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Kalman Filter Channel Estimation Based Inter Carrier Interference Cancellation techniques In OFDM System

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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 lead to loss of orthogonality of subcarriers causing inter carrier interference (ICI) in OFDM signal. In this paper, MMSE and DFIC (Decision Feedback ICI Cancellation) equalizers are implementedtoremove ICI. The information of Channel Impulse Response (CIR) required for equalizing the OFDM signal is estimated on every subcarrier using time domain Kalman Filter. The performance of MMSE and DFIC equalizers are compared on the basis of bit error rate (BER) of equalizers.

KEYWORDS—OFDM, Inter Carrier Interference,Channel Impulse Response,Kalman filter, MMSE,DFIC, BER

I. INTRODUCTION

The 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. However, time varying frequency selective multipath channels destroy the orthogonality of OFDM subcarrier introducing intercarrier interference.

Several algorithms have been proposed for channel estimation and ICI mitigation in OFDM system. In [1], Mostofi introduced two new methods to mitigate ICI in an OFDM system with coherent channel estimation. Both methods use a piece-wise linear model to approximate channel time-variations. The first method extracts channel time-variations information from the cyclic prefix. The second method estimates these variations using the next symbol. These methods would improve the performance in a highly time-variant environment with high delay spread.In [2], pulse shaping technique for ICI power reduction in OFDM systems is investigated. A number of pulse shaping functions such as Rectangular pulse shape, Sinc power pulse (SP) and Improved sinc power pulse (ISP) have been considered for ICI power reduction.

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. In [4], Anastasios designed ICI-mitigating block linear filters to mitigate the effects of time variations within a transmission block. Also examined how they are modified in the context of space-time block-coded transmissions. Paper [5], studied ICI self-cancellation of data-conjugate method to reduce ICI effectively, which can make remarkable improvement of the BER performance and it is better than the data-conversion method and the original OFDM with or without convolution coding. In [6], self ICI cancellation technique based on time domain windowing is proposed which is affected by frequency offset as well as Doppler spread. Reference [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. Reference [8] 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, Least Square and time domain Kalman filter (TDKF) to estimate channel impulse response on every sample of OFDM symbol. The estimated coefficients are applied to MMSE and DFIC equalizers to equalize received OFDM signal. The channel estimators like Least Square and Kalman Filters are compared and proved that Kalman filter is better than LS as it improves BER of both of the equalizers.

II.SYSTEM DESCRIPTION

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.

