International Journal of Scientific & Engineering Research Volume 9, Issue 9, September-2018
ISSN 2229-5518

Adaptive direct channel estimation in OFDM system using Superimposed Training Sequence (STS) technique

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Abstract—In Orthogonal Frequency Division Multiplexing (OFDM) system, there is an attractive characteristic which is the OFDM system considered a simple one tap equalizer in the linear channel distortions. Nevertheless, channel estimation is still an important part of the system that must be designed and implemented with high accuracy due to many problems occur in the wireless communication channels such as diffraction, reflection, shadowing and scattering etc. In this work, we investigate direct channel estimation method in time domain for time varying Rayleigh fading channel using Superimposed Training Sequence (STS pilot) and Recursive Least Square (RLS) adaptive algorithm. Superimposed Training Sequence provide simple channel estimation without loss in bandwidth efficiency and gives better performance. Time varying OFDM adaptive direct channel estimation in time domain and system performance comparison has been made, with adaptive equalization estimation (inverse channel estimation in time domain) in terms of bit error rate against signal to noise ratio plots. MATLAB OFDM system based simulation program is implemented for this purpose and for different modulation schemes such as BPSK, QPSK, 16QAM and 64QAM.

Keywords— OFDM system, Superimposed Training Sequence, Kalman RLS adaptive algorithm, direct channel estimation, equalization.

1. Introduction

In high speed data communication systems, like digital broadcasting (audio/video), mobile radio systems and the wireless LAN systems, the (OFDM) system has many features made this system attractive for mitigating the inter symbol interference (ISI) in these system. The (OFDM) consider a special case of the multicarrier transmission and it is one of the techniques used parallel transmission, where a single data stream is sent over a number of lower rate subcarriers [1],[2]. In OFDM, the time varying multipath channels leads to the inter symbol interference (ISI) and a loss in orthogonality of the subcarrier which cause the inter carrier interference (ICI) [3]. Thus, the channel estimation stage will be very important in the receiver to know the channel characteristics and recovered the transmitted data accurately, usually the channel estimation process performed in frequency domain. The received signal will be dispersed in frequency due to the Doppler effect, when either the transmitter, receiver or the obstacles is moving. For example, if we transmitted a pure tone from fixed transmitter, then the spectrum of the received signal in moving receiver will be shifted by a finite frequency. The shifted frequency is related with the motion velocity and the angle between the direction of the signal arrival and the direction of movement. Thus, Doppler phenomenon has a big effect on the transmitted signal. In our simulation, the transmitted signal will pass through Rayleigh fading channel with three paths and maximum Doppler frequency (80 Hz), this value represents the maximum Doppler shift might the signal suffered when the receiver inside a car that moving on a freeway. In such channels, the estimation process is a big challenge and the efforts to overcome this challenge are commonly depend on training methods. Among them, there is a popular method which is frequency multiplex training pilots with the transmitted data symbols [4]. Due to the (ICI) which corrupt the pilots, too many pilots must be used in the transmitter to achieve better channel estimation, and that will lead to increase the channel capacity. Recently, the channel estimation based on superimposed training sequence has been proposed due to the potential increase in bandwidth efficiency.

In the previous works, December 1999, Peter Hoeher and Fredrik Tufvesson [5], for channel estimation purpose, they utilized superimposed training sequence (STS) technique and coherent receiver that used Viterbi algorithm. October 2002, Ning Chen and G. Tong Zhou [2], to get simple channel estimation and equalization, with no losses in spectral efficiency. A superimposed pilot schema is proposed to characterize the channel for OFDM systems. December 2006, Qinghai Yang and Kyung Sup Kwak [3], the time varying multipath channel estimation schema is proposed based on superimposed training methods and find the optimal superimposed sequences to achieve better performance and higher bandwidth efficiency than the conventional pilot-aided method. February 2010, Jinesh P. Nair and Ratnam V. Raja Kumar [6], in this paper the Least Squares (LS) algorithm is used for channel estimation in time domain based on (STS) technique through time varying channel which experience frequency selective fading in (MIMO-OFDM) system.

In this paper, we investigate superimposed training sequence pilot schema in the transmitter with adaptive filter based on the Recursive Least Square (RLS) algorithm in the receiver to identify the direct channel characteristics in OFDM system. The (STS) use the first order statistic of

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ISSN 2229-5518

the data, it does not require dedicated slots for the training and can be considered as a semi blind method for estimation [2]. By using MATLAB software (M file), we performed a "code" in MATLAB program to simulate whole OFDM system with different modulation schemes such as (BPSK, QPSK, 16QAM and 64QAM) and estimate the channel effect by design an algorithm used in the transmitter and the receiver to eliminate the interference cancellation.

