

Successive Data Schism and Interpolation for Channel Estimation in OFDM using Wavelet Denoising

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Abstract— This paper presents a new technique of interpolation for channel estimation in OFDM (Orthogonal Frequency Division Multiplexing) system based on a pilot signal through wavelet shrinkage denoising. Channel estimation for OFDM system is generally carried out by transmitting known pilot symbols in given positions of the frequency-time grid. Using interpolation methods the channel can be estimated from the coefficients extracted of those pilots. The proposed interpolation is an improved method for successive data schism and interpolation. This interpolation based on mean and variance to calculate the interpolated points between two known points. Simulation results show that the proposed interpolation can be controlled by β and ξ factor for the mean and variance respectively. Simulation results shows that the OFDM system over Wavelet de-noising filter will increase the performance of the system by 3-4 dB.

Keywords— estimation, orthogonal frequency division multiplexing (OFDM), Comb type, Block type, Wavelet denoising.

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) technique has paid more attention in wireless communication system in the recent period [1]. OFDM is a digital multi-carrier modulation scheme, which uses a large number of closely-spaced orthogonal sub-carriers that is particularly suitable for frequency-selective channels and high data rates. This technique transforms a frequency selective wide-band channel into a group of non-selective narrow-band channels, which makes it robust against large delay spreads by preserving orthogonality in the frequency domain as in frequency selective fading channels wideband signals suffer inter-symbol interference while those narrowband signals only experience fading. This system is a modern multiplexing technique that has very desirable properties. It is bandwidth efficient due to the orthogonality of the subcarriers and is able to cope with frequency selective fading channels very well due to the spreading of the data.

Therefore, OFDM systems are strong candidates for an air interface of future fourth-generation mobile wireless systems. In order to achieve the potential advantages of OFDM systems, the channel coefficients should be estimated carefully. To reduce inter-carrier interference we need to estimate the channel and the parameters used to approximate the channel variations.

Channel estimation is an important and necessary function for modern wireless receivers. With even a limited knowledge of the wireless channel properties, a receiver can gain insight into the information that was sent by the transmitter. The goal of channel estimation is to measure the effects of the channel on known or partially known transmissions. A channel will change with changing conditions and topology. The interpolation of the channel for comb-type based channel estimation can depend on linear interpolation, spline cubic interpolation, and time domain interpolation [2].

Next section gives a description of the system model. Section III gives the methods of channel estimation and describes our new type of interpolation for the channel estimation of OFDM system. Section VI explains a Wavelet denoising. Simulation parameters of OFDM system given in section V. The discussion of the result given in section IV and the conclusion is given in section VII.

II. SYSTEM MODEL

This section will describe transmitter and receiver structures of OFDM system based pilot signal using wavelet denoising for channel estimation.

A. Transmitter Structure

As shown in Fig. 1, the vector of data s is mapped according to constellation of modulation scheme. N_f and N_t pilot symbols are inserted periodically with the distance D_f and D_t in frequency or time grid. Serial vector of the result data converted to $N \times K$ vectors by a serial-to-parallel converter where N is the number of total sub-carriers in one OFDM

symbol and K is the total number of OFDM symbols in the frame. At this time, each OFDM symbols vector in the frame $x_N = [x_1(k) \ x_2(k) \ x_3(k) \dots x_N(k)]$ will be modulated using N point Inverse Fast Fourier Transform (IFFT). Insertion of the Guard interval to prevent possible inter-symbol interference in OFDM signals, and the resultant symbol $x_M(n)$ is:

$$X_M(n) = \begin{cases} X(N+n), & n = -N_g, -N_g + 1, \dots, -1 \\ X(n), & n = 0, 1, \dots, N-1 \end{cases} \quad (1)$$

where N_g is the length of the guard interval. At the terminal end of the transmitter, the resulted OFDM vector in the frame will be sent serially through the time varying frequency selective channel. The channel will be described using baseband equivalent impulse response as $h(k) = [h_1(k) \ h_2(k) \dots h_{L_f}(k)]^T$ where L_f is the length of channel [3]. The channel is modelled as an impulse response $h(t)$ followed by the complex additive white Gaussian noise (AWGN).

