Adaptive Carrier Frequency Offset and Channel Estimation for MIMO-OFDM System

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***Abstract* — The issue of Carrier Frequency Offset (CFO) and channel estimation are very important for Multi Input Multi Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM). Previously, the problem of channel estimation and CFO are considered and for that adaptive algorithm is proposed by using this algorithm CFO and channel parameter are estimated at the same time. A multiple model is used in which many sub channel models is constructed. The sub channel and CFO separately estimated so by using this method computational complexity can be reduced. This paper uses the kalman filter and EKF with sinc function for proper synchronization and to achieve a minimized mean square error (MSE) compared to first order and second order method. Finally, Different simulations are shown to prove the performance with compare to other methods.**

Keywords: - Multi-Input Multi-Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM), Carrier Frequency Offset (CFO), Extended Kalman Filter.

I. INTRODUCTION

The combination of both the techniques MIMO-OFDM i.e. Multi Input Multi Output Orthogonal Frequency Division Multiplexing achieve remarkable advertency for broadband communication[1,4].The MIMO-OFDM gives the many advantages such as high data speed, antenna diversity, low complexity and also reduces inter symbol interference (ISI) effect. The sensitivity of CFO i.e. carrier frequency offset the carrier frequency mismatches between receiver and transmitter oscillators. The phase errors induces due to CFO and because of that in subcarriers loss of Orthogonality occurs and leads to inter carrier interference (ICI) and the desired signals are attenuated. The effective signal to noise ratio is reduces because of these effects at OFDM reception and the performance of system is degraded [5]. The channel parameters are required to achieve maximum diversity gain and to handle the theoretical capacity so, for design of MIMO-OFDM system estimation of channel is necessary. For channel estimation and tracking many researchers have been taken. To track a MIMO-OFDM channel an extended kalman filter with the pilot-symbol-aided method has been proposed in [13]. With a pilot-symbol-aided method, channel estimation may degrade the data throughput and may occupy the available bandwidth [14]-[15]. Using a kalman based filter, decision-directed channel estimation in the frequency domain was proposed in [18]. All these researches consider only problem of channel estimation. Due to mismatch between transmitter and receiver oscillators CFO is not taken into those algorithms. The channel estimation occupy results depends on the exact carrier frequency at the receiver, The channel estimation and the idea of joint CFO has been initially praposed.For OFDM system and then extended to MIMO-OFDM system[15]-[17]. For point-to-point MIMO-OFDM system a closed form joint CFO and channel estimation was proposed and extended to MIMO-OFDM system [11]. However, the solutions of closed form are not real time so that for fading channel environment they are not suitable. For MIMI-OFDM system a pilot-aided algorithm has been developed for operating in a fast time-varying environment [10]. These estimations done by using basis expansion model (BEM) technology and extended kalman filter (EKF). The number of channel taps increases, as the channel delay spread increases, and a BEM coefficients have to be estimated with a large number and more pilot symbol are required for this. The motivation of this paper is to reduce the complexity of the system and solves the problems of CFO (carrier frequency offset) and channel estimation and also to reduce the minimum mean square error by using sync function with Kalman filter and increase the signal to noise ratio.

II. SYSTEM MODELS OF MIMO-OFDM SYSTEM

In current and future wireless communication MIMO-OFDM plays an important role. To achieve high data speed and better bit rate MIMO channels are introduced and it is used with OFDM to provide good quality of service, high transmission rate, and low probability of error. With N_t transmit antennas, N_r receive antenna & N_c subcarrier is considered with MIMO system.