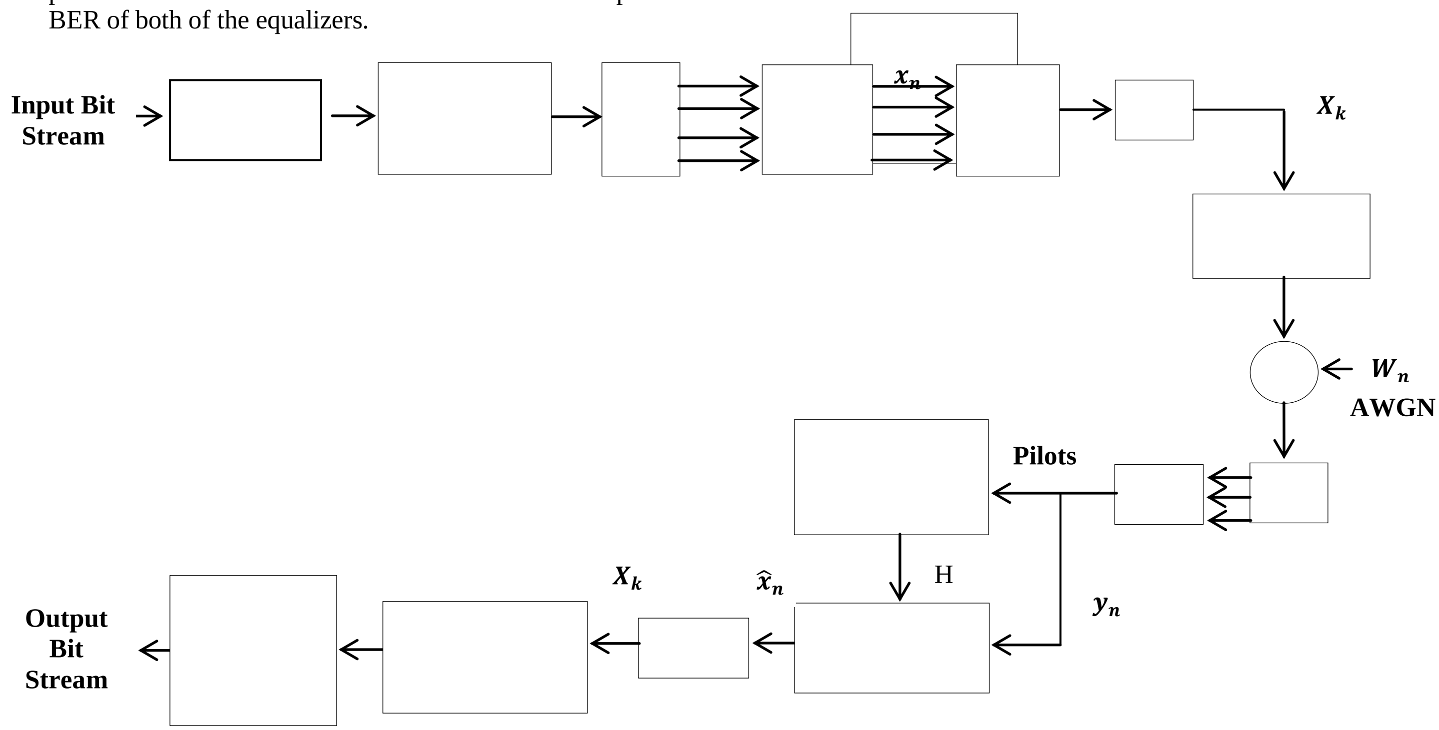

Fig.1. Block Diagram of OFDM System

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

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

Where, x_n represents n^{th} sample of IFFT output.

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

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

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

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

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

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

III. 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.

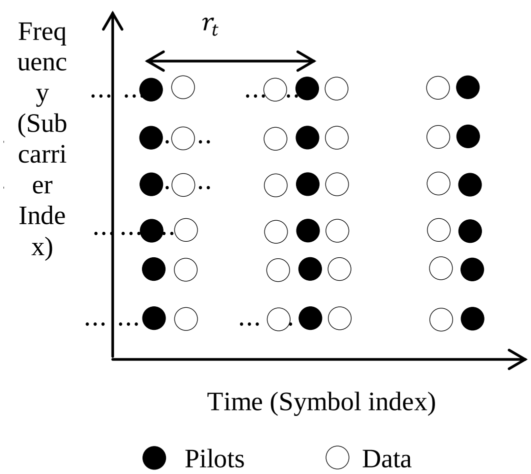

Fig2. Block-Type Pilot Pattern

A. Least Square Channel Estimation

Based on a priori known transmitted symbol, we estimated the channel information at pilot subcarriers by the least-squares estimator. The solution of LS channel estimation is

$$\hat{H}_{k,LS} = \frac{Y_k}{X_k} = H_k + \frac{W_k}{X_k} \quad (7)$$

Where W_k is complex white Gaussian Noise on Pilot index k.

B. Kalman Filter Channel Estimation

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,

$$y_n = x_n^T\overline{h_n} + w_n (8)$$

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,

$$\bar{h}_{n+1} = \phi\bar{h}_n + v_n (9)$$

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

$$a=(2\pi f_d T_s) \quad (10)$$

$$\sigma=\sqrt{(1-a^2)} \ (11)$$

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

Using equations (8) and (9), the Kalman algorithm for estimation of CIR includes following recursions,

$$P_n = \phi P_{n-1}\phi^T + Q_n (12)$$

$$K_n = P_n x_n^{\ T}\left[\bar{x}_n P_n \bar{x}_n^{\ T} + R_n\right]^{-1} (13)$$

$$e_n = y_n - \widehat{y_n} = y_n - \overline{x_n}\widehat{\overline{h}_{n-1}} (14)$$

$$\bar{h}_n = \phi\widehat{\bar{h}_{n-1}} + K_n e_n (15)$$

$$P_{n+1} = [I - K_n \bar{x}_n^{\ T}]\, P_n (16)$$

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. ICI CANCELLATION

A. 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.

$$y_n = \bar{x}_n^{\ T} h_n + w_n \quad (17)$$

The CIR samples , estimated by Kalman filter are expressed as

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

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

$$\text{MSE} = \{|x_n - \hat{x}_n|^2\} = trace\{E\{(x_n - Gy_n)(x_n - Gy_n)^H\}\}$$
$$= R_{x_n x_n} - R_{x_n y_n}G^H - GR_{x_n y_n}^{\ \ H} + GR_{y_n y_n}G^H \quad (18)$$

Differentiating (18) with respect to G we get,

$$\frac{\partial \text{MSE} = \{|x_n - \hat{x}_n|^2\}}{\partial G} = 2GR_{y_n y_n} - 2R_{x_n y_n} = 0 \quad (19)$$

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
$R_{y_n y_n} = \sigma_{x_n}^2 HH^H + \sigma_{w_n}^2 I_N$,
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

$$G_{mmse} = R_{x_n y_n} R_{y_n y_n}{}^{-1} = H^H \left(HH^H + \frac{\sigma_{w_n}^2}{\sigma_{x_n}^2} I_N \right)^{-1} \quad (20)$$

B. DFIC Equalization

A decision-feedback ICI cancellation equalizer is a nonlinear equalizer that contains a forward filter and a feedback filter. The forward filter is similar to the linear equalizer; while the feedback filter contains a tapped delay line whose inputs are the decisions made on the equalized signal. The purpose of a DFE is to cancel Inter Carrier Interference while minimizing noise enhancement. By contrast, noise enhancement is a typical problem with the linear equalizers.

