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# Inter Carrier Interference mitigation in OFDM system using Kalman Filter Channel Estimation

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*Abstract*— **Orthogonal frequency division multiplexing (OFDM) is one of the modulation scheme, used for high speed mobile communication. However, fast time varying multipath channels leads to loss of orthogonality of subcarriers and introduces inter carrier interference (ICI). In this study, MMSE equalizer is implemented to remove ICI. The information of Channel Impulse Response (CIR) required for equalizer is estimated on every subcarrier using time domain Kalman Filter. In further study, decision feedback equalizer will be implemented of which performance will be compared on the basis of bit error rate (BER) with that of MMSE equalizer.**

***Keywords—OFDM,Inter Carrier Interference,Channel Impulse Response,Kalman filter, MMSE equalizer, BER***

## I. INTRODUCTION

This Orthogonal Frequency Division Multiplexing (OFDM) is modulation technique used in high bit rate wireless communication systems since it can prevent inter symbol interference (ISI) using cyclic prefix and it has immunity to frequency selective fading environment. In OFDM system, a broadband signal is converted into a set of orthogonal narrowband signals for parallel transmission. For time-invariant frequency selective multipath channels, CIR is assumed to be constant within one OFDM symbol block. In this case simple one tap equalizer can recover data symbols at OFDM receiver [1]. However, time varying frequency selective multipath channels destroy the orthogonality of OFDM subcarrier introducing inter carrier interference.

Several algorithms have been proposed for channel estimation and ICI mitigation in OFDM system. Reference [2] proposed time domain channel estimator in which CIR are assumed to be varied in linear fashion with symbol duration. However, at high normalized Doppler frequency, this assumption does not hold true. In [3] time domain channel estimation method is proposed to cancel out ICI due to rapidly time varying channels. This technique estimates the fading channel by exploiting the time variant nature of the channel as a provider of time diversity and reduces computational complexity using SVD method. An MMSE channel estimator is proposed in [4] that uses both time and frequency domain correlation functions of fading channels. In [5], self ICI cancellation technique based on time domain windowing is proposed which is affected by frequency offset as well as Doppler spread. In [6], time domain ICI filter is designed which is based on the maximization of signal to interference plus noise ratio (SINR). The filer is proposed for both SISO and MIMO OFDM system. Paper [7] used the ICI coefficient matrix to model linear relationship between transmitted and received signals. For ICI equalizer, MMSE solution is used. However, intensive computational burden is required to solve the channel statistics. In [8], two methods were introduces to mitigate ICI using piece-wise linear model to approximate channel time variations. Reference [9] proposed various channel estimation methods including frequency domain least square estimator, frequency domain Kalman filter estimator, time domain Kalman filter estimator etc.

In this paper we study, time domain Kalman filter (TDKF) to estimate channel impulse response on every sample of OFDM symbol. The estimated coefficients are applied to MMSE equalizer to equalize received OFDM signal.

## II. SYSTEM DESCRIPTION

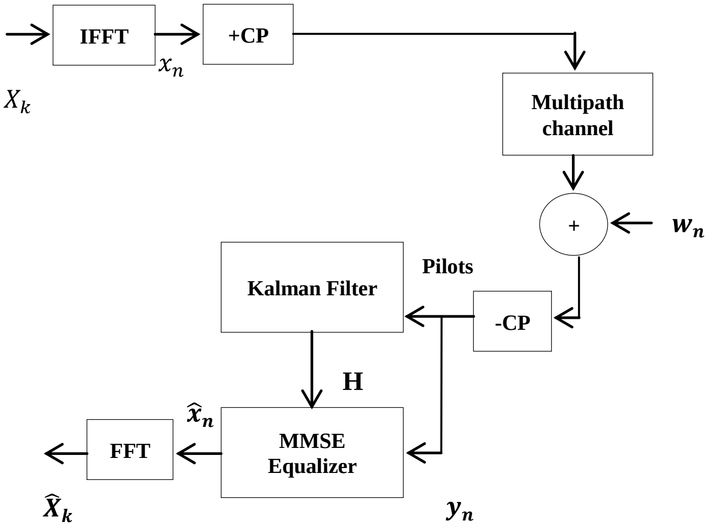

Fig 1. Block Diagram of OFDM System

In an OFDM system, several input bits are encoded into one sample. These samples are modulated using 16-QAM modulation technique to obtain output in frequency domain $(X_k)$. Such N samples are grouped by serial to parallel (S/P) converter $\{X_k\}_{k=0}^{N-1}$ as one OFDM symbol.

To make every subcarrier of OFDM symbol orthogonal to each other, each sample in symbol is modulated by N-point inverse fast Fourier transform (IFFT) expressed as

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k\, e^{j2\pi kn/N}, \; n = 0 \dots \dots N-1 \qquad (1)$$

Where, $x_n$ represents $n^{th}$sampleof IFFT output.