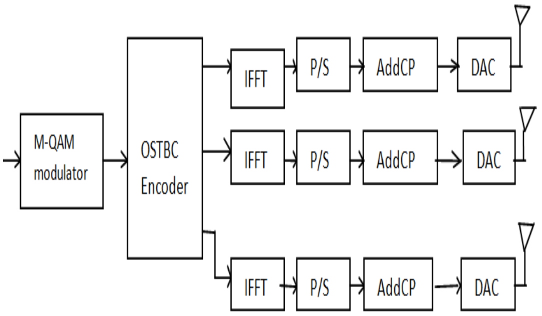

Fig. 1: Block diagram of MIMO-OFDM Transmitter

As shown in fig.1 an M-ary QAM (Quadratic Amplitude Modulator) modulate the information bits. These modulated symbols are encoded by using OSTBC (Orthogonal Space Time Block Coding) encoder [1]. The data which is transmitted is encoded in blocks, which are divides among spaced antennas & across time. Cyclic prefix is added to remove the interference in the system. In order to achieve diversity the OFDM signal are transmitted through number of antennas. For each antenna OFDM signal is obtained by using IFFT & by using FFT these signal can be detected. At the receiver end CP is removed & N Point FFT is performed for each receiver. Using serial to parallel the data which is modulated is converted into low rate parallel data stream. It also solves the multipath fading in channel. The transmitted signal will be regenerated by using equalizer from received signal. The equalizer requires channel information to reduce the MSE between transmitted signal and regenerated signal. Channel estimation is used to estimate the channel parameter from received signal.To obtain the output signal demodulation operation are performed.

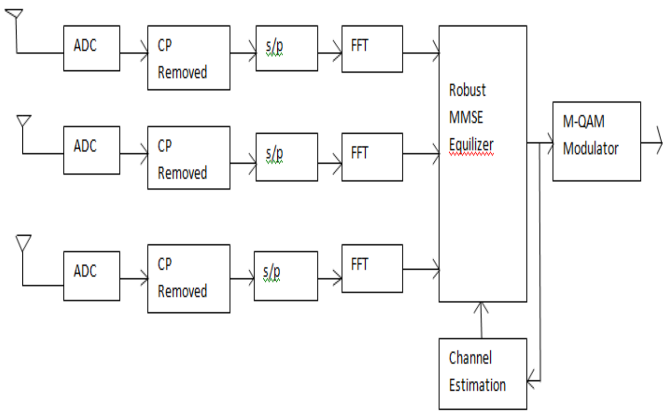

Fig. 2: An MIMO-OFDM receiver with decision-directed channel tracking

The impulse response of time domain channel from $\boldsymbol{j^{th}}$ transmit antenna to the $\boldsymbol{i^{th}}$ receive antenna of $\boldsymbol{l^{th}}$ path sampling of the complex time-varying fading channel with length, L at the OFDM symbol is represented as $\boldsymbol{h_1^{j,i}(n)}$. An AR process can match its special characteristics, for a Rayleigh fading channel [1]. Due to simplicity and accuracy the second order AR model is used here. So, the$\boldsymbol{n^{th}}$ OFDM symbol of $\boldsymbol{l^{th}}$ path of time domain channel impulse response from the $\boldsymbol{j^{th}}$ transmit antenna to the $\boldsymbol{i^{th}}$ receive antenna is given by

$$h_1^{j,i}(n) = a_1^{j,i}(n-1)h_l^{j,i}(n-1) + a_2^{j,i}h_l^{j,i}(n-2) + w_l^{j,i}(n) \quad \text{... (1)}$$

For i=0, .., $N_r - 1$, j=0, …, $N_t - 1$, and l=0, …, $N_c - 1$,
Where $w_l^{j,i}(n)$ is a zero mean complex white Gaussian process, $a_1^{j,i}(n)$ And $a_2^{j,i}(n)$ parameter are determined by Doppler frequency shift due to change in velocity of the mobile station. These parameter are defined in [16] as,

$$a_1^{j,i}(n) = 2r_d \cos\left(2\pi f_D^{j,i}(n)T\right), a_2^{j,i} = -r_d^2 \quad \text{.... (2)}$$

Where $f_D^{j,i}(n)$the maximum Doppler frequency is shift in the n^{th} symbol period and r_d is the pole radius that corresponds to the steepness of the peaks of the power spectrum. The possible assumption that the any antenna velocities pair between transmitter and receiver are all equal in any time instant i.e. $a_1^{j,i}(n) = a_1(n), \forall i, j$.

