COMPARISON OF CHANNEL ESTIMATION AND EQUALIZATION TECHNIQUES FOR OFDM SYSTEMS

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ABSTRACT

In OFDM (Orthogonal frequency division multiplexing) systems, channel estimation and channel equalization play a key role in overcoming distortions caused by phenomena like fading, delay spread and multipath effect. In this paper, channel estimation and equalization techniques are analyzed to improve the performance of OFDM system. The channel estimation techniques considered here are estimation using wiener filter and frequency domain approach. Prior Channel estimation leads to simple equalization. The channel equalization techniques employed here are based on LMS algorithm and one tap frequency domain equalization, under different channels; AWGN, Rayleigh and Rician channels. Eye patterns for different channels are compared in simulation. It is observed from simulation that wiener filter provides better estimation and OFDM performance is better under AWGN channel than fading channels. SER curves shows 6dB improvement in AWGN performance than fading channels to achieve 0.1 SER. In addition, MSE performance shows fast convergence for AWGN channel.

KEYWORDS

AWGN, channel estimation, LMS, OFDM.

1. INTRODUCTION

OFDM technology is a popular technique for transmission of signals over wireless channels, due to its many advantages such as the high spectral efficiency, robustness to frequency selective fading, and the feasibility of low-cost transceiver implementations [1].

As channel estimation and equalization is found to greatly affect the performance of OFDM systems, they are considered as a prime subject of analysis in this paper. In this paper the channel estimation is done prior to demodulation using wiener filter which uses the autocorrelation and cross-correlation of input and output sequences to determine the channel. Later, channel equalization is done in one step using frequency domain approach. Then the simulations are carried out for AWGN, Rayleigh and Rician channels.

The outline of this paper is organized as follows. In Section II, the OFDM systems are briefly introduced. Then the channel estimation technique used in the simulations is discussed in Section III. Section IV discusses the channel equalization in general and also with respect to OFDM. Simulation results and its analyses are presented in Section V, and finally conclusions are given in Section VI.

2. OFDM SYSTEM MODEL

OFDM is a special case of multi-carrier transmission where a single data stream is transmitted over a number of low rate subcarriers. The idea of OFDM is to split the total transmission bandwidth into a number of orthogonal subcarriers in order to transmit symbols using these subcarriers in parallel. OFDM has become the basis of many telecommunication standards including wireless local area networks (LANs), digital terrestrial television (DTT) and digital radio broadcasting in much of the world [2].

2.1 Description of Basic OFDM System

OFDM signal is generated by modulating the input data using QAM (Quadrature amplitude modulation). QAM is used here because it is efficient in conserving bandwidth. After modulation serial to parallel conversion is made and symbols are mapped on to orthogonal subcarriers using IFFT (Inverse Fast Fourier Transform). Cyclic prefix (which is typically a repetition of the last samples of data portion of the block that is usually appended to the beginning of the data payload) is added after parallel to serial conversion. Cyclic prefix is useful in maintaining orthogonality and thus helps in eliminating ICI (Inter-Carrier Interference); it also in addition eliminates the ISI (Inter Symbol Interference) effect.

At the receiver end, cyclic prefix is removed and serial to parallel conversion is done. The FFT of each symbol is then taken to convert the received signal back to frequency domain. After this, by proper channel estimation and equalization the original transmitted spectrum is found. Later, parallel to serial conversion is done and then finally demodulation is carried out. The generic base-band discrete-time block diagram of the OFDM transceiver system depicting the above described procedure is shown in Figure 1.