2. Channel Estimation

Wireless communication channel changes with time due to the motion of the transmitter, receiver or the obstacles in the channel. The communication between the transmitter and receiver is affected by the surrounding environments such as (poles, buildings, hills and other obstacles). The transmitted signal will be distorted due to the interference in multipath fading channel, therefore the transmitted data cannot recovered in the receiver accurately. When the channel is time varying, channel estimation process is highly desired at the receiver. We can classify the channel estimation into two broad categories.

i. Inverse channel estimation.
ii. Direct channel estimation.

3. Inverse channel estimation (Equalization)

When there are single carrier modulations, the OFDM system is preferable where simple one tap frequency domain equalizer (FDE) used to equalize the OFDM signal which pass over frequency selective fading channel. When the channel impulse response remains constant over one symbol period, at each subcarrier the received signal will be as follows [7]

$$Y_{i,k} = H_{i,k}X_{i,k} + W_{i,k} \qquad (1.1)$$

Where $X_{i,k}$, $H_{i,k}$ and $W_{i,k}$ represent the transmitted signal, channel impulse response (CIR) andthe Additive White Gaussian Noise (AWGN) respectively. The transmitted signal is restored by one tap equalizer as follows

$$\hat{X}_{i,k} = G_{i,k}Y_{i,k} \qquad (1.2)$$

Where $G_{i,k}$ represents the equalizer coefficients at$k$-th subcarrier through i-th symbol. Without prior information about the channel, the adaptive algorithms can adjust the coefficients of the equalizer to reduce $E\left\{\left|\hat{X}_{i,k} - X_{i,k}\right|^2\right\}$. The error $e_{i,k}$ signal is obtained by comparing the equalized signal$\hat{X}_{i,k}$ with the reference signal. After that, the coefficients of the equalizer are adjusted in accordance with the error signal

$$G_{(i+1),k} = G_{i,k} - g_{i,k}e_{i,k} \qquad (1.3)$$

Where $g_{i,k}$ represents the gain factor, depends on the (RLS) algorithm. In the training mode, the reference signal is known pilot data to the transmitter and the receiver.

Equation (1.1) can be written in the matrix vector form as follows

$$Y = HX + W \qquad (1.4)$$

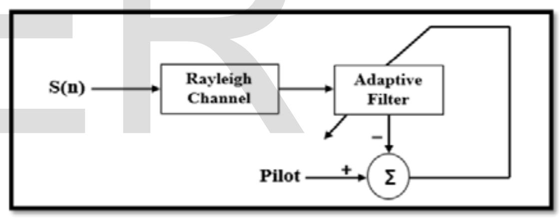
The channel matrix$H$ becomes diagonal when the (CIR) remains constant through one OFDM symbol duration. In this case, we can easily recovered the transmitted signal by using a simple equalizer as shown

$$X = H^{-1}Y \qquad (1.5)$$

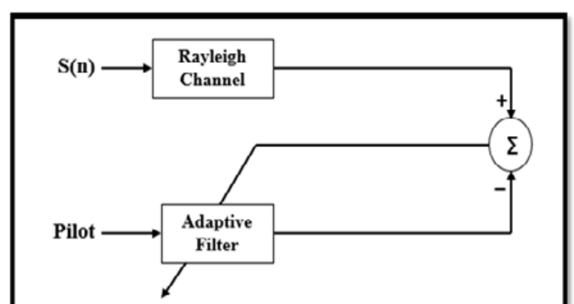
The channel variation with time increases with the Doppler frequency increment. Moreover, the (ISI) and the inter carrier interference (ICI)will increase as a result of the Doppler frequency increment. If the (CIR) changes during one OFDM symbol duration, the channel matrix$H$ will be no longer diagonal. Therefore, there is difficulty in solving (1.4) [8].

4. Direct channel estimation

Direct channel estimation is an adaptive technique that estimates the channel coefficients up to prespecified length as the actual propagation channel varies with time. Unlike the inverse channel estimation, the direct channel estimation method is robust, not complicated and need less calculation time. Fig.1 shows the concept of the direct and inverse channel estimation in time domain.



(a) Inverse channel estimation



(b) Direct channel estimation

Fig. 1. Direct and inverse channel estimation schemes.