III.ADAPTIVE ALGORITHM FOR JOINT CFO AND CHANNEL ESTIMATION

Here, for designing the joint frequency offset and channel estimator one receiver antenna ($N_r = 1$) is considered. The same procedure of estimation is adopted for other receiver antennas. However, to achieve a more accurate estimate, the estimation from different receiver antennas can also be combined. Since, the same receiver oscillator shared by all receiver antennas. The $h_l^{j,i}(n)$ time domain impulse response can be simply expressed as $h_l^j(n)$. The $S_{i,k}(n)$ i.e. training signal means the signal from the i^{th} sub channel of the k^{th}transmit antenna.
For all subcarrier the received vector $\underline{r}$(n) is defined as,

$$\underline{r}(n) = \left[r_0 \;\; r_1 \ldots \ldots r_{N_{c-1}}\right]^{\wedge}T \in C^{N_c}$$

Therefore, for each sub channel received vector signal can be expressed as,

$$r_{i,}(n) = y_i(n) + w_i(n), i = 0, \ldots, N_c - 1 \quad \text{... (3)}$$

$$\text{Let,} \quad h_i(n) = \left[h_0^i(n) \quad h_1^i(n) \qquad h_{N_c-1}^i(n)\;\right]^H \quad \text{..... (4)}$$

$$\underline{h}(n) = \left[h^{H_0}(n) \qquad \underline{h}^{H_1}(n) \ldots . \underline{h}^{H_{N_t-1}}(n)\right]^H$$

The joint CFO and channel estimation problem can be transformed into the below state –space equations,

$$X(n) = G(X(n-1)) + V(n) \quad \text{... (5)}$$

$$\underline{r}(n) = D(X(n)) + w(n) \quad \text{... (6)}$$

Where,

$$X(n) = \begin{bmatrix} v(n) \\ a_1(n) \\ \underline{h}(n) \\ \underline{h}(n-1) \end{bmatrix}, G(X(n)) = \begin{bmatrix} bv(n) \\ a_1(n) \\ a_1(n)\underline{h}(n) + a_2\underline{h}(n-1 \\ \underline{h}(n) \end{bmatrix}, V(n) = \begin{bmatrix} w_v(n) \\ w_a(n) \\ V_h(n) \\ 0 \end{bmatrix} \quad \text{..(7)}$$

However, in equation (5), the joint estimation is a non-linear problem due to coupling. For any linear estimation method it is not easy to estimate them simultaneously. To solve the non-linear estimation problem the Extended Kalman Filter is introduced.
From the dynamics of the state equations in (5) and Kalman filter algorithm as below,

$$\hat{X}(n|n-1) = G(\hat{X}(n-1|n-1)) \quad \text{.... (8)}$$

$$\hat{X}(n|n) = \hat{X}(n|n-1) + K_a(n)\underline{e}(n) \quad \text{.... (9)}$$

Where,

$$\underline{e}(n) = \underline{r}(n) - \underline{D}(\hat{X}(n|n-1) \quad \text{..... (10)}$$

And $K_a(n)$ is Kalman gain. Here, $\underline{e}(n)$ denotes the prediction error. $K_a(n)$ Minimizes the covariance $E\{\underline{e}(n)\,\underline{e}(n)^T\}$ of the prediction error. The error covariance matrices $P(n|n)$ of the smooth range prediction and estimation and the extended kalman gain $K_a(n)$ are obtained from the equations which are as follows:

$$P(n|n-1) = gP(n-1|n-1)g^h + \sigma v^2 I \quad \text{... (11)}$$

$$K_a(n) = P(n|n-1)d^H[dP(n|n-1)d^H] + Q_w^2]^{-1} \quad \text{... (12)}$$

$P(n|n) = [I - K_a(n)d]P(n|n-1)$ …. (13)