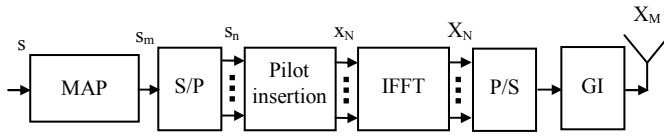


Fig. 1 Transmitter structure of the OFDM

B. Receiver Structure

At the receiver side as shown in Fig. 3, the received signal will be demodulated using N point (FFT), where the resulted signal will be as follow:

$$y_n(k) = x_n(k)H_n(k) + n_n(k) \quad k=1,2,\dots,K \quad n=1,2,\dots,N \quad (2)$$

Where $n_n(k)$ is the FFT sample of the additive white Gaussian noise, and $H_n(k)$ is the frequency domain of the channel coefficient for the n th sub-carrier and the k th OFDM symbol. Channel coefficients will be extracted from the received pilot signal by using LS channel estimation in frequency domain as the receiver know the sample at that signal as:

$$\tilde{H}_p(k) = \frac{y_p(k)}{x_p(k)} = H_p(k) + \frac{n_p(k)}{x_p(k)} \quad (3)$$

where $x_p(k)$ is the pilot sample in the OFDM signal, $\tilde{H}_p(k)$ is the coefficient of the channel at that pilot sample [3]. Where the channel will be estimated then filtered using a wavelet de-noising as it can be seen in Fig 2 then using the estimated channel to be combined with received signal to reduce the channel from that signal.

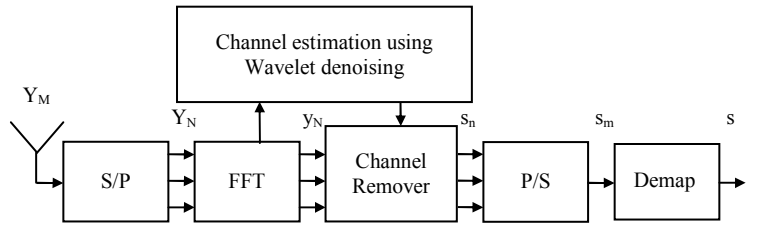


Fig. 2 Receiver structure of OFDM system

III. CHANNEL ESTIMATION

In this section we will discuss the pilot sample arrangement and our proposed method of interpolation for the estimation of the channel.

A. Pilot Samples arrangement

There are two main types for distribution of the pilot in OFDM symbol which are Comb type and Block type as shown in figure 3.

In block-type pilot based channel estimation, OFDM channel estimation symbols are transmitted periodically, in which all sub-carriers are used as pilots. If the channel is constant during the block, there will be no channel estimation error since the pilots are sent at all carriers as can be seen in figure 3.a.

In comb-type shown in figure 3.b, pilot based channel estimation, an efficient interpolation technique is necessary in order to estimate channel at data sub-carriers by using the channel information at pilot sub-carriers.

B. Alnuaimy-Mahamod Interpolation

Alnuaimy-Mahmod interpolation is based on the mean and variance of two adjacent points. This new type of interpolation can be controlled by β and ξ factor. Those factors give the interpolation more flexibility for the perfect estimation of the channel.

