CHANNEL ESTIMATION USING MAXIMUM LIKELIHOOD & LEAST SQUARE ALGORITHMS IN OFDM SYSTEMS

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ABSTRACT

A blind channel estimation scheme for OFDM systems is based on the maximum likelihood (ML) principle. Redundant information contained within the cyclic prefix enables this estimation without additional pilots. For pilot based system least square (LS) estimation is applied to orthogonal frequency division multiplexing (OFDM) systems and gives estimates of a multipath channel and the transmitted data sequence. Simulation results have confirmed good performance of the algorithm. The approach combines different modulation schemes on adjacent subcarriers, such as QPSK and QAM. It shows the results for bit error rate and mean square error with signal to noise ratio. It is important to note that probability of error (POE) is proportional to Eb/No, which is a form of signal-to-noise ratio. The performance evaluation of pilot based Least Square algorithm has been compared with blind Maximum Likelihood interms of BER, MSE with SNR.

KEYWORDS: *Least Square, Maximum Likelihood, OFDM*

1. INTRODUCTION

In multiuser OFDM the orthogonality of the subcarriers facilitates a subcarrier- division of different users, where one OFDM symbol contains many users. Orthogonal frequency division multiplexing (OFDM) systems have recently gained increased interest. OFDM is used in the European digital broadcast radio system and is being investigated for other wireless applications such as digital broadcast television and mobile communication systems, as well as for broadband digital communication on existing copper networks [1] [2]. Here two estimators are addressed in OFDM system. The first estimation is based on the Maximum likelihood algorithm. This estimator is applied for blind system. In statistics, maximum-likelihood estimation (MLE) is a method of estimating the parameters of a statistical model. When applied to a data set and given a statistical model, maximum-likelihood estimation provides estimates for the model's parameters. A second estimation is based on the pilot insertion. In this pilot based estimation, Least Square algorithm is used. A bit error rate and a mean square error estimate generated at the receiver with the aid of pilot symbols known to the receiver [3] [4] [5]. Redundancy in the transmitted OFDM signals also offers the opportunity for synchronization. This paper present and evaluate the maximum likelihood (ML) estimation and pilot based least square (LS) estimation of the BER and MSE with SNR in OFDM systems.

2. THE OFDM SYSTEM MODEL

Figure 1 shows a typical block diagram of OFDM system with pilot signal assisted. The binary information data are grouped and mapped into multi-amplitude-multi-phase signals.
This paper focuses discussion on estimation of one OFDM symbol instead of a sequence of symbols for the reason to be justified below. At the transmitter side, the serial input data is converted into M parallel data streams, and each data stream is modulated by a linear modulation scheme, such as QPSK& QAM. If QPSK is used, for instance, the binary input data of 2M bits will be converted into M QPSK symbols by the serial-to-parallel converter (S/P) and the modulator. The modulated data symbols, which we denote by complex-valued variables X(0),……,X(m),…..,X(M-1),are then transformed by the IFFT, and the complex-valued outputs x(0),….., x(k),…, x(M-1) are converted

back to serial data for transmission. A guard interval is inserted between the symbols. If the guard interval is longer than the channel delay spread, and if we discard the samples of the guard interval at the receiving end, the ISI will not affect the actual OFDM symbol [6]. Therefore, the system can be analysed on symbol-by-symbol basis. At the receiver side, after converting the serial data to M parallel streams, the received samples y(0),….., y(k),…., y(M-1) are transformed by the FFT into Y(0),…..,Y(m),…..,Y(M-1), which should be equivalent to the data symbols X(0),……,X(m),…..,X(M-1)in the absence of channel distortion and/or noise. They are then demodulated and restored in a serial order.