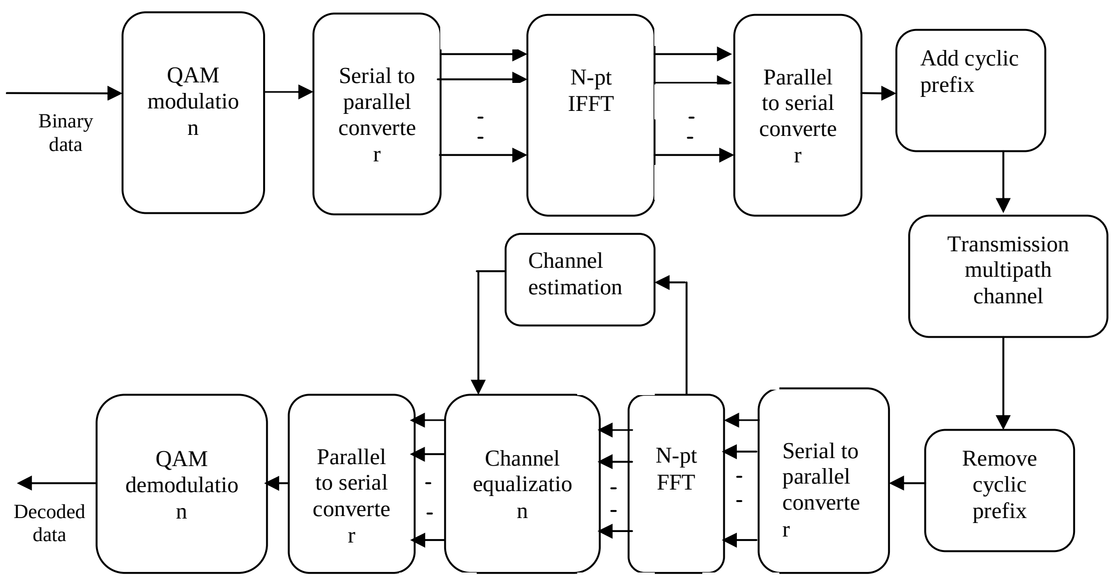

Figure1. Block diagram of an OFDM system

3. CHANNEL ESTIMATION

In case of OFDM systems, a dynamic estimation of channel is very much necessary before the demodulation since the radio channel is frequency selective and time-varying for wide band mobile communication systems [3]. In literatures it is found that a simpler way of estimating the channel is through the use of wiener filter (WF). Wiener filters are basically a class of optimum linear filters which involve linear estimation of a desired signal sequence from another related sequence. The coefficients of a Wiener filter are calculated to minimize the average squared distance between the filter output and a desired signal. The Wiener-Hopf equation which forms the basis of wiener filter is given as

$$R_x w^0 = p_{dx} \tag{1}$$

Using this channel estimation is made as follows

$$w^o = R_x^{-1} p_{dx} \tag{2}$$

Where $R_x$is autocorrelation matrix of input sequence, and $p_{dx}$is cross-correlation matrix between filter input and desired response, w^0indicates wiener filter coefficients.

Channel estimation can also be done using frequency domain (FD) approach. It mainly decreases the computational complexity that is found in time domain. The input-output relationship in frequency domain is given by equation (3).

$$Y = diag(X)H + N = diag(X)Q_{P+1}h + N \tag{3}$$

Where Y, X and H are N-length FFT's of y (output), x (input) and h (channel) respectively and N is additive white Gaussian noise. Q_{P+1} is the matrix which contains first P+1 columns of Q (Q is $N \times N$ DFT matrix). Both the above channel estimation techniques are compared using a common channel in MATLAB.

4. CHANNEL EQUALIZATION

Channel equalization is the process of reducing amplitude, frequency and phase distortion in a channel with the intent of improving transmission performance. The basic operation of channel equalization is to inverse the effect of the channel. As it can be seen in Fig.1 channel equalization is always carried out after channel estimation.

Adaptive equalization is a technique that automatically adapts to the time varying properties of the communication channel. LMS algorithm is one such popular technique that can be used for adaptive channel equalization. The criterion used in this algorithm is to minimize the Mean Square Error (MSE) between the desired equalizer output and the actual equalizer output [4].

$$Error = desired\,output - actual\,output \tag{4}$$

The LMS algorithm seeks to minimize the mean square error given in the equation (4). The basic equation which is iteratively used in LMS algorithm is

$$w(n+1) = w(n) - \alpha e^{*}(n)u(n) \tag{5}$$

In equation (5), $u(n)$is the input signal, $w(n)$ is the equalizer filter taps and α indicates the step-size. The parameter α controls the convergence rate of the algorithm. The output of the filter with the LMS algorithm approximated weights is the equalized signal and is as given in equation (6).

$$y(n) = w^H(n)u(n) \tag{6}$$

The channel equalization using LMS algorithm is done as shown in Figure 2. In the block diagram, input is generated by random number generator(1) and it is passed through the channel. Random number generator(1) after suitable delay also supplies the desired response applied to the adaptive equalizer in the form of training sequence. Random number generator(2) serves as a source of additive white noise that corrupts the channel output. These two random generators are independent of each other. The adaptive equalizer (which is implanted using LMS algorithm) has the task of correcting the distortion produced by the channel in the presence of noise [6]. The difference between the equalizer output and the reference signal (delayed input signal) is used by the LMS algorithm to minimize the mean square error between the actual output and desired output. In this way LMS equalizes the channel output.