4.1 System Model

4.1.1 Superimposed Training Sequence (STS)

Direct channel estimation method permits for simple channel estimation and minimizing the loss in spectral efficiency. The (STS)can be considered as a semi blind method for channel estimation.Fig.2 illustrates baseband OFDM system model which using superimposed training sequence for channel estimation. The transmitted signal is expressed as follows [2]:

The periodic pilots will be added to each block of the transmitted symbols in time domain before transmission in OFDM system. This adding technique will increase the data rate due to avoiding use additional time slots for training signal, allow for channel estimation simply and keep tracking the channel variation.

$$x_i(n) = \frac{1}{N}\sum_{n=0}^{N-1} X_i(k)\, e^{j\frac{2\pi nk}{N}} \qquad (1.6)$$

$$0 \le n \le N-1$$

Where N is the block length of serial data symbols which represented by $S_i(k)$.

$$x^g(n) = x(n+N-G)_N \qquad (1.7)$$

$$0 \le n \le N+G-1$$

Where G is the guard interval (GI). The pilot sequence is algebraically added to the IFFT output to generate the baseband signal

$$x^{gp}(n) = x^g(n) + p(n) \qquad (1.8)$$

$$0 \le n \le N+G-1$$

The sequence of the pilot $p(n)$ that is known for the both the transmitter and the receiver will be as follows

$$p(n) = \sum_{m=0}^{R-1} \alpha\delta(n-mP) \qquad (1.9)$$

$$0 \le n \le N+G-1$$

Where $\delta(.)$, α And P are the Kronecker delta function, the Pilot Amplitude and the pilot period respectively and R represents the number of periods, $R = \left\lfloor\frac{(N+G)}{P}\right\rfloor$. The received signal formula will be as follow

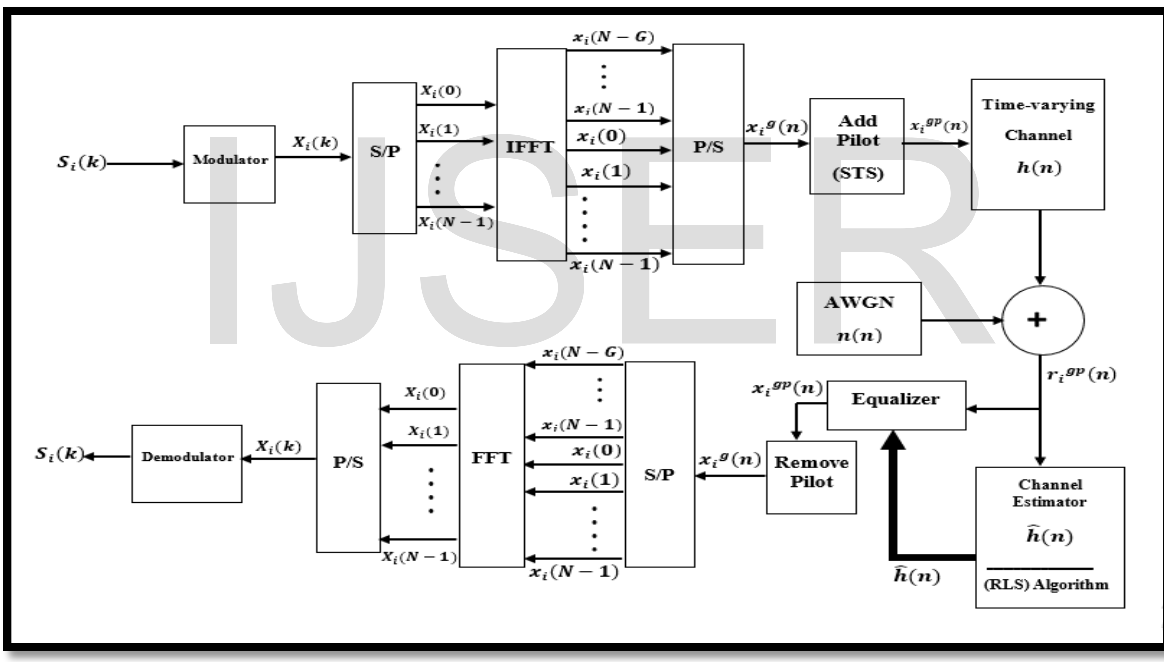


Fig. 2. Baseband model in OFDM system.

ISSN 2229-5518

$$r^{gp}(n) = x^{gp}(n) \star h(n) + n(n) \quad (1.10)$$

$$0 \leq n \leq N + G - 1$$

Where h(n) and n(n) represent the channel impulse response (CIR) with length L and the additive white Gaussian noise respectively and ($\star$) indicates the linear convolution. $\hat{h}(n)$ is the estimated time varying channel impulse response. In our simulation, the $\hat{h}(n)$values shown in table (1).