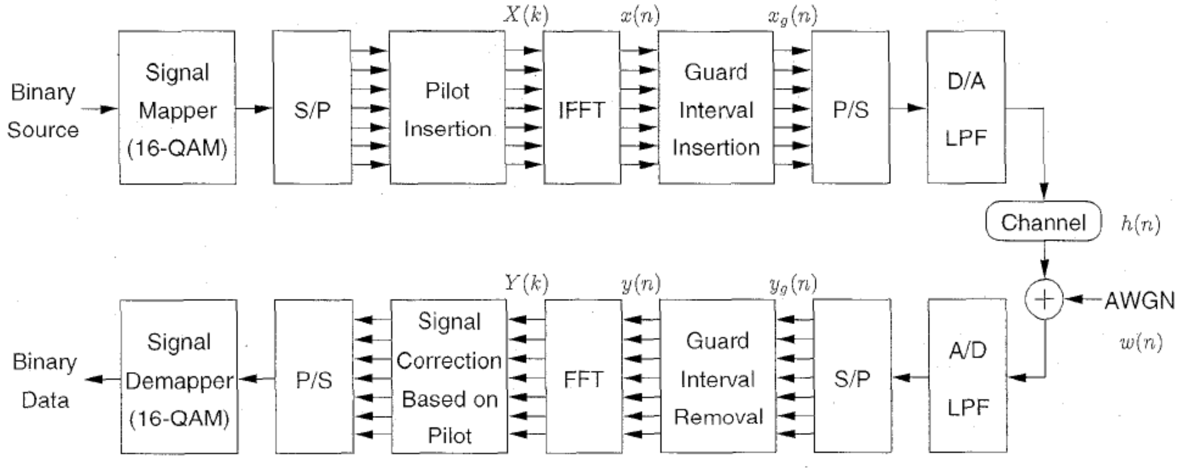

Figure 1: Baseband model of a typical pilot based OFDM system

1.1 maximum likelihood (ml) estimator without pilot insertion

Here consider a multipath channel model with the length of its impulse response at most L time units, where the time unit is $\frac{2M}{R(M+N)}$ for QPSK& QAM modulation. Here R is the source data rate; M is the number of subcarriers; and N is the length of the guard interval. Using the notation for OFDM symbols, the output of the channel can be written as,

$$y(k) = \sum_{l=0}^{L-1} h_l x(k-1) + n(k), 0 \le k \le M-1 (1)$$

Where, $(h_0,.....h_{L-1})$ is the channel impulse response; and $n(k)$ is the additive white Gaussian noise. Note that $y(k), x(k), n(k)$ and h_l are all complex valued. This model essentially assumes that the channel is slowly fading, i.e. the channel is constant during one OFDM symbol.

If cyclic prefix is used for the guard interval, inter-carrier interference in a multipath channel can be also avoided [6]. Then it can be shown that the following simple relation between $Y(m)$ and $X(m)$ holds,

$$Y(m) = (\sum_{l=0}^{L-1} h_l \exp - j2\Pi \frac{ml}{M}) X(m) + N(m) (2)$$

$$Y(m) = H(m)X(m) + N(M), 0 \le m \le M-1 (3)$$

Where, $H(m)$ is the complex frequency response of the channel at sub-channel m, and $N(0),......,N(M-1)$ are the FFT or DFT of $n(0),......,n(M-1)$. If $n(0),......,n(M-1)$ i.e. Gaussian random variables, so are the transformed variables $N(0),......,N(M-1)$.

Equation (3) shows that the received signal is the transmitted signal attenuated and phase shifted by the frequency response of the channel at the sub-channel frequencies and disturbed by noise.

We can solve the channel estimation and signal detection problem by using Eq. (2) or (3). The channel frequency response parameters $H(0),......,H(M-1)$ are generally correlated among each other, whereas the impulse response parameters $H_0,......,H_{L-1}$ may be independently specified, thus the number of parameters in the time domain is smaller than that in the frequency domain. Therefore, it is more appropriate to apply the ML algorithm to (2), i.e., find ML estimate of the channel in the time domain. We consider joint estimation of the channel and the transmitted signal. To simplify notation, we use $\underline{X}, \underline{h}, \underline{Y}$ to represent the transmitted signal, the channel impulse response and the received signal, respectively. The likelihood function of $\underline{Y}$, given $\underline{X}$ and $\underline{h}$, is

$$f(\underline{Y}/\underline{X},\underline{h}) = \frac{1}{(2\Pi\sigma^2)^M}\exp\left\{-\frac{D(\underline{h},\underline{X})}{2\sigma^2}\right\} \quad (4)$$