Where, $g = \frac{\partial G(X)}{\partial X} =$

$$\begin{bmatrix} b & 0 & 0 & . & . & 0 \\ 0 & 1 & 0 & . & . & 0 \\ 0 & \underline{h}(n) & a_1 I_{N_t N_c} & . & . & a_2 I_{N_t N_c} \\ 0 & 0 & I_{N_t N_c} & . & . & 0_{N_t N_c} \end{bmatrix} \quad \ldots (14)$$

Here it is noted that, $\underline{r}(n) \in C^{N_c}$, X (n)$\in C^{(2N_tN_c+2)}$, $K_a(n) \in C^{(2N_tN_c+2)*N_c}$, $P(n|n) \in C^{(2N_tN_c+2)*(2N_tN_c+2)}$, g$\in C^{(2N_tN_c+2)*(2N_tN_c+2)}$, and d$\in C^{N_c*(2N_tN_c+2)}$. There is a matrix ($\in C^{N_c*N_c}$) is inverted if $K_a(n)$ is calculated. So, the computational complexity is very high.

IV.ADAPTIVE MULTIPLE SUBCHANNEL ESTIMATION

A Multiple model, which includes many sub channel models, is proposed. The transmitted impulse response vector $H_i(n)$ for sub channel i as follows.

$H_i(n) = [h_i^0(n) \quad h_i^1(n) \quad h_i^{N_t-1}(n)]^H$ …. (15)

Related with eq. (3), following state space equation can be obtained for i =0,….,$N_c - 1$.

$X_i(n) = G_i(X_i(n-1)) + V_i(n)$ ….(16)

$r_i(n) = D_i(X_i(n)) + w_i(n)$ … (17)

Where,

$$X_i(n) = \begin{bmatrix} v(n) \\ a_1(n) \\ H_i(n) \\ H_i(n-1) \end{bmatrix}, G_i(X_i(n)) \begin{bmatrix} bv(n) \\ a_1(n) \\ a_1(n)H_i(n) + a_2H_i(n-1 \\ H_i(n) \end{bmatrix}, V_i(n) \begin{bmatrix} w_v(n) \\ w_a(n) \\ V_{h_i}(n) \\ 0 \end{bmatrix}$$

$D_i(X_i(n)) = y_i(n) = \sum_{k=0}^{N_t-1} S_{i,k}(n)\, e^{j\frac{2\pi i v(n)}{N_c}} h_i^k \sum_{k=0}^{N_t-1} S_{i,k}(n)\, h_i^k$ … (18)

By using the extended kalman filter, the following equations are obtained

$\hat{X}_i(n|n-1) = G_I(\hat{X}_i(n-1|n-1))$ … (19)

$\hat{X}_i(n|n) = \hat{X}_i(n|n-1) + K_{a_i}(n)\underline{e}(n)$ ….(20)

Where

$$e_i(n) = r_i(n) - d_i(\hat{X}_i(n|n-1)$$

The extended kalman gain $K_a(n)$ and error covariance matrices $P_i(n|n)$ of the smooth range prediction estimation are Obtained as follows:

$P_i(n|n-1) = g_iP_i(n-1|n-1)g_i^H + \sigma v^2$ .. (21)

$K_{a_i}(n) = P_i(n|n-1)d_i{}^H\left[d_iP(n|n-1)d_i{}^H\right] + Q_w^2]^{-1}$ ..(22)

$P_i(n|n) = [I - K_{a_i}(n)d]P_i(n|n-1)$ ..(23)

Where

$$g_i = \frac{\partial G_i(X_i)}{\partial X_i} = \begin{bmatrix} & b & 0 & 0\ldots..0 \\ & 0 & 1 & 0\ldots.0 \\ 0 & H_i(n) & a_1 I_{N_t} & a_2 I_{N_t} \\ & 0 & 0 & I_{N_t} & 0_{N_t} \end{bmatrix}$$

$$d_i = \frac{\partial D_i(X_i)}{\partial X_i}\left[j\frac{2\pi i}{N_c}y_i \quad 0 \quad s_{i,0}(n) \quad s_{i,1}(n) \ldots\ldots \quad s_{i,N_{t-1}}(n) \quad 0 \quad 0..0\right]$$

There are N_c extended kalman filter to estimate $\hat{X}_i(n|n), i = 1 \ldots, N_c$. The covariance of $E\{e_i(n)e_i^T(n)\}$ of the smooth range prediction error is expressed as,

$E\{e_i(n)e_i^T(n)\} = \Omega_i(n) = d_iP(n|n-1)d_i^H + Q_w^2$ … (24)

For i=0,….,$N_c - 1$.Each $\hat{X}_i(n|n)$ have v(n) and $a_1(n)$.

