted that MSE in OFDMA-FL-ANN is least than one in OFDMA system as shown in figure (7-A). Value of enhancement in MSE between OFDMA and OFDMA-FL-ANN is calculated as shown in figure (8-B).

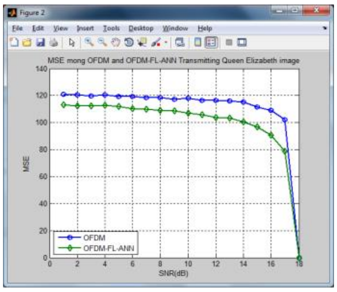


A-OFDM



B-OFDM – FL-ANN.

Figure (7) Transmitting "Queen Elizabeth's image" by Basic OFDM and OFDM-FL-ANN.



A-MSE for both OFDM and OFDM-FL-ANN when Transmitting "Queen Elizabeth's image"

B- Improvement Value MSE for both OFDM and OFDM-FL-ANN.

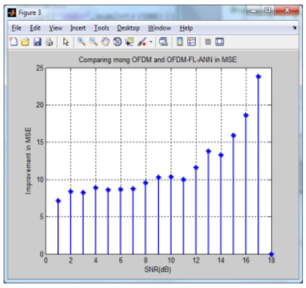


Figure (8) MSE for OFDM and OFDM-FL-ANN when Transmitting "Queen Elizabeth's image" by Basic OFDM and OFDM-FL-ANN and improvement value.

5-Conclusion

In this research, a methodology was proposed to estimate noise of channel W_k using ANN part and to estimate channel state information H_k using fuzzy part in parallel to improve OFDM system. Basic OFDM and OFDM – FL – ANN is modeled using matlab Simulink using two channels AWGN and Rayleigh fading to study effects of noise, frequency Doppler and multipath. Finally Queen Elizabeth's image is transitioned using OFDM and OFDM – FL-ANN model in matlab Simulink as case study.

The average of enhancement 40.011, 0.55 Mbps and 10.8291 for both BER, throughput and MSE in respectively for all SNR from 1dB to 18 dB.

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