The equalization of OFDM signal using DFIC is described below:

The CIR samples, estimated by Kalman filter are expressed as

H= $\{\hat{h}_n \;\; , \; 0 \leq n \; \leq N-1\}$

First the QAM modulated data is convolved with CIR samples $\hat{h}_n$ and then AWGN noise is added into it. The OFDM signal to be equalized with DFIC is given as

$$y_n = \bar{x}_n{}^T \hat{h}_n + w_n$$

The feed forward weights are considered as 2N and feedback weights are considered as N+1. Where N; is number of channel impulse response for one OFDM symbol.

In this work, The dfe(); function creates an equalizer object that is used with the equalize(); function to equalize a signal as given below,

eqobj = dfe(nfwdweights,nfbkweights,alg)

Where nfwdweights, is number of feed forward complex weights, nfbkweights is number of feedback complex weights and alg refers to the adaptive algorithm the equalizer has used. In this project we have used lms algorithm.

This eqobj object is used to equalize the signal $\boldsymbol{y_n}$ with, equalize() command as below,

Eq_dfe= equalize(eqobj,$\boldsymbol{y_n}$);

Where, Eq_dfe is equalized output of the DFIC equalizer.

Similarly, we have used the CIR samples estimated by LS estimator and applied to the DFIC equalizer.

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. Here 4 number of multi paths chosen. The OFDM pilot arrangement is chosen at r_t= 3. Fig.3 shows 256 bits of one OFDM symbol. Fig.4 shows the OFDM signal after sending through multi paths and adding AWGN noise to it. Fig.5 shows OFDM spectrum. Fig.6 shows the graph of comparison of bit error rate (BER) performance of MMSE equalizer with both Least Square and Kalman filter estimators. It proves how BER performance of MMSE equalizer is improved due to Kalman Filter channel estimator. Fig.7 shows the graph of comparison of BER performance of DFIC equalizer with both Least Square and Kalman filter estimators. Fig 8 shows comparison of BER performance of MMSE and DFIC equalizers using Kalman Filter Channel Estimator. It proves that non-linear DFIC equalizer improves the Bit Error Rate than that of MMSE equalizer.