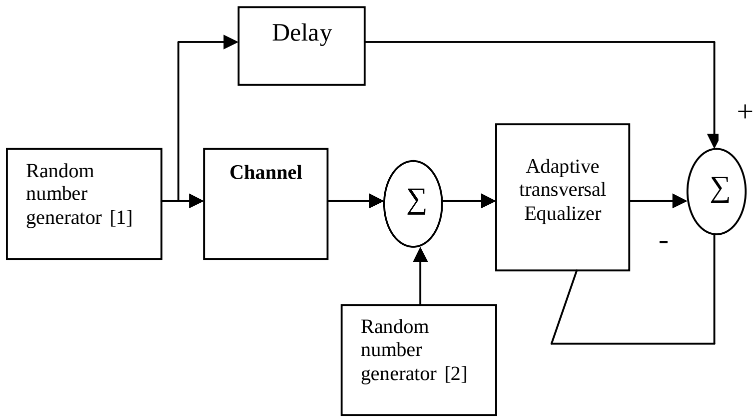

Figure 2. Block diagram of adaptive channel equalization [6]

In Figure 2 the channel used can be AWGN, Rayleigh or Rician. Thus it is necessary to discuss each of these channel models. The AWGN channel is simply represented as

$$y = x + n \quad (7)$$

Where n is the Guassian random noise and x is the input, y is output.

The Rayleigh channel is as depicted in equation 8.

$$P(r_{Ra}) = \frac{r_{Ra}}{\sigma} exp(-\frac{{r_{Ra}}^2}{2\sigma^2}) \quad (8)$$

Where r_{Ra} is the sample function of Rayleigh distributed random process and σ is the variance. The received signal after passing through the Rayleigh channel can be depicted in two equivalent ways as in equation 9 and 10.

$$\hat{s}(t) = A\sum_{i=0}^{D(t)-1} a_i(t)\cos\{2\pi f_c[t - \tau_i(t)]\} \quad (9)$$

Where $a_i(t)$ and $\tau_i(t)$ are gain factor and delay for a specific path i at specific time t. Equation (10) can be equivalently written as:

$$\hat{s}(t) = Ar_{Ra}(t)\cos[2\pi f_c t + \varphi_{Ra}(t)] \quad (10)$$

Where $r_{Ra}(t)$ and $\varphi_{Ra}(t)$ are amplitude and phase from a particular measurement of a Rayleigh distributed random process.

The Rician channel is best described by its probability density function (PDF) given by the equation 11.

$$f_R(\rho) = \exp\left(\frac{-\rho^2 - V_1^2}{P_{dif}}\right) I_0\left(\frac{2\rho V_1}{V_{dif}}\right) \quad (11)$$

$$K = \frac{specular\ power}{Nonspecular\ power} = \frac{V_1^2}{P_{dif}} \quad (12)$$

Where $I_0(.)$ is a zero order modified Bessel function.

Channel equalization can also be carried out in frequency domain. In case of OFDM, since each subchannel has a different gain, one-tap gain adjustment can be applied to compensate subchannel scaling. Equalization is used to facilitate the use of same modular decision device on all subchannels [5]. The one-tap equalization is so simple that it can be described in just one equation. Equation (13) shows how the one-tap channel equalization is done.

$$Y = inv\big(diag(hf)\big)X\ where\ hf = fft(channel) \quad (13)$$

Where Y, hf and X are FFT's of output signal, channel and input signal to the channel. From the equation it can be inferred that channel needs to be known. Thus for one-tap equalization proper channel estimation is essential. But in case of LMS algorithm, only with the help of desired signal and channel output, the equalizer taps are found by an iterative method and that is used to find the equalized signal.