To remove ISI, the cyclic prefix of length *gi* is appended to form the transmitted block as $\{x_{-gi}\ , x_{-gi+1}\,, \dots \dots .. x_{0,} x_{N-1,}\}$

Assuming that multipath fading channel consist of L resolvable paths, the received data after removing cyclic prefix can be expressed as,

$$y_n = \sum_{l=0}^{L-1} h_{n,l}\, x_{n-l} + w_n = x_n^T \bar{h}_n + w_n \qquad (2)$$

Where subscript T denotes transpose and $h_{n,l}$ is time varying tap gain of $l^{th}$ path at time n, which can be represented as

$$x_n = [x_n x_{n-1} \dots \dots .. x_{n+L-1}]^T \&$$

$$\bar{h}_n = [h_{n,0} h_{n,1} \dots \dots .. h_{n,L-1}]^T$$

$w_n$is an additive white Gaussian noise with zero mean and variance $R_n$. The demodulated data in frequency domain is obtained by N-point FFT of $y_n$ as

$$Y_k = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} y_n\, e^{-j2\pi kn/N}$$

$$= \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} \sum_{l=0}^{N-1} H_{l,k-m}\, e^{-j2\pi kn/N} X_m + W_k$$

$$= \alpha_{k,k} X_k + \sum_{\substack{m=0 \\ m\neq k}}^{N-1} \alpha_{k,m}\, X_m + W_k \qquad (3)$$

Where,$\alpha_{k,k}$represents multiplicative distortion of $X_k$ subcarrier expressed as,

$$\alpha_{k,k} = \sum_{k=0}^{L-1} H_{0,l}\, e^{-j2\pi kn/N} \qquad (4)$$

$$\alpha_{k,m} = \sum_{k=0}^{L-1} H_{k-m,l}\, e^{-j2\pi lm/N} \qquad (5)$$

$\alpha_{k,m}$represents ICI coefficients from subcarrier m to subcarrier k and $W_k$ is FFT of $w_n$.

$H_{k-m,l}$denotes N-point FFT of time varying CIR $h_{n,l}$ expressed as

$$H_{k-m,l} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} h_{n,l}\, e^{-j2\pi kn/N} \qquad (6)$$

## III. TIME DOMAIN KALMAN CHANNEL ESTIMATION

In mobile OFDM system, the channel impulse response changes in several OFDM symbols. To solve the channel equalization problem, pilots are inserted in OFDM symbols for continuous channel estimation. We can insert pilots with different patterns including comb-type pilots, block-type pilots and scattered pilots. In this paper block type pilot arrangement is used. A typical block-type pilot pattern is shown in fig 2. Where, each pilot symbol is transmitted for every $r_t$ symbol.

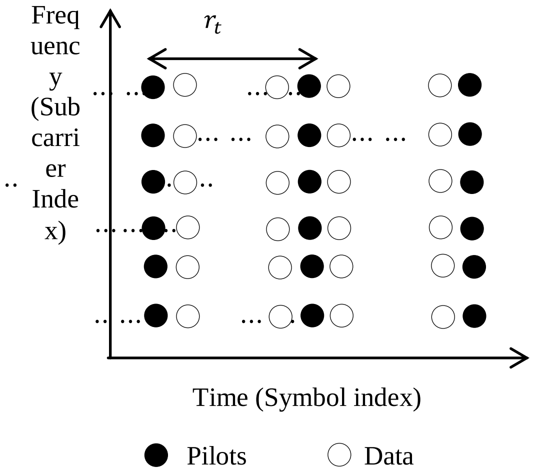

Fig 2. Block-Type Pilot Pattern

The time domain Kalman channel estimator is used to estimate CIR values, which depends on pilot symbols. The received OFDM symbol in vector form is,

$$y_n = x_n^T \bar{h}_n + w_n \qquad (7)$$

The variance of measurement noise $w_n$ is $R_n$.

To establish state estimation algorithm by Kalman filter , we model channel impulse response as first autoregressive (AR) process given as,

$$\bar{h}_{n+1} = \phi\, \bar{h}_n + v_n \qquad (8)$$

Where ϕ= diag [a] and a is fading parameter given by using Yule- Walker rule [10] as

$$\text{a} = J_0\,(2\pi f_d T_s) \qquad (9)$$

$$\sigma = \sqrt{(1-a^2)} \qquad (10)$$

$v_n$is process noise vector having zero mean, standard deviation σ and variance $Q_n$.