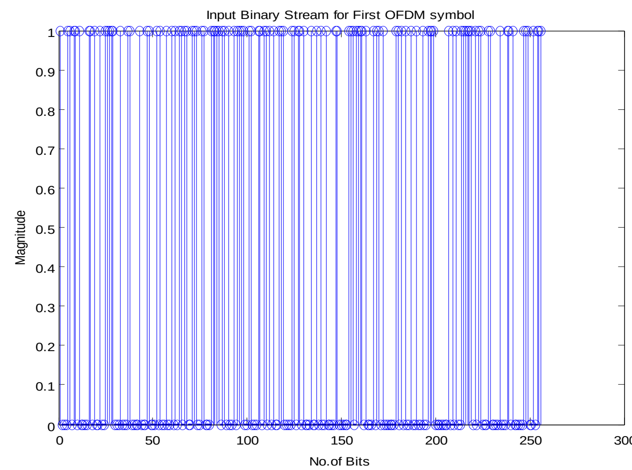

Fig3. Input Binary Stream of First OFDM Symbol

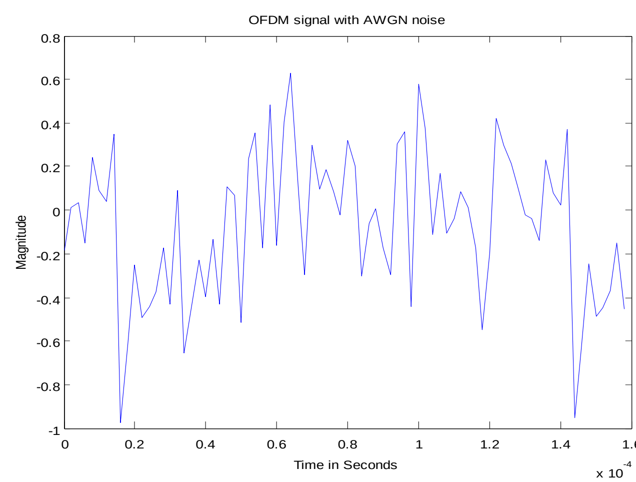

Fig 4. OFDM signal through Multi pathsand adding AWGN noise

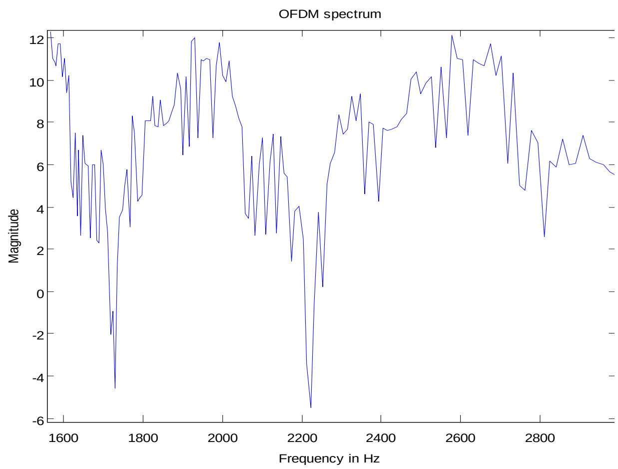

Fig 5. OFDM Spectrum

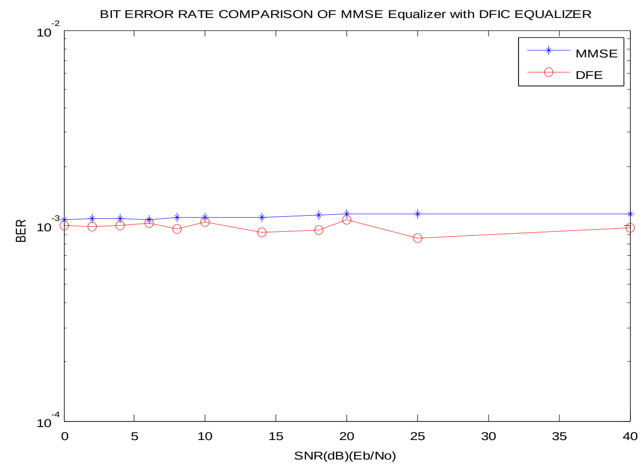

Fig 8. BER performance of MMSE and DFIC Equalizers with KALMAN Channel Estimator

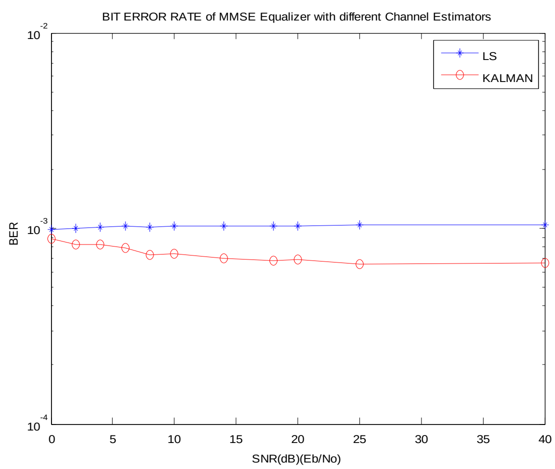

Fig 6. BER performance of MMSE Equalizer with LS and KALMAN Channel Estimator

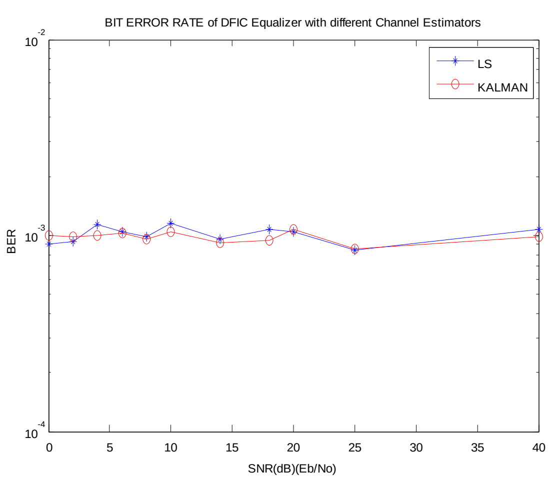

Fig 7. BER performance of DFIC Equalizer with LS and KALMAN Channel Estimator

VI. CONCLUSION

In this paper, we implemented the 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 as well as DFIC equalizers. MMSE and DFIC equalizers equalize received OFDM signal. We also proved that non-linear DFIC equalizer improves the Bit Error Rate as compared to linear MMSE equalizer and cancel out the noise.

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