1) Formulation

- 1) Calculate the mean and variance for two adjacent points to interpolate the new points in between, as follow:

$$\bar{x}(x_{p,p+1}) = \frac{1}{N_p} \sum_{i=1}^{N_p} x_i \quad (9)$$

$$\sigma^2(x_{p,p+1}) = \frac{1}{N_p} \sum_{i=1}^{N_p} (x_i - \bar{x}_{p,p+1})^2 \quad (10)$$

- 2) Multiply the mean and the variance by β and ξ factors respectively which will be explained in the next section.
- 3) Calculate the two interpolated points using the following equation:

$$x_{e1,2} = \frac{c_1}{2} \pm \sqrt{c_2 + \left(\frac{c_1}{2}\right)^2} \quad (11)$$

where x_e is the interpolated values, while c_1 and c_2 are:

$$c_1 = N_p \times \beta \bar{x} - (x_p + x_{p+1}) \quad (12)$$

$$c_2 = \frac{N_p \times (\beta \bar{x})^2 + N_p \times (\xi \sigma^2) - (x_p + x_{p+1} + c_1)}{2} \quad (13)$$

- 4) Use the resultant number of points to interpolate others following the same steps (1-3) in order to get the required number of the interpolated points.

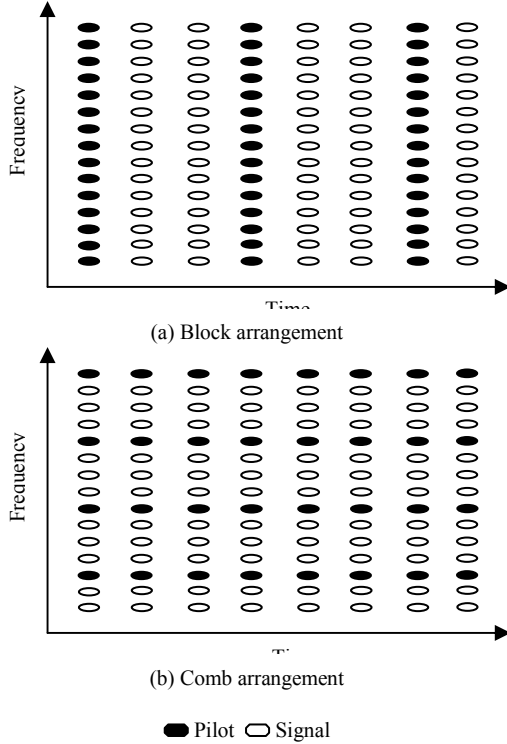


Fig. 3 Pilot arrangement

2) β and ξ factors

β and ξ factors are the modification factors for the mean and variance respectively. These factors control the calculated values to be closer or further from the known values.

β factor controls the calculated values of the interpolation as those can be upper, lower or on the line (in between) of the used values. When β equal to 1 the calculated values will be on the line of the used values for interpolation. As β increased the interpolated values gets higher to the used sample while as it is decreased the interpolated values gets down to the used values. This factor may cause error in the interpolated values especially when the used points are real values; this factor can cause generation of complex values. Therefore, the default value for β factor is 1. We avoid changing the value of this factor, but we can change if we need.

ξ factor controls the calculated values of the interpolation to be closer to used points or further but in between. When ξ equal to 0.5 the calculated samples will be a mid point between to the used points (i.e. close to each

other). As ξ increase the interpolated values getting closer to the used values, but when ξ equal to 1 the values will be much closer or equal to the used ones as β equals to 1 (i.e. equals to the values of the used points).

3) Samples Interpolation

The subdivision of the symbols should be submitted to some rules. The interpolation should be made between two adjacent samples to create two other samples lay in between. The new interpolated samples can be used to calculate other points. The possible number of the interpolated points can be calculated according to the following equation:

$$N = N_p + 2 \times (N_p - 1) \quad (14)$$

where N is the total number of the samples after calculation and N_p is the number of the used samples. N_p will be updated to be equal to N each time we repeat the interpolation, as shown in fig 4.

We can also get other distributions for the interpolation which is un-uniform distributions according to variant values of ξ factor as shown in fig 5.