TABLE 1

The non-zero tabs of the channel ($\hat{h}(n) = 0$, elsewhere)

(n)	h_1	h_{11}	h_{21}
$\hat{h}(n)$	1.2014	0.6295	0.1744

4.2 Pilot Amplitude

The transmitter and the receiver have prior knowledge about the sequence and the amplitude of the superimposed pilot. For simplicity, the pilot amplitude (α) is selected to be real valued [9]. Fig. 3 illustrates the BER performance when the pilot amplitude changes for QPSK modulation in OFDM system through Rayleigh fading channel with three paths and maximum Doppler frequency ($f_m = 80Hz$). This scheme shows the advantage of imposed the pilot onto $x^g(n)$ once for each p (pilot period) symbols instead of the conventional way which insert the pilot into the OFDM symbols. The larger pilot amplitude may give better accuracy for the channel estimation but that will increase the power of the transmitted signal and causes more distortion in pilot removal block, such in our simulation when ($\alpha = 16$) introduced bad BER performance. Therefore, the optimal BER performance is achieved when ($\alpha = 10$) instead of larger values.

5. Simulation Results

In this section, by using computer simulation we show the performance of the direct channel estimation in OFDM system which used (STS) technique and adaptive (RLS) algorithm compare with the inverse channel estimation (Equalization) that used conventional pilot, the simulation