Where σ^2 is the variance of both real and imaginary components of $n(k)$ and is equivalent to

$$\frac{1}{2}E\left[|n(k)|^2\right]$$

and the function $D(\underline{h},\underline{X})$, which we call the "distance" function, is defined as

$$D(\underline{h},\underline{X}) = \sum_{m=0}^{M-1}\left|Y(m - \sum_{l=0}^{L-1} h_l \exp - j2\Pi\frac{ml}{M}X(m)\right|^2 \quad (5)$$

We need to find $\underline{h}$ and $\underline{X}$ that jointly maximize $f(\underline{Y}/\underline{X},\underline{h})$ or equivalently, minimize the distance function $D(\underline{h},\underline{X})$.

1.2 LEAST SQUARE (LS) ESTIMATOR WITH PILOT INSERTION

For comb-type pilot subcarrier arrangement, the Np pilot signals $Xp(m), m = 0,1,......., Np-1$ are uniformly inserted into $X(k)$. That is, the total N subcarriers are divided into Np groups, each with $L = N/Np$ adjacent subcarriers. In each group, the first subcarrier is used to transmit pilot signal. The OFDM signal modulated on the k^{th} subcarrier can be expressed as

$$X(k) = X(mL + l)$$

$$= \begin{cases} Xp(m), l = 0 \\ \inf ormationdata, l = 1,2,....., L-1 \end{cases} \quad (6)$$

The pilot signals { $Xp(m)$ } can be either equal complex values to reduce the computational complexity, or random generated data that can also be used for synchronization.

Let

$$\hat{H}_{p,ls} = \left[H_{p,ls}(0)H_{p,ls}(1)........H_{p,ls}(N_p-1)\right]^T$$

$$= Xp^{-1}Yp$$

$$Hp = \left[H(0), H(L-1), ..., H((Np-1).N-1)\right]^T \quad (7)$$

be the channel response of pilot subcarriers, and

$$Yp = \left[Y(0), Y(1), ..., Yp((Np-1)\right]^T \quad (8)$$

be the vector of received pilot signals. The received pilot signal vector Y, can be expressed as

$$Yp = Xp.Hp + Ip + Wp \quad (9)$$

Where $Xp = \begin{bmatrix} Xp(0) & . & . & . & 0 \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ 0 & . & . & . & Xp(Np-1) \end{bmatrix}$

Ip , is the vector of IC1 and W, is the vector of Gaussian noise in pilot subcarriers.

In conventional comb-type pilot based channel estimation methods, the estimate of pilot signals, based on least squares (LS) criterion [7], and is given by:

$$\overline{Hp} = [Hp,ls(0),Hp,ls(1),.......,Hp,ls(Np-1)]^T$$

$$= Xp^{-1}Yp$$

$$= \left[\frac{Yp(0)}{Xp(0)}\ \frac{Yp(1)}{Xp(1)}\ ....\ \frac{Yp(Np-1)}{Xp(Np-1)}\right]^T \qquad (10)$$

The LS estimate of Hp is susceptible to Gaussian noise and inter-carrier interference (ICI). Because the channel responses of data subcarriers are obtained by interpolating the channel responses of pilot subcarriers, the performance of OFDM system based on comb-type pilot arrangement is highly dependent on the rigorousness of estimate of pilot signals.

1.3 Simulation Result

In this simulation, we implemented two algorithms for estimation of OFDM system. First estimation is based on without insertion of pilot i.e. Blind channel estimation. For this estimation Maximum Likelihood algorithm is used. The second estimation is based on the pilot insertion. This pilot based estimation is done with Least Square algorithm. The results are shown in figures bellow.