5. Simulation Results

In this section, simulations for wiener filter channel estimation and equalization using LMS and frequency domain approach are carried out. Once the channel is known by estimation, equalization becomes simple.

5.1 Channel estimation

Channel estimation is first performed by Weiner filter method and frequency domain method. The estimated coefficients for both the techniques are shown in table 1. The comparison of estimated coefficients obtained using the two estimation techniques are also shown graphically in Figure 3. It can be inferred from the table that wiener filter channel estimation is more accurate in estimating channel coefficients.

Table 1. Comparison between WF Estimation and FD Estimation.

Type of channel estimation	**Actual channel coefficients**	**Estimated coefficients**
Weiner filter	[0.3000 ,-0.5000, 0. 1.0000 , 0.2000, -0.3000]	[0.3000, -0.5000 0.0000, 1.0000 0.2000, -0.3000]
Frequency domain approach	[0.3000 ,-0.5000, 0. 1.0000 , 0.2000, -0.3000]	[0.3002,-0.4990,-0.0004. 0.9974 0.1977, -0.2983

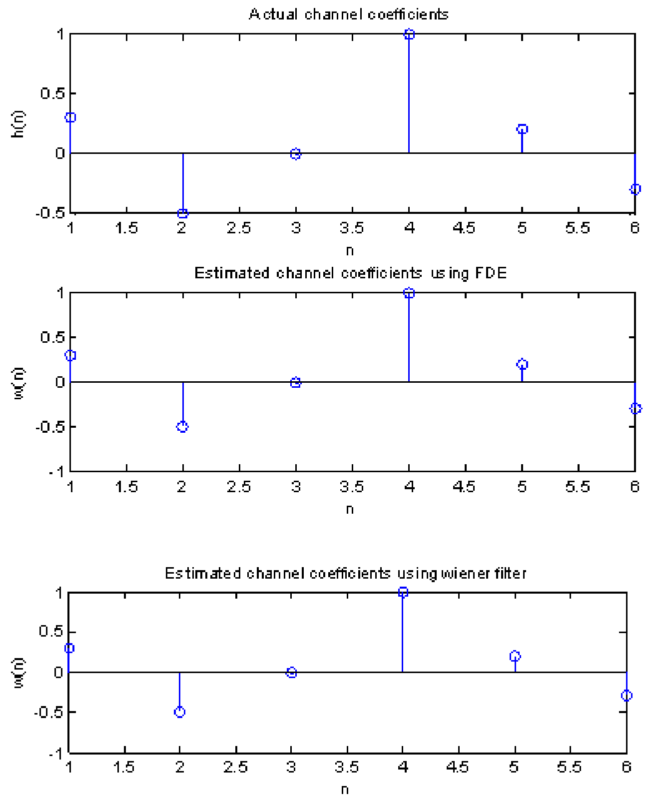

Figure 3. Actual and estimated coefficients for FD estimation and WF estimation.

5.2 Channel Equalization

Channel equalization using LMS algorithm is performed as shown in Figure 2. The results are shown in Fig.4 for channel being raised-cosine filter.

$$h(n) = \begin{cases} \frac{1}{2}\left[1 + \cos\left(\frac{2\pi}{W}(n-2)\right)\right], & n = 1,2,3 \\ 0, & otherwise \end{cases} \quad (14)$$

where $h(n)$is the impulse response of the raise-cosine channel, W is a parameter that controls the amount of amplitude distortion produced by the channel. W controls the eigenvalue spread of the autocorrelation matrix of the tap inputs in the equalizer, with eigenvalue spread increasing with W.

The Figure 4 shows the simulation result for three values of W i.e. 2.9, 3.3 and 3.5. The plot shows that as W increases the MSE converges to a large value. The channel in Figure 2 is replaced with AWGN, Rayleigh and Rician channels and their effects are illustrated in Figure 5. It can be seen from the plot that AWGN channel converges faster than Rayleigh and Rician channels.

