A Novel Scheme for Frequency Synchronization and Kalman Filter Based Channel Estimation for OFDM Transmission System

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Abstract

OFDM has recently been applied widely in wireless communication system due to its high data rate transmission capability with high bandwidth efficiency and its robustness to multipath delay. In this paper we present the improved scheme of frequency offset estimation technique using joint symbol timing for OFDM-based transmission systems. The frequency-offset estimation utilizes a repetitive signal structure inside an OFDM symbol which is used to enlarge the range and increase the accuracy of offset estimation. Also, a Kalman filter based channel estimation scheme is proposed by training sequences are used to estimate the channel response in frequency domain and a scalar Kalman filter scheme is designed to refine the estimated parameters.

Key terms: *OFDM, Channel estimation, Least Kalman filter, Synchronization.*

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a promising technique for achieving high data rate and combating multipath fading in wireless communications. The principle of OFDM is to split a high–rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of sub carriers. OFDM signal more immunity to multipath fading by the addition of suitable guard interval to each OFDM symbol to remove the influence of frequency selective fading in broadband transmission [1]. The current areas of applications are digital audio broadcasting, digital video broad casting, wireless LAN and wireless MAN.

OFDM communication has been recently applied to WLANs for high data rate communication typically more than 100Mbps. The OFDM based transmission systems are known to be sensitive to symbol and frequency synchronization errors, and non-linear distortion [2]. Propagation inside buildings suffers from large shadowing and multipath effects becoming a serious problem for wireless LAN systems defined by the IEEE 802.11a standards. A number of frequency estimation techniques have been developed for OFDM applications and a reliable synchronization is achieved by transmitting training symbols [3].

In this paper presents a novel frequency offset reduction using joint symbol timing for a burst data is proposed and shown to have a good accuracy with large estimation range. The channel model for OFDM communication is estimated based on Kalman filter algorithm [4]. Several pilot based channel estimation techniques are proposed in literatures. Least square [LS] based pilot channel estimation techniques and its modification dealt in [5]. However, these methods are not optimum when considering the MSE.

Minimum mean square error [MMSE] based channel estimation in frequency domain equalization is proposed [5]. The major disadvantage of this is high computational complexity. A novel modification method is LS based channel estimation is proposed in this paper. The proposed method refines the LS channel estimates and its gives better performance in mean square sense. The refining process is based on Kalman filter in which channel parameters are recursively estimated from LS channel estimates.

The rest of the paper is organized as follows. Section II addresses the OFDM channel model for IEEE802.15.3a WPANs. Section III presents the system model for OFDM communication. Section IV introduces the improved scheme of frequency offset synchronization technique. In section V, a novel estimation scheme using training sequences and kalman filtering is proposed. Section VI highlights the simulation results and discussions under various channel conditions to validate our method.

2. Channel model

The most famous multipath OFDM indoor channel models are tap-delay line Rayleigh fading model, Saleh-Valenzuela model and Δ-K model [6]. The arrival of multi-path components is modeled by using statistically a random process; it is based on Poisson distribution. The multipath arrival of OFDM signals are grouped into two categories; cluster arrival and ray arrival within a cluster. The impulse response of OFDM channel can be written as

$$h(t) = X \sum_{l=0}^{L-1} \sum_{k=0}^{K-1} \alpha_{k,l}\, \delta(t - T_l - \tau_{k,l}) \qquad (1)$$

Where $\alpha_{k,l}$ is the multipath gain coefficient of k^{th} ray related to l^{th} cluster. T_l is the delay or arrival time of first path of l^{th} cluster. $\tau_{k,l}$ is the delay of k^{th} path within the l^{th} cluster relative to T_l. X is the lognormal shadowing term. The ray arrival and cluster arrival distribution time are given by

$$p(T_l/T_{l-1}) = \lambda \exp[-\lambda (T_l - T_{l-1})] \quad l > 0 \qquad (2)$$

$$p(\tau_k/\tau_{k-1}) = \lambda \exp[-\lambda (\tau_k - \tau_{k-1})] \quad l > 0 \qquad (3)$$