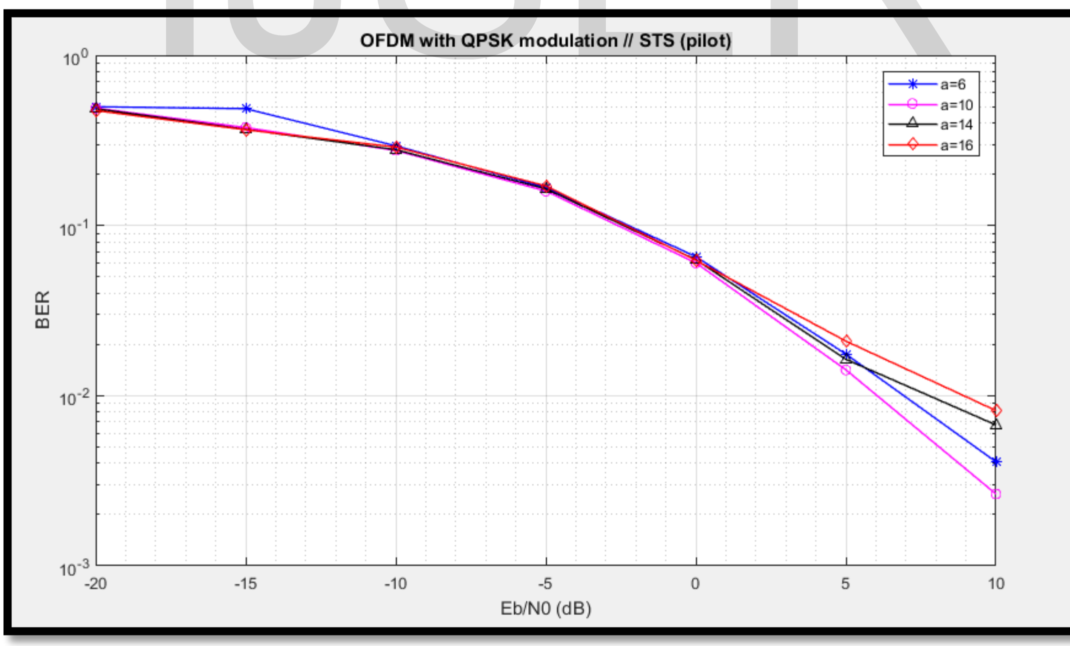


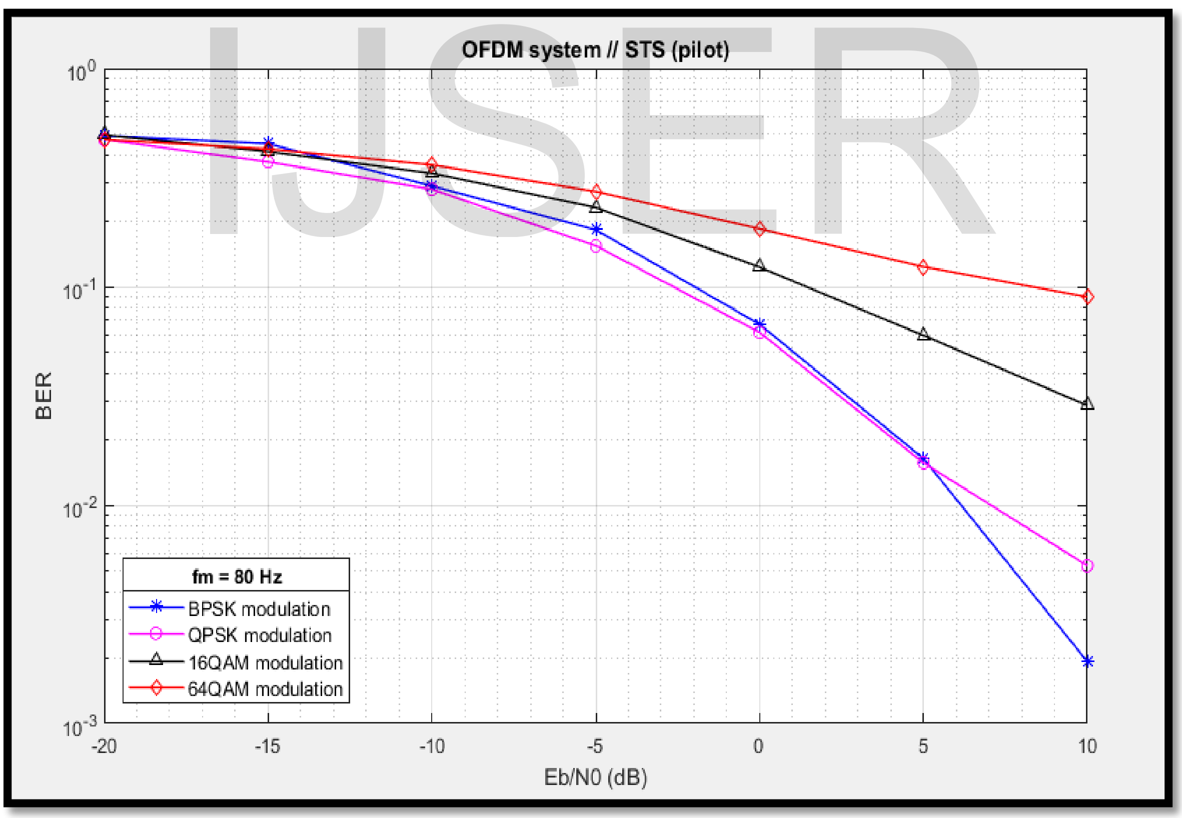
Fig. 3. BER versus Eb/No with different pilot amplitudes for QPSK modulation.

follows IEEE 802.11 specification. The transmitted signal will suffer from fast and frequency selective fading due to the Doppler shift and the multipath respectively [8]. The performance is measured through the Bit Error Rate (BER) in the system versus the energy per bit to noise power spectral density (PSD) ratio (Eb/No) which is significant parameter in digital communication system and measured in (dB). Fig. 4 and 5 show (BER) versus (Eb/No) with different modulation techniques such as (BPSK, QPSK, 16QAM, 64QAM) for the two above mentioned methods of channel estimation.