To obtain the estimation result accurately, calculate the weighting for each extended filter. The likelihood function $\wedge_i$ and the weighting w_i for i^{th}EKF, respectively, is given by

$$\wedge_i(n) = N(e_i(n); 0, \Omega_i(n))$$

…. (25)

$$w_i(n) = \frac{\wedge_i(n)}{\sum i \wedge_i(n)}$$

Where, $N(e_i(n); 0, \Omega_i(n))$ denotes the guassian density function of $e_i(n)$ with zero mean and covariance $\Omega_i(n)$. The estimated v(n) and $a_1(n)$ can be given as:

$$\hat{v}(n) = \sum_{i}^{N_{c-1}} w_i\, \hat{X}_i(n)[1 \ 0 \ \ldots.0 \ ^T]$$

…. (26)

$$\hat{a_1}(n) = \sum_{i}^{N_{c-1}} w_i\, \hat{X}_i(n)[0 \ 1 \ 0 \ \ldots.0 \ ^T]$$

Here, $r_i(n) \in C^1$, $X_i(n) \in C^{(2N_t+2)}$, $K_a(n) =\in C^{(2N_t+2)*1}$, $P_i(n|n) \in C^{(2N_t+2)*(2N_t+2)}$, $g_i \in C^{(2N_t+2)*(2N_t+2)}$, d$\in C^{1*(2N_t+2)}$.As shown above it is observed that when $K_a(n)$ is calculated, no matrix shall be inverted. So, this algorithm can reduce the computational complexity and to reduce minimum mean square error (MSE) the sinc function is used with kalman filter.It synchronizes the information with filter and very best results are obtained by using syncKF.

The sync function is defined as follows:

$$\text{Sinc (x)} = \begin{cases} \frac{\sin(\pi x)}{\pi x}, & x \neq 0 \\ 1, & x = 0 \end{cases} \quad \ldots(27)$$

For a step size h>0 the series,

$C(f,h)(x) \equiv \sum_{k=-\infty}^{\infty} f(kh)S(k,h)(x)$ …. (28)

Where S (k, h)(x)is the scaled and translated k^{th} Sinc function given by,

$$\text{S (k) (x) = sinc } \left(\frac{x-kh}{h}\right)$$

is called Whittaker cardinal expansion of f whenever the series converges. The infinite series defining these approximations are truncated as

$C_N(f,h)(x) \equiv \sum_{k=-N}^{N} S(k,h)(x)f(kh)$ ….. (29)

For a given positive integer N. $C_N(f,h)(x)$ Defines interpolation of f(x) with $C_N(f,h)(x) =$ f(x) at all sinc points given by $x_k = kh$.Sinc interpolation provides approximation that exhibit exponentially decaying absolute errors.

V.EXPERIMENTAL RESULTS

In this work, the results are shown via numerical calculations on MATLAB Platform. The kalman filter and extended kalman filter is used with sinc function. In this the parameter α is considered and by considering the different values of α the results are as follows. The following fig represents the SNR vs MSE. The Fig(3) shows the results for different values of α.