3. System model

The OFDM transmission system model is represented in Fig.1. The mathematical representation of OFDM symbol can be written as,

$$a(k) = \sum_{m=0}^{N-1} A_m e^{j2\pi m \Delta f t} \qquad \epsilon\ (0 <_ k <_ T_s) \qquad (4)$$

where N is the number of sub carriers, A_m is the m-ary data to be transmitted. k is the discrete sample points, T_s is the symbol duration, and Δf is the sub carrier frequency spacing. The N different data carriers are each set apart by the frequency Δf. For orthogonality, $\Delta f T_s = 1$. The OFDM modulated block at time k after cyclic prefix insertion is

$$\boldsymbol{X}_{cp}(k) = \boldsymbol{T}_{cp}\, \boldsymbol{F}_N\, \boldsymbol{a}(k) \qquad (5)$$

Where $\mathbf{T}_{cp}$ is the cyclic prefix insertion matrix of dimension (N+L) x N, defined as

$$\boldsymbol{T}_{cp} = \begin{pmatrix} \boldsymbol{0}_{Lx(N-L)} & \boldsymbol{I}_L \\ \boldsymbol{I}_{N-L} & \boldsymbol{0}_{(N-L)xL} \\ \boldsymbol{0}_{Lx(N-L)} & \boldsymbol{I}_L \end{pmatrix} \qquad (6)$$

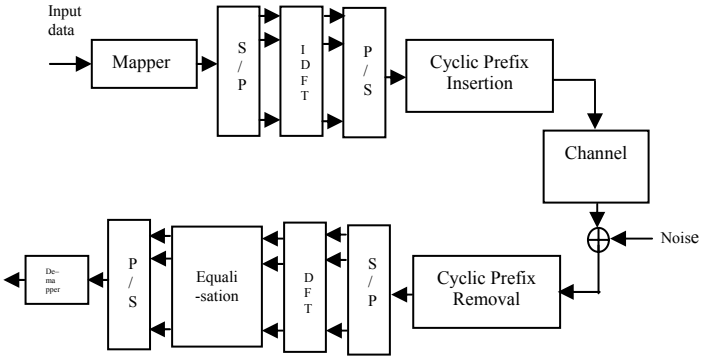

Figure.1. *system model*

and $\mathbf{F}_N$ is the NxN inverse discrete Fourier transform matrix. N is the total number of sub carriers. The vector **a** is the Nx1 symbol vector and L is the length of the cyclic prefix. The received signal after wireless channel is

$$\boldsymbol{y}(k) = \boldsymbol{H}\, \boldsymbol{T}_{cp}\, \boldsymbol{F}_N\, \boldsymbol{a}(k) + \boldsymbol{v}(k) \qquad (7)$$

Where **H** is the channel convolution toeplitz matrix of size (N+L) x (N+L) and **n** is the noise term

$$\boldsymbol{H} = \begin{pmatrix} h_0 & 0 & \ldots & 0 & 0 & \ldots.. & 0 \\ h_1 & h_0 & \ldots\ldots & 0 & 0 & \ldots. & 0 \\ 0 & 0 & \ldots.. & 0 & h_{Lh-1} & \ldots. & h_0 \end{pmatrix} \qquad (8)$$

The channel is assumed to remain stationary for the duration of one OFDM block. The channel taps are also assumed to be independent of each other and an impulse

$$\boldsymbol{r}(k) = \boldsymbol{R}_{CP}\, \boldsymbol{y}(k) = \boldsymbol{R}_{CP}\, \boldsymbol{H}\, \boldsymbol{T}_{cp}\, \boldsymbol{F}_N\, \boldsymbol{a}(k) + \boldsymbol{R}_{CP}\, \boldsymbol{v}(k) \qquad (9)$$

circulant. The received N x 1 signal block after cyclic prefix insertion, followed by transmission on the wireless channel and cyclic prefix removal is then expressed as,

$$\boldsymbol{r}(k) = \boldsymbol{H}_c\, \boldsymbol{X}_c(k) + \boldsymbol{w}(k) \qquad (10)$$