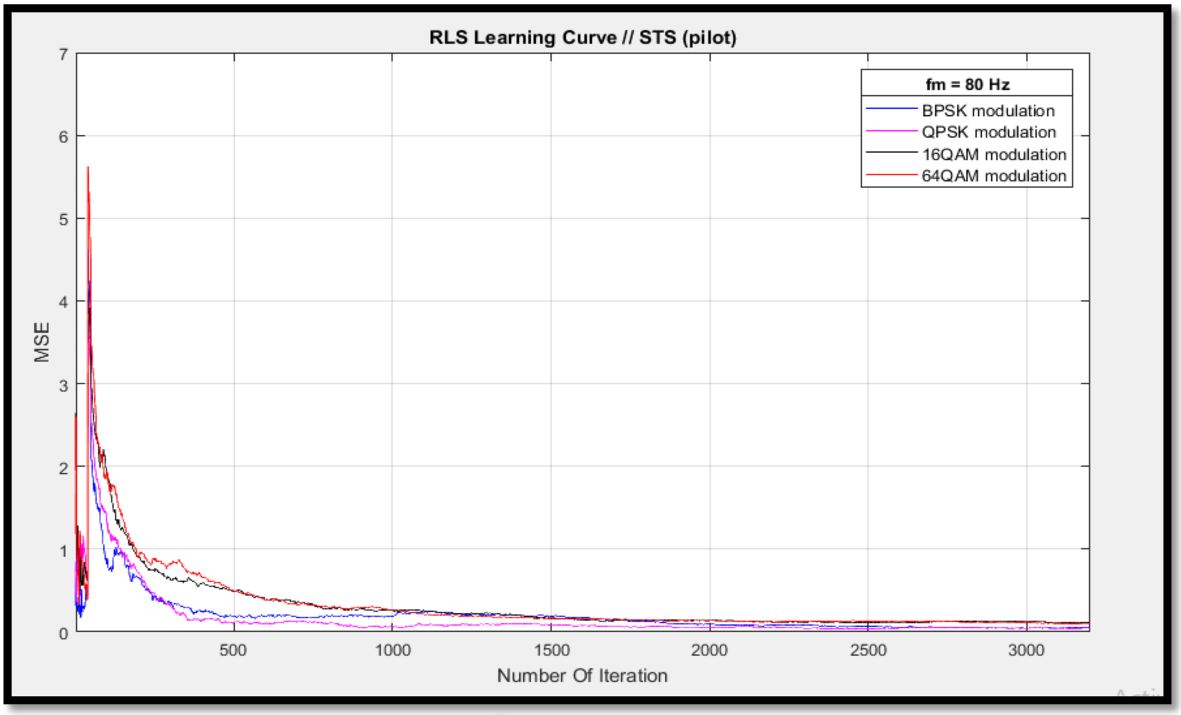
TABLE 2

Simulation parameters in OFDM system

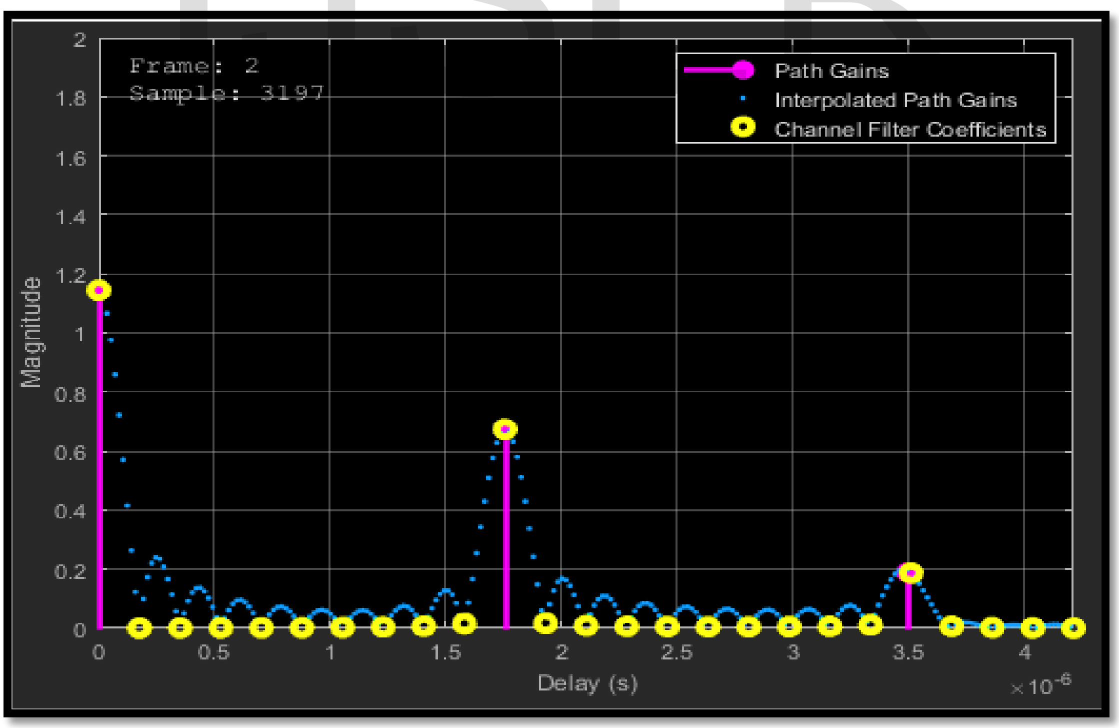
Variable	Value	Description
FFT	64	Fast Fourier Transform size
BW	20 MHz	Channel Bandwidth
f_c	900 MHz	Carrier Frequency
CP	16 samples	Cyclic prefix
nBlocks	40	Number of blocks
α	10	Pilot Amplitude
P	40	Pilot Period
Chan	channel	Rayleigh Fading Channel
L	40	Channel Length
f_m	80 Hz	Maximum Doppler Shift
D	$1e^{-6}$[0 1.75 3.5]	Multipath Delay vector / three paths
G	[0 -3 -6] dB	Multipath Gain vector / three paths