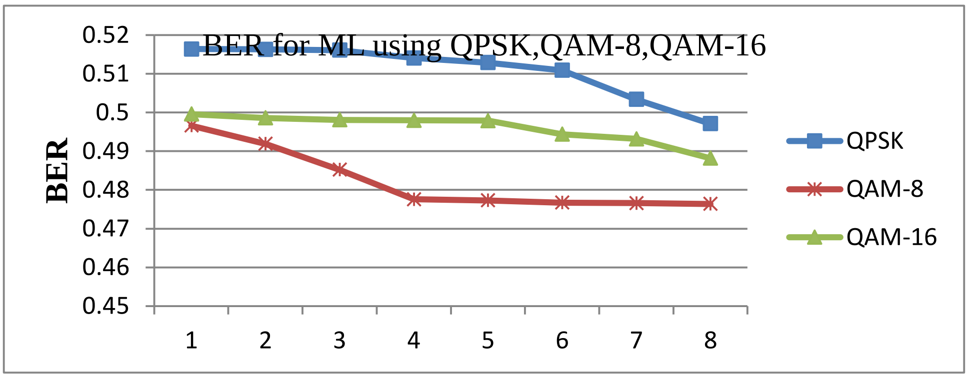

Figure 2: Bit Error Rate for Maximum Likelihood algorithm

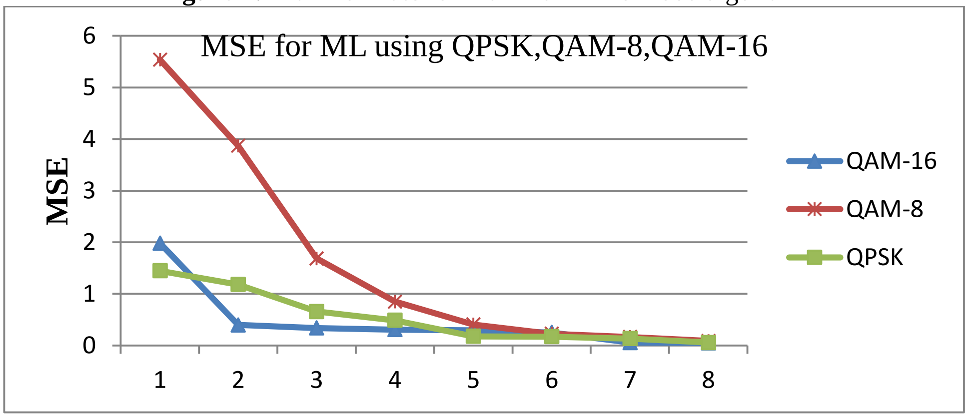

Figure 3: Mean Squared Error for Maximum Likelihood algorithm

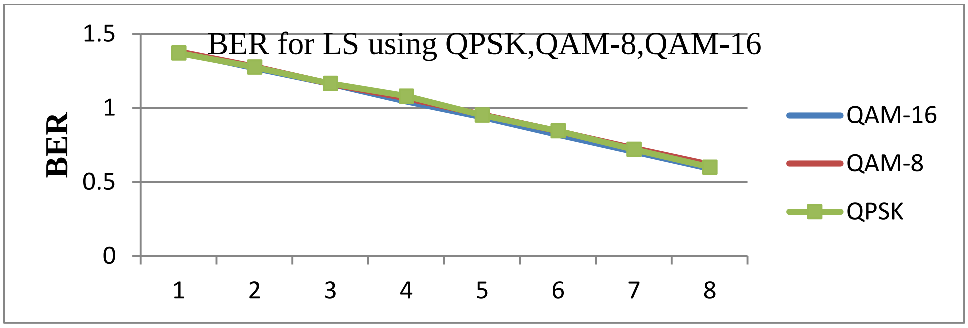

Figure 4: Bit Error Rate for Least Square algorithm

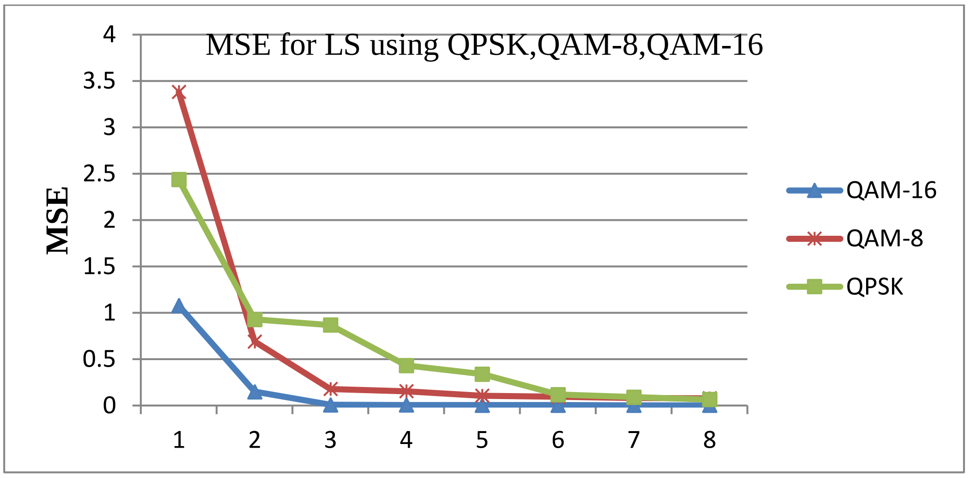

Figure 5: Mean Squared Error for Least Square algorithm

Figure 2 shows simulation results for bit error rate (BER) for the maximum likelihood (ML) algorithm. Here different modulation schemes are used such as QPSK, QAM-8 & QAM-18. From the graph it is clear that QAM-8 gives less BER than other modulation schemes. While for the same parameters in least square (LS) algorithm estimation, all the modulation schemes gives approximately same results with small difference which is shown in figure 4.

For mean squared error (MSE) estimation with same algorithms i.e. ML algorithm and LS algorithm same modulation schemes are used. This simulation shows that for both algorithmsQAM-16 gives less mean squared error. This is shown in figure 3 and figure 5.

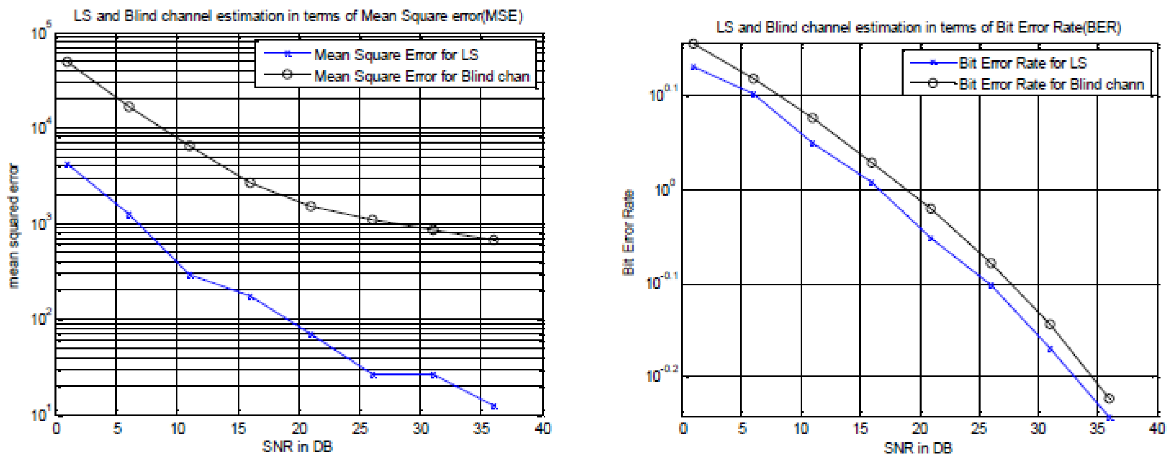

Figure 6: Comparison of Blind& Pilot based channel estimation with BER & MSE with SNR in dB

Figure 6 shows the performance comparison of Blind channel estimation and Pilot based estimation. For this simulation ML and LS algorithms are used. This figure shows that BER as well as MSE is less for the Least Square algorithm than the Maximum Likelihood algorithm for the same value of SNR in dB.

3. CONCLUSIONS

The simulation study of blind channel estimation and pilot based channel estimation is done with OFDM system. For this QPSK & QAM modulation schemes are used. This simulation result shows that for estimation using maximum likelihood algorithm QAM-8 gives less BER. While for same algorithm QAM-16 gives less value of MSE

For LS algorithm same parameters are evaluated. The BER is approximately same for all the modulation schemes. While for the estimation of the MSE, QAM-16 gives better results

Finally bit error rate (BER) and mean squared error (MSE) is less for the pilot based estimation as compared to the blind channel estimation.

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