where $\mathbf{X}_c(k) = \mathbf{F}_N\, \mathbf{a}(k)$ and $\mathbf{w}(k) = \mathbf{R}_{CP}\, \mathbf{v}(k)$. $\mathbf{H}_c$ is the circular convolution matrix. Then the receiver performs a discrete Fourier transform (DFT) as follows

$$\boldsymbol{r}_c(k) = \boldsymbol{F}_N^H\, \boldsymbol{H}_c\, \boldsymbol{F}_N\, \boldsymbol{a}(k) + \boldsymbol{n}(k) \qquad (11)$$

where $\mathbf{n}(k) = \mathbf{F}_N^H\, \mathbf{w}(k)$ and $\mathbf{F}_N^H$ is the DFT matrix. Due to the fact that ciculant matrices implement circular

convolutions, they are diagonalzed by DFT and IDFT operations and thus equations can be rewritten as,

$$\boldsymbol{r}_c(k) = \boldsymbol{D}(k)\,\boldsymbol{a}(k) + \boldsymbol{n}(k) \qquad (12)$$

where the diagonal matrix D (k) = $\mathbf{F_N}^{H}\,\mathbf{H_c}\,\mathbf{F_N}$ contains the frequency response of the channel evaluated at the sub carrier frequencies. In a multicarrier modulation, the initial wideband frequency selective fading channel has been turned into set of N narrowband flat fading channels estimates. In Fig 2. note that T1 serves as a cyclic prefix (CP) for T2, T2 is the CP for T3, and so on.

4. Frequency offset synchronization

An OFDM symbol offset is synchronized by multistage approaching technique. In this way, one OFDM preamble, lasting over 4 short OFDM symbol periods consists of one symbol period for silence, two symbol periods for symbol and frequency-offset synchronization, and one symbol period for equalization. These symbol periods are identical known OFDM symbols of length Ns = 16. The each OFDM symbol contains useful information plus some known pilot bits, which are typically used for updating the phase of channel

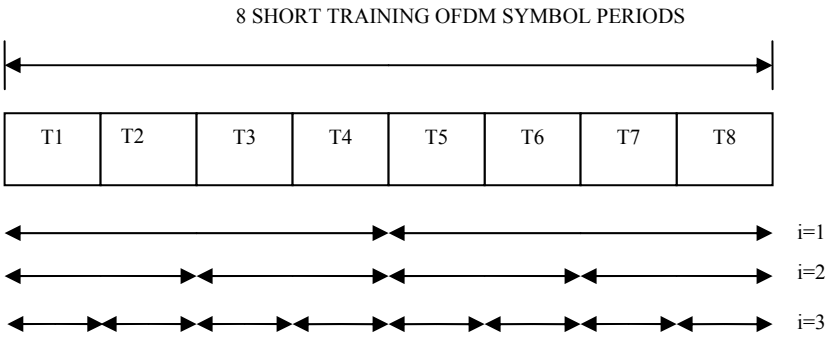

Figure 2. *Preamble structure for the multistage frequency offset estimator when M=8*

The OFDM preamble for the proposed frequency-offset estimator is composed of $M=2^k$ (k=1,2 …) repetitive slots. In such symbol structure, an M/2 number of base subblocks are bundled to obtain a new primary sub block such that two primary subblocks of an N/2 samples come to exist in the one OFDM symbol. Further, an M/4 number of base subblocks are bundled to obtain a new second block such that four secondary subblocks come to exist in the one OFDM symbol. In this way, $M/2^i$ of base subblocks is bundled to obtain a 2^i number of ith sub blocks. Then, the frequency offset is estimated by correlating the adjacent ith – stage subblocks as follows

$$\varepsilon_i = \frac{2^i}{2\pi}\arg\{\sum_{n=0}^{\frac{N}{2^i}-1} y_n * y_{N/2}^{\,i+n}\} \qquad (13)$$

The received signal of the OFDM preamble for frequency-offset estimation, y_n, is given by,

$$y_n = \sum_{k=0}^{N-1} X_k(t)\,H(k)\,e^{2\pi jn(k+\varepsilon)/N} + \omega_n$$
$$n=0,\ 1\ldots\ N\text{-}1 \qquad (14)$$

where H (k) is the transfer function of the channel at the frequency of the kth carrier, ε is the relative frequency offset of the channel, and ω_n is the complex envelope of additive Gaussian noise (AWGN). The multistage procedure for frequency offset estimation is shown in fig 3.