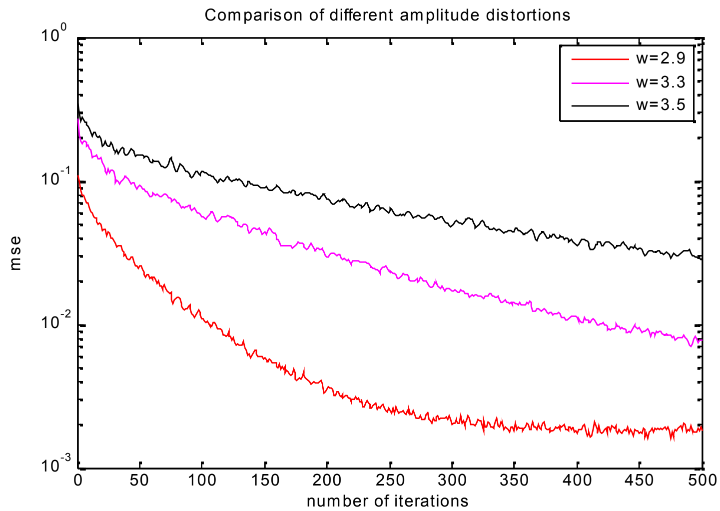

Figure 4. Output of adaptive equalizer using α=0.025, M=11

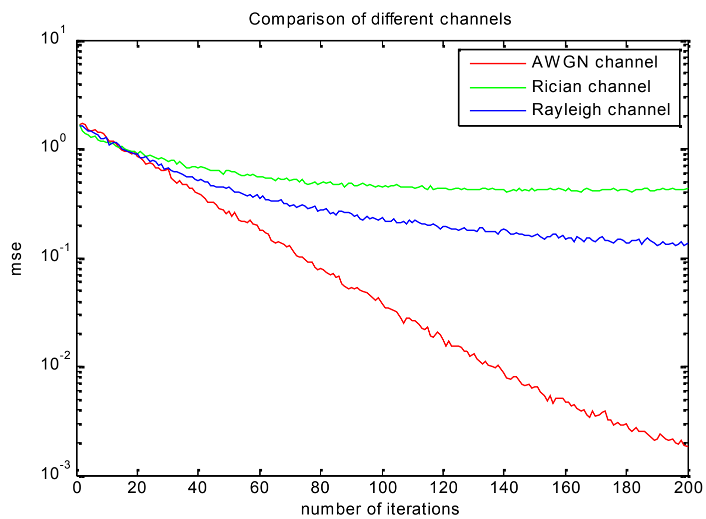

Figure 5. Output with AWGN, Rayleigh and Rician channel

SER (symbol error rate) plots of OFDM system with channel estimation made using wiener filter under AWGN; Rayleigh and Rician channels are compared and shown in Figure 6. Rayleigh channel is found to give a better output compared to Rician channel. To achieve SER of 0.1, 6dB additional requirement of SNR required with fading channel compared to AWGN.

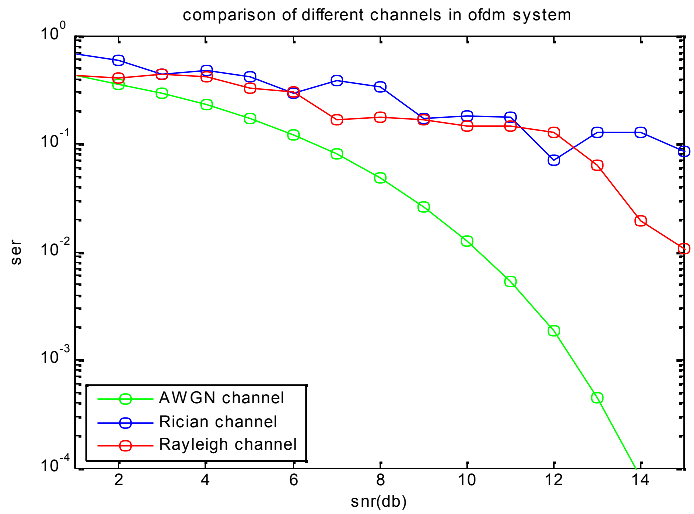

Figure 6. SER plots comparing three different channels in OFDM systems.