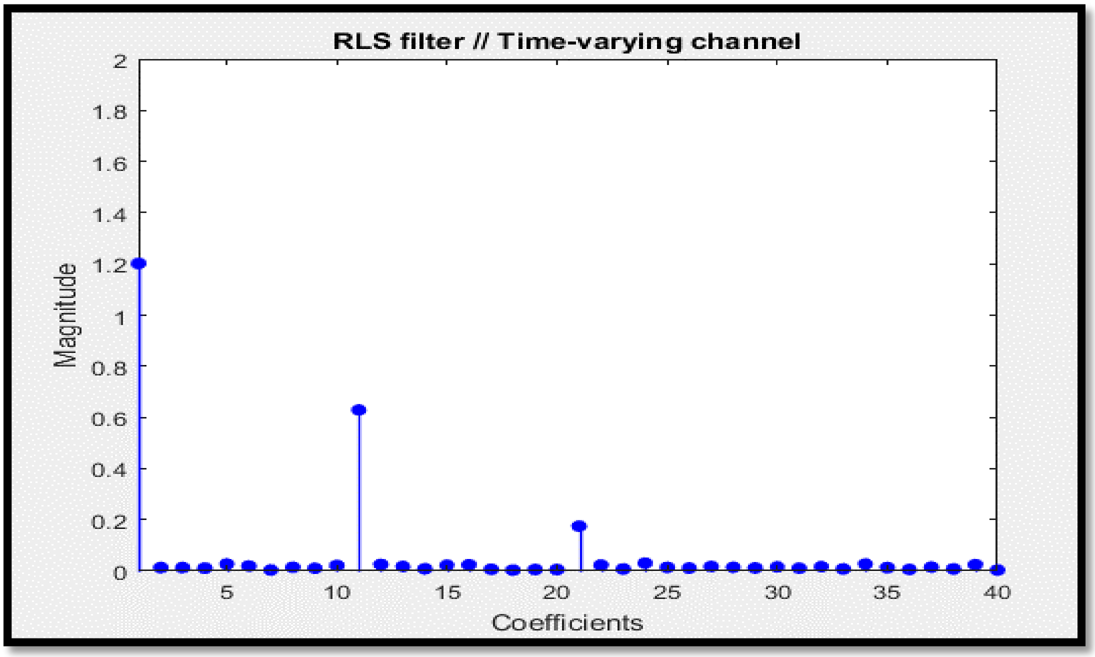
(a) (BER) versus (Eb/No) with different modulation techniques