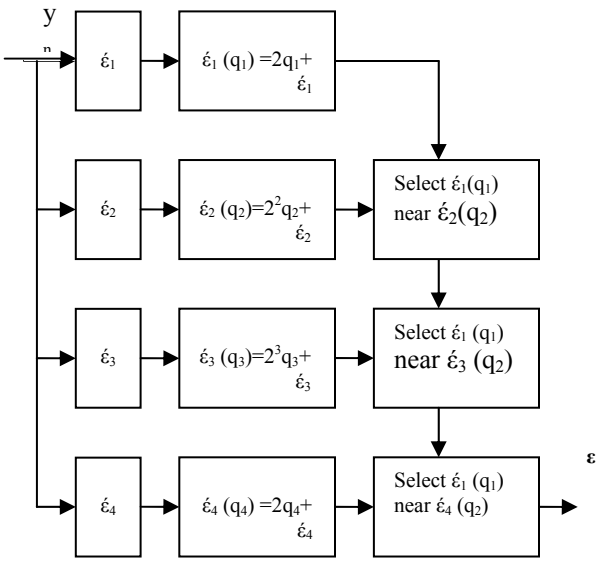

Figure 3. *Multistage procedure for proposed freauency offset estimation*

In this paper, the frequency offset is estimated by four iterations. Since ε is normalized by the subcarrier spacing, the estimation range for the ith-stage becomes $|\acute{\varepsilon}_i| < 2^{i-1}$. After receiving one OFDM symbol for frequency-offset estimation, all estimated values of $\acute{\varepsilon}_i$ (i=0,1,2…k) are obtained using equation (14).

5. Kalman filter based channel estimation

Dynamic channel estimation is necessary before demodulation of OFDM signals since the radio channel is time varying and frequency selective for wideband systems. Channel estimation in OFDM systems mainly classified in two types namely pilot based and blind channel estimation. Blind channel estimation method gives high throughput efficiency but the complexity of this method is high. This paper mainly focuses on pilot based channel estimation.

The single tap equalization is performed in the frequency domain at the receiver. In LS method the channel estimates are obtained by simply dividing the received signal with the training symbol. Let i denotes the subcarrier index of the k^{th} OFDM symbol. $\mathbf{a}_{i,k}$ represents the data symbol of i^{th} subcarrier of k^{th} OFDM symbol. The LS channel estimation can be mathematically defined as,

$$r_c(i,k) = \frac{H(i,k)}{a(i,k)} + \frac{n(i,k)}{a(i,k)} \quad (15)$$

Let v(i,k) = n(i,k) / a(i,k). The LS estimate may be regarded as fundamental channel estimation for an OFDM system. Since $\hat{H}^{LS}(i,k)$ can be modeled as the true channel response H(i,k) plus the channel noise v(i,k), a state space equation can then be expressed as following

$$H(i,k+1) = H(i,k) + w(i,k) \quad (16)$$

$$\hat{H}^{LS}(i,k) = H(i,k) + v(i,k) \quad (17)$$

where w(i,k) represents system state variable noise which is used to characterize the varying of true channel response. A scalar Kalman filtering algorithm [7] then can be used to get a refining estimation of channel frequency response $\hat{H}(i,k/k)$ from $\hat{H}^{LS}(i,k)$ as follows

$$P(i,k/k-1) = P(i,k-1/k-1) + \sigma^2_w$$

$$K_k = P(i,k/k-1) / (P(i,k/k-1) + \sigma^2_v)$$

$$\hat{H}(i,k/k) = \hat{H}(i,k-1/k-1) + K_k(\hat{H}^{LS}(i,k) - \hat{H}(i,k-1/k-1)$$

$$P(i,k/k) = (1-K_k)P(i,k/k-1) \quad (18)$$

where σ^2_w represents the variance w(i,k) and σ^2_v represents the variance of v(i,k). P(i,k-1/k-1) is prior variance estimation and P(i,k/k-1) is a posterior variance estimation. K_k is the Kalman gain. $\hat{H}$(i,k-1/k-1) is a prior estimation of the true channel response and $\hat{H}$(i,k/k-1) is a posterior estimation of the true channel response. The more accurate channel estimate for each data symbol can be gain through above equations.