The eyepatterns of different channels are analyzed. As it can be seen, the eye diagram also shows that in AWGN channel Inte symbol Interference is less than Rayleigh and Rician. The eyepattern in general depicts various characteristics like jitter, delay, quality factor, SNR etc. Eye opening (i.e. height, peak to peak) measures the additive noise; eye overshoot depicts the peak distortion due to interruptions on the signal path. Eye width gives the time synchronization and jitter effects and the eye closure measures the ISI (Inter symbol interference) and additive noise. The eye closure is observed in both Rayleigh and Rician channels depicting its worst performance. The eye patterns of AWGN, Rayleigh and Rician are shown in Figure 7, 8 and 9 respectively.

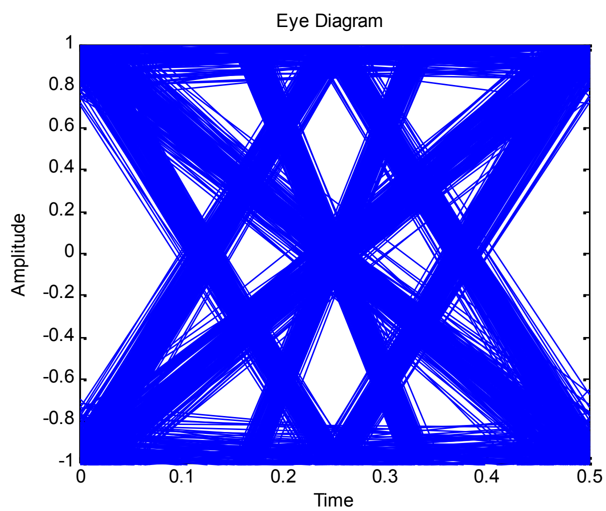

Figure 7. Eye pattern of AWGN channel

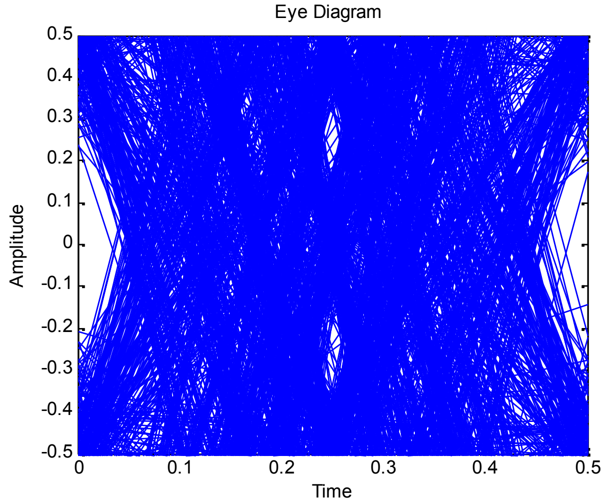

Figure 8. Eye pattern of Rayleigh channel

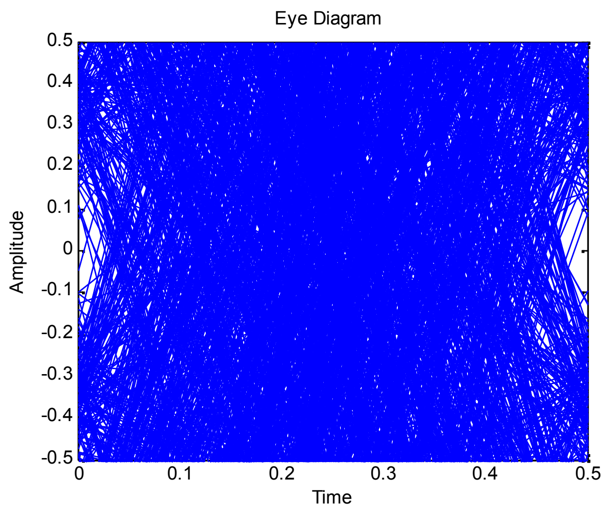

Figure 9. Eye pattern of Rician channel

6. CONCLUSION

In this paper, OFDM system is analyzed with channel estimation and equalization under different channels. Wiener filter estimation and one-tap equalization in frequency domain were found to perform well for OFDM system. Simulation results show weiner filter is better method of estimation that has reduced the equalization complexity. Eye diagram shows severity of Intersymbol Interference in Rician channel and Rayleigh channel than AWGN. BER curves shows performance under different channels.

ACKNOWLEDGEMENTS

This work has been supported as part of the project work by BMSCE, Bangalore.

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