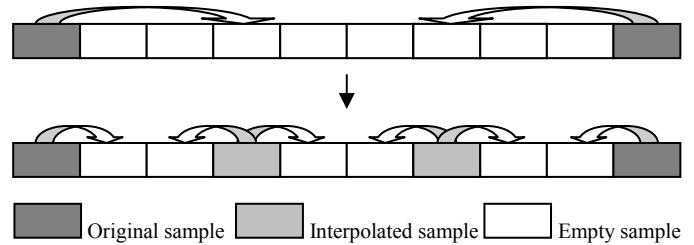


Fig.4 Interpolation subdivision

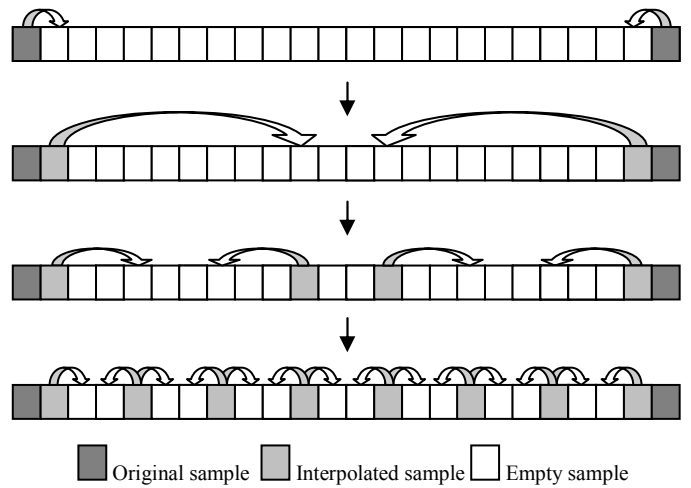


Fig. 5 Interpolation distribution based on variant values of ξ factor

IV. WAVELET DENOISING

Wavelet de-noising can bring to more accurate estimation for the channel by reducing the effect of the noise on the estimated channel. As the noisy estimated channel pass through the wavelet de-noising filter the estimated signal will be more

accurate. The general wavelet de-noising procedure is as follows [4]:

- 1) Apply wavelet transform to the noisy signal to produce the noisy wavelet coefficients to the level which we can properly distinguish the PD occurrence.
- 2) Select appropriate threshold limit at each level and threshold method (hard or soft threshold) to best remove the noises.
- 3) Inverse wavelets transform of the thresholded wavelet coefficients to obtain a de-noised signal.

V. SIMULATION

In this paper, the simulation of OFDM system of specific parameter, shown in Table 1 has been considered. Comb type pilot arrangement of OFDM symbols will be considered over Rayleigh fading channel and Additive White Gaussian Noise.

Table 1. OFDM system Parameter

Parameter	Specifications
IFFT and FFT Size	1024
Number of Pilot	114
Pilot rate	1/9
Guard Interval	256
Guard Type	Cyclic Extension
Sample Rate	44.1 kHz
Doppler frequency	100 Hz
Signal constellation	BPSK

Multi-path Rayleigh fading channel model for ATTC (Advanced Television Technology Center) is considered in our simulation, where static case impulse response is given by [2]:

$$h(n) = \alpha(n) + 0.3162\alpha(n-2) + 0.1995 \cdot \alpha(n-17) + 0.1296\alpha(n-36) + 0.1\alpha(n-75) + 0.1\alpha(n-137) \quad (15)$$

VI. RESULT

Figure 6 shows, the effect of ξ factor of Alnuaimy-Mahamod interpolation on OFDM system over Binary Phase Shift Keying (BPSK). Different values of ξ factor are used over fixed value of β factor (i.e. β equal to 1). We choose the value of ξ that give best and worst performance of OFDM system with some other values that give other performances for the system in between. The best performance can be achieved is when ξ equal to 0.61 and the worst case is when ξ equal to 0.67. When ξ equal to 0.61 the performance of the system exceeds the performance of the system at 0.67 values of ξ factor by about 3.4 to 3.5 dB of Signal to Noise Ratio (SNR) at 10^{-3} Bit Error Rate (BER). ξ equal to 0.61 has been considered to check the effect of β factor of the interpolation on the system. Figure 7 shows, the performance of the system for different values of β factor of the proposed interpolation on the system. 0.96 and 1.08 values of β give the best and the worst performance of OFDM system

respectively. When β equal 0.96 the performance of OFDM system exceeds by 4.5-5 dB over the system with 1.08 of β at 10^{-3} BER.