Using equations (7) and (8), the Kalman algorithm for estimation of CIR includes following recursions,

$$P_n = \phi P_{n-1} \phi^T + Q_n \qquad (11)$$

$$K_n = P_n {x_n}^T \left[\bar{x}_n P_n {\bar{x}_n}^T + R_n\right]^{-1} (12)$$

$$e_n = y_n - \hat{y}_n = y_n - \bar{x}_n \hat{\bar{h}}_{n-1} (13)$$

$$\bar{h}_n = \phi \hat{\bar{h}}_{n-1} + K_n e_n \qquad (14)$$

$$P_{n+1} = [I - K_n {\bar{x}_n}^T]\, P_n \qquad (15)$$

Where, $P_n$ is known as state prediction error covariance matrix, $P_{n+1}$ is state filtering error covariance matrix and $K_{n+1}$ is Kalman gain.

## IV. TIME DOMAIN MMSE EQUALIZATION

As shown in fig (1) MMSE equalizer equalizes the received data $y_n$ using CIR samples,$\hat{h}_n$estimated by Kalman filter.

$$y_n = \bar{x}_n{}^T h_n + w_n \qquad (16)$$

The CIR samples ,estimated by Kalman filter are expressed as

$$\text{H}= \{\hat{h}_n \ , \ 0 \le n \le N-1\}$$

To find N × N equalizer matrix G that minimizes the cost function MSE=$\{|x_n - \hat{x}_n|^2\}$, where $\hat{x}_n$ = G$y_n$ is equalizer output.

$$\text{MSE}=\{|x_n - \hat{x}_n|^2\} = trace\{E\{(x_n - Gy_n)(x_n - Gy_n)^H\}\}$$
$$= R_{x_n x_n} - R_{x_n y_n} G^H - G R_{x_n y_n}{}^H + G R_{y_n y_n} G^H \qquad (17)$$

Differentiating (17) with respect to G we get,

$$\frac{\partial \text{MSE}=\{|x_n - \hat{x}_n|^2\}}{\partial G} = 2\text{G}R_{y_n y_n} - 2R_{x_n y_n} = 0 \qquad (18)$$

The MMSE solution is $G_{mmse} = R_{x_n y_n} R_{y_n y_n}{}^{-1}$.

Since $x_n$ is uncorrelated with$w_n$,
$R_{x_n y_n}$ = E$\{x_n x_n{}^H\}H^H = \sigma_{x_n}^2 H^H$ and
$R_{y_n y_n} = \sigma_{x_n}^2 H H^H + \sigma_{w_n}^2 I_N$ ,
where, $\sigma_{x_n}^2$ is signal power and $\sigma_{w_n}^2$ is noise power,
$I_N$is N× N identity matrix.

Thus MMSE solution is given as

$$G_{mmse} = R_{x_n y_n} R_{y_n y_n}{}^{-1} = H^H \left( H H^H + \frac{\sigma_{w_n}^2}{\sigma_{x_n}^2} I_N \right)^{-1} \qquad (19)$$

## V. SIMULATION RESULTS

An OFDM system with 64 subcarriers and 16 cyclic prefixes (CP) and such 64 symbols is simulated in Jake's Rayleigh fading time varying mobile channel. 16- QAM modulation technique is used. The number of multipaths to be chosen are 4. The OFDM pilot arrangement is chosen at $r_t$= 3.
Fig (3) shows bit error rate (BER) performance of MMSE equalizer for Least Square and Time Domain Kalman filter channel estimation. Graph shows that Kalman filter improves the Bit error rate of MMSE equalizer.

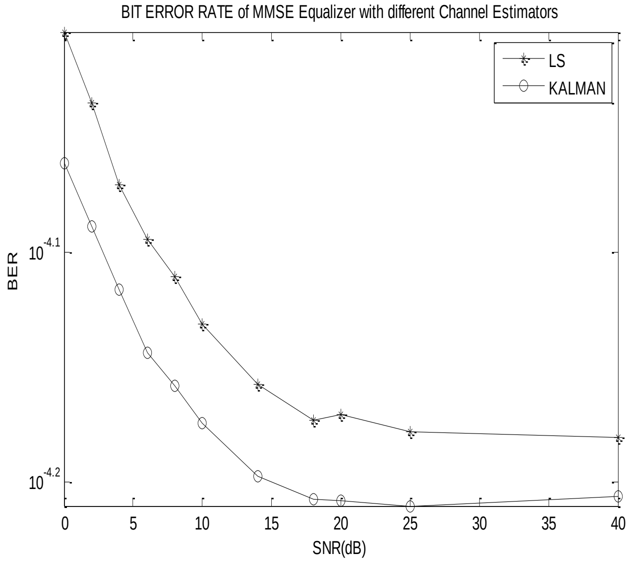

Fig3. BER performance of MMSE Equalizer with LS and KALMAN Channel Estimator

## VI. CONCLUSION

In this paper, we implemented time domain Kalman filter as a channel estimator. The performance of TDKF is comparable to other estimators as it gives CIR on every sample and improves the bit error rate of MMSE equalizer. MMSE equalizer equalizes received OFDM signal.In further study, we will implement decision feedback equalizer which may improve bit error rate.

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