5.1. Adaptive co-variance estimation:

The variances used in the Kalman filtering are not known a prior in most of practical applications. Both channel AWGN and state variable noises can be adaptively estimated from the estimated sequence [8]. Let α and β variables that are related with variance of state variable noise (σ^2_w) and channel noise (σ^2_v) . The recursive estimation of α and β for each subcarrier in an OFDM symbol is processed as,

$$\alpha(i,k+1) = \rho_1\alpha(i,k) + (1-\rho_1)((\hat{H}^{LS}(i,k))^2 - \hat{H}^{LS}(i,k))$$

$$\beta(i,k+1) = \rho_2\beta(i,k) + (1-\rho_2)((\hat{H}(i,k))^2 - \hat{H}(i,k)) \quad (19)$$

Where $0 < \rho_1\rho_2 < 1$ are the forgotting factors. Then the state variable noise and channel noise are estimated as,

$$\sigma^2_w(k+1) = (1/N)\sum_{m=0}^{N-1}\alpha(m,k+1) \quad \sigma^2_v(k+1) = (1/N)\sum_{m=0}^{N-1}\beta(m,k+1) \quad (20)$$

These parameters are used as variances for next OFDM symbol in the same subcarrier.

6. Results and discussions

In this section the performance of proposed adaptive channel estimation technique is analyzed for different OFDM channel models. The number of orthogonal carriers comprising an OFDM block is set to N=128 and a cyclic prefix of length L=32 is added. QPSK modulation scheme is employed for simulation. Fig.4. shows the BER analysis of the proposed method for all OFDM channel models. It can be seen, when the delay spread increases, the BER performance decreases. This is reasonable since the larger the delay spreading, the more number of multipath and larger channel estimation errors. Fig.5 shows the MSE performance of the proposed method and LS method. It is observed that the proposed method provides almost 4 dB better performances than the LS method for CM 1 and CM 3 channels. When the channel has medium or large delay spreading, the proposed method is necessary for channel estimation.

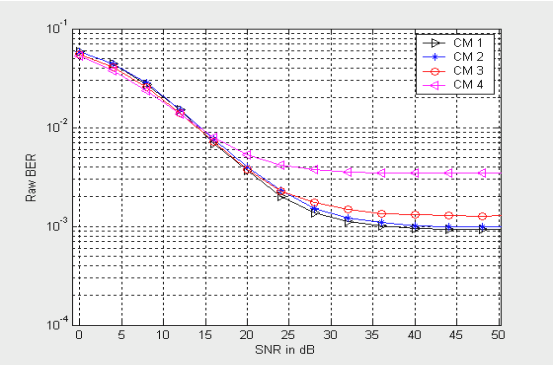

Figure 4 *BER Analysis of the proposed estimator*

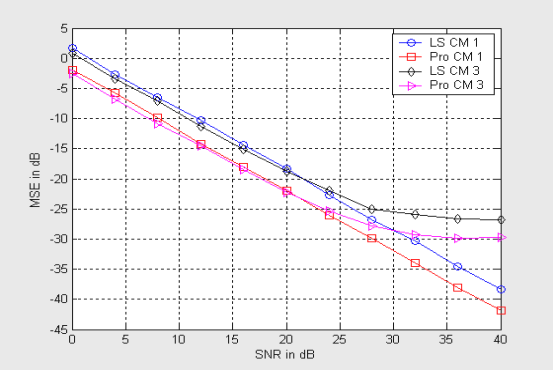

Figure.5.*MSE*

7. Conclusion

In this paper, a burst synchronization technique using joint symbol timing for an OFDM preamble is proposed. Also, a modification in LS based channel estimation for OFDM is proposed by pilot based adaptive channel estimation in OFDM systems. A modification in LS based channel estimation for OFDM is proposed. The performance in terms of MSE is found to be minimum in the proposed method as compared LS method. The results given in this paper are of greatest importance in design and analysis of future OFDM systems.

8. References

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