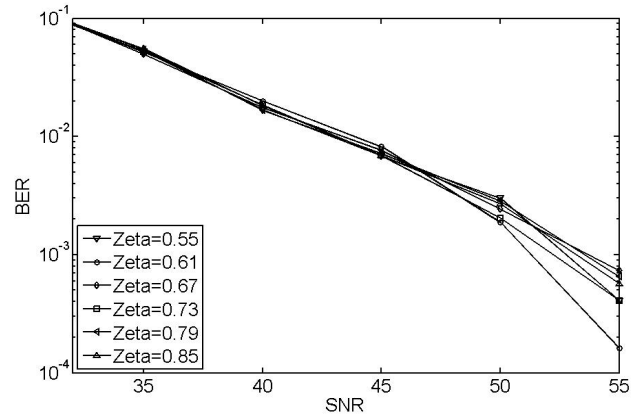


Fig. 6 ξ factor Effect of Alnuaimy-Mahamod interpolation on the system performance.

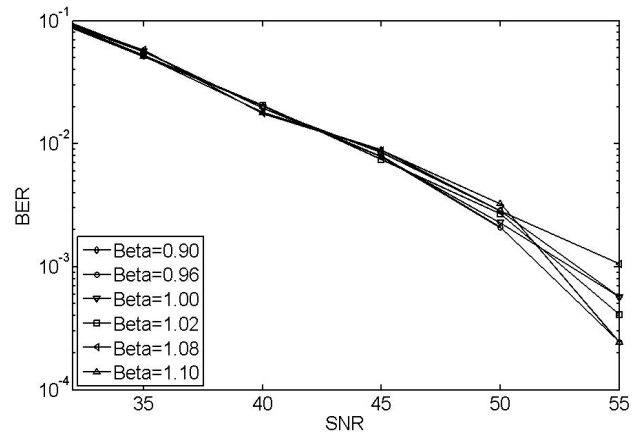


Fig. 7 β factor Effect of Alnuaimy-Mahamod interpolation on the system performance.

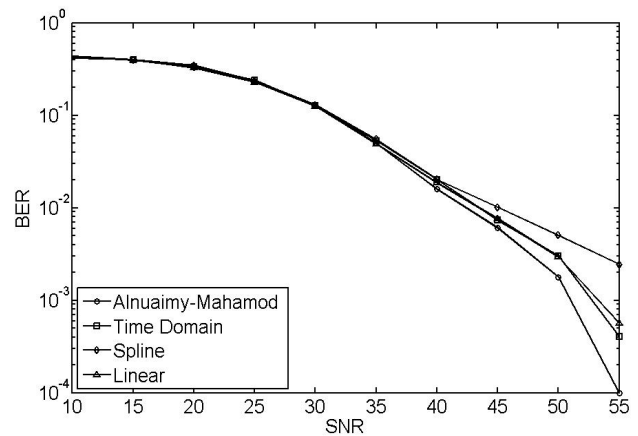


Fig. 8 Comparison between the performances of different type of interpolation on OFDM system based on Bit Error Rate (BER)

The legends "Linear, Spline, Cubic, Time Domain and Alnuaimy-Mahamod" shown in figure 8 and 9, denote interpolation schemes of comb-type channel estimation with the LS estimate at the pilot frequencies.