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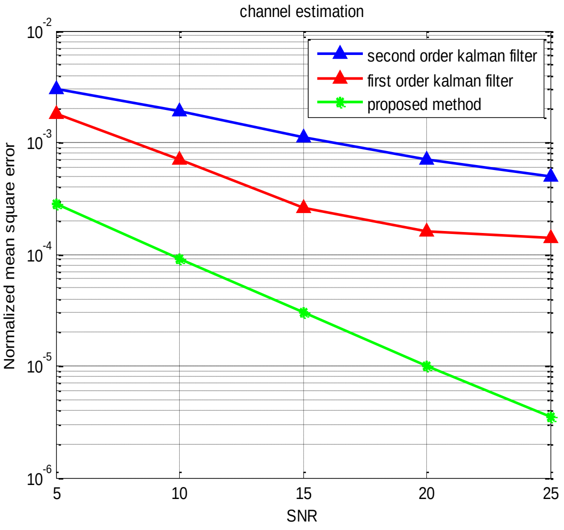

Fig(a).For α=1.

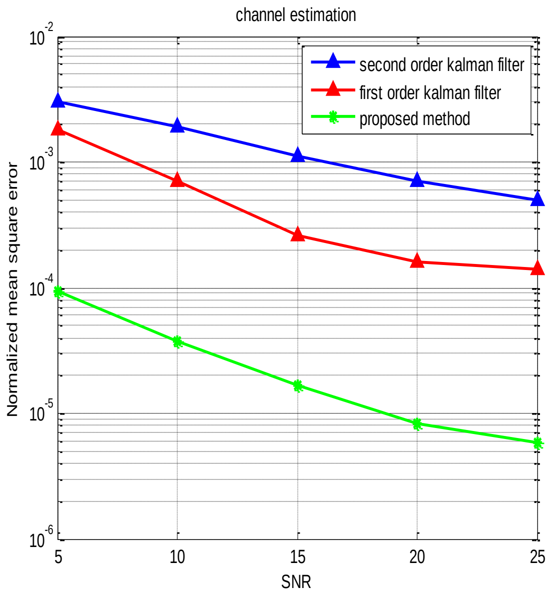

Fig.(b).For α=2

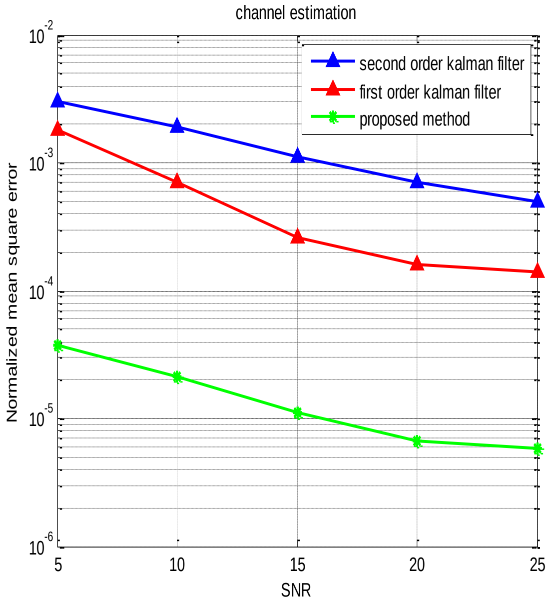

Fig. (c).For α=3

Fig.3. Comparison between fig (a), (b), (c) for different values of α.

As compare to above three figure, it is noted that as the value of α gets increased the MSE i.e. minimum mean square error gets decreased and SNR increased. The compared methods are the algorithms which can provide the channel estimation and prediction simultaneously. The MSEs, using different values are as above.

VI.CONCLUSION AND FUTURE WORK

In this paper, an adaptive carrier frequency offset and channel estimation for MIMO-OFDM has been proposed. By using a non-linear state space dynamic equation the channel model is constructed it includes CFO, channel gains and dynamics of channel so channel model becomes huge non-linear and computational complexity gets increased .A multiple model is constructed which contains many sub channel model the CFO can be separately estimated with sub channel state and the accurate CFO is obtained by estimated integrating CFO from sub channel model using weighting technology. This is our future work. so, the computational complexity gets reduced. It has been shown via numerical calculations on MATLAB that proposed work provides the minimized MSE (mean square error) by using kalman filter with Sinc function. The proposed algorithm will be modified for channel estimation in the tracking mode after that the channel parameters are estimated which is used to design the MMSE equalizer this MMSE equalizer wishes to be obtained by using the information of the estimation algorithm.

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