(b) Learning curve of the (RLS) algorithm



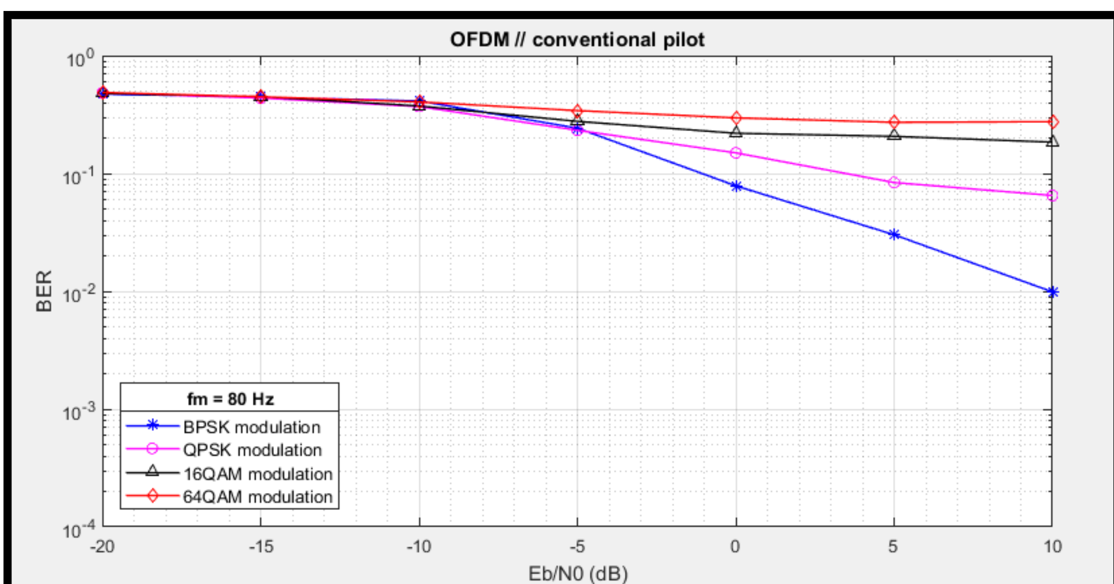
(c) Channel impulse response $h(n)$



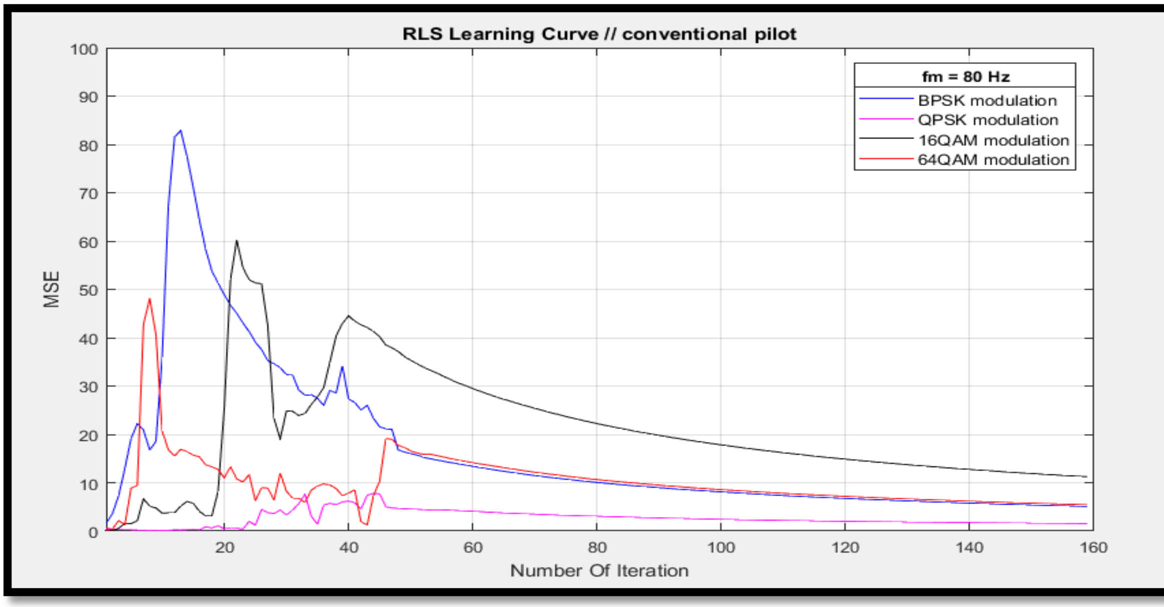
(d) Estimated channel impulse response $\hat{h}(n)$

Fig. 4. Performance of the direct channel estimation method

Fig. 4 illustrates the performance of the OFDM system when using our investigated scheme for direct channel estimation method. Note from Fig. 4-a that the performance of (STS) technique and (RLS) algorithm is better over smaller signal constellations (less complex) such as (BPSK), moreover when (Eb/No) is very high all these BER curves will experience the error floor problem. This occur because the signal is playing as noise role in channel estimation block. Fig. 4-b shows the convergence speed of the (RLS) algorithm with different modulation scheme. Due to the time varying channel, Fig. 4-c and d are taken at the same time and from Fig. 4-d we can see the accuracy of the estimation and the tracking when there is variation in (CIR) of the Fig. 4-c.



(a) (BER) versus (Eb/No) with different modulation techniques



(b) Learning curve of the (RLS) algorithm

Fig. 5. Performance of the inverse channel estimation method (Equalization).

Fig. 5 shows the performance of the OFDM system when using inverse channel estimation method (Equalization) with conventional pilot. Fig. 5-a illustrates that the performance of this method is not good compared with our investigated method. In Fig. 5-b, the convergence speed of the (RLS) algorithm is slow in this method for estimation and it needs more training Sequence (pilot) in each block for better performance.

6. Conclusions

In this work, we investigate adaptive direct channel estimation method in time domain based on (STS) periodic pilot using (RLS) adaptive algorithm in OFDM system to identify the time varying Rayleigh fading channel with various modulation schemes such as BPSK, QPSK, 16QAM and 64QAM. This method is simple and has high spectral efficiency, the system introduce good performance even with high Doppler shift (the (CIR) changes during one OFDM symbol duration) and it is minimize the (ISI) effect. The performance results of the investigated method is illustrated by the numerical simulations.

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