Alnuaimy-mahamod interpolation of 0.96 and 0.61 values of β and ξ factors respectively, have been selected for the Comparison between the performances of different type of interpolation on OFDM system based on Bit Error Rate, as shown in figure 8. At 10^{-2} BER the performance of the system using the proposed interpolation, exceed by about 2 to 2.1 dB, 2.4 to 2.3 dB and 2.5dB to 3 dB over Time Domain, Spline and Linear interpolation respectively.

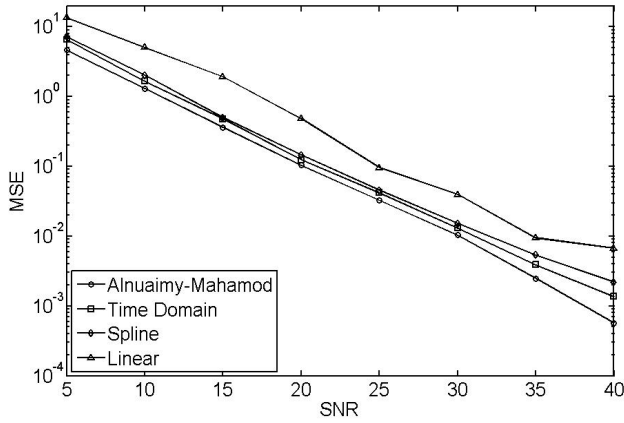


Fig. 9 Comparison between the performances of different type of interpolation on OFDM system based on Mean Square Error (MSE)

Figure 9 shows the comparison between the performances of different type of interpolation on OFDM system based on Mean Square Error (MSE) for the estimation of the channel. It is obvious that, the estimation of the channel of OFDM system based on our proposed type of interpolation is better than other type of estimation. Alnuaimy-Mahamod interpolation gives more accuracy for the estimation of the channel over AWGN.

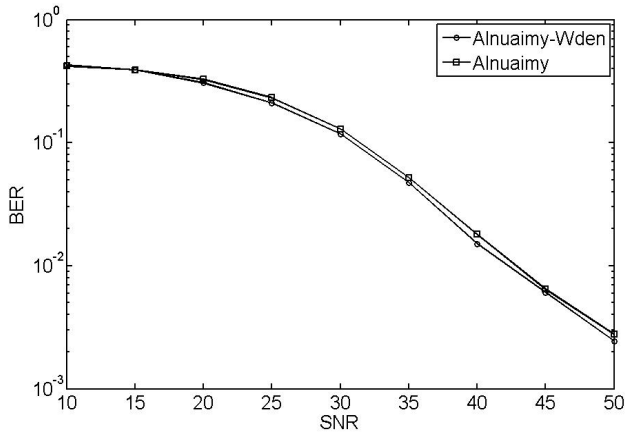


Fig. 10 OFDM system Performance based on Alnuaimy-Mahamod interpolation with and without wavelet denoising

The legends "Alnuaimy-Wden and Alnuaimy" shown in figure 10 represent OFDM system based on Alnuaimy-Mahamod interpolation with and without Wavelet denoising respectively. It is clear from the figure that the performance of OFDM system based on Alnuaimy-Mahamod interpolation for the estimation of the channel enhanced by

adding of wavelet denoising filter on the pilot signal by about 1.5 dB to 2 dB over the same system without wavelet denoising.

VII. CONCLUSIONS

In this paper, a full review of comb type pilot based channel estimation is given. Channel estimation based on comb type pilot arrangement is presented by giving the channel estimation methods at the pilot frequencies and the interpolation of the channel at data frequencies. The simulation results show that comb-type pilot based channel estimation based Alnuaimy-Mahamod interpolation gives better estimation for the channel over other types of interpolation by about 2 dB to 5 dB at 10^{-3} BER.

The estimation of the channel for OFDM system based Alnuaimy-Mahamod interpolation enhanced to 1.5 dB to 2 dB by submitting of pilot signals to wavelet denoising filter.

Major changing in the values β factor (i.e. more than 1.5) and (i.e. more than 1) ξ factor causes error in the estimation of the channel coefficients as a value of.

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