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Abstract- In this paper, risk-sensitive filter (RSF) based channel estimation has been proposed for MIMO-OFDM system. The uniqueness of the risk sensitive filter's performance in the presence of uncertainty is explored for channel estimation problem. In general, the channel estimation problem is formulated as the estimation of time varying coefficients of FIR filter. Estimation of channel is very critical task to recover the error free signal at the end of the receiver under the unknown statistics of the channel. Several Kalman based algorithms are proposed for channel estimation in MIMO-OFDM system under different channel considerations using traditional pilot based estimation. Auto regressive (AR) model is used to formulate the parameters to be estimated. Unlike to the traditional pilot based approach, in this work combined orthogonal pilot aided (COPA) channel estimation is used to eliminate the same frequency interference created by the OFDM frequency among different transmit-receive antenna pairs. The results proved that proposed estimator is outperforming when compared with Kalman under uncertainty in parameter.

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I. Introduction

Multiple-Input Multiple-Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM) combination will provide high data rates and mitigate the effects of the multipath delay in wireless communication[1]. The advantages originate from the multiple spatial channels, which are provided by the multiple antennas together with the scattering environment surrounding the transmitters and the receivers. As the wireless environment is time varying, channel estimation became as essential part of the receiver [2- 4]. The accurate estimation of the channel statistics will provide the better diversity gain and coherence detection and decoding.

Pilot aided channel estimation is proved as better approach to estimate the channel with more accuracy [13,14]. But it suffers interference created by the OFDM frequency among different transmit-receive antenna pairs. To overcome this Combining the design of the joint orthogonal pilot for the MIMO-OFDM system has proposed in [15-17], which has designed the pilot data format maintaining the orthogonal property between different OFDM subcarriers of different transmitting-receiving antenna pair and same transmitting-receiving antenna pair, at the same time, the pilot symbols are inserted into the data frame at the transmitter according to the polygon form in the change of the OFDM subcarriers in transmitting-receiving antenna pair.

Most of the conventional methods work in a symbol-by-symbol scheme using the correlation of the channel only in the frequency domain i.e., the correlation between the sub-channels. More advanced algorithms are based on the Kalman Filter (KF), to also exploit the time- domain correlation [11,12]. KFs require a linear recursive state-space representation of the channel. However, the exact Clarke model does not admit such a representation. An approximation often used in the literature consists of approaching the fading process as auto-regressive [5,6]. Hence, a widely used channel approximation is based on a first-order Auto-Regressive model (AR), as recommended [5],. The KF appears to be convenient for the very high mobility case, which leads to quasi-optimal channel estimation. In the present study, we consider multi-path channel estimation in multi-carrier systems (i.e., OFDM systems). In this context, we are interested in evaluate the performance of KF and RSF under parameter uncertainty [26-29]. To do this, we use the least-square (LS) estimator at the pilots of current OFDM symbol. This first step explores the frequency-domain correlation of the channel and the knowledge of the delays to convert the primary observation at pilot frequencies.

This paper is organized as follows: Section II introduces the MIMO-OFDM system model, In Section III explored the arrangement of pilots in combined orthogonal scheme and its significance in estimation during the same frequency inference, Section IV discussion on time varying channel model and channel model with parameter uncertainty. Section V introduces the KF and RSF channel estimation methodology in parameter uncertainty.

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II. System Model

Consider a MIMO system equipped with transmit antennas and receive antennas. The block diagram of baseband MIMO-OFDM system is shown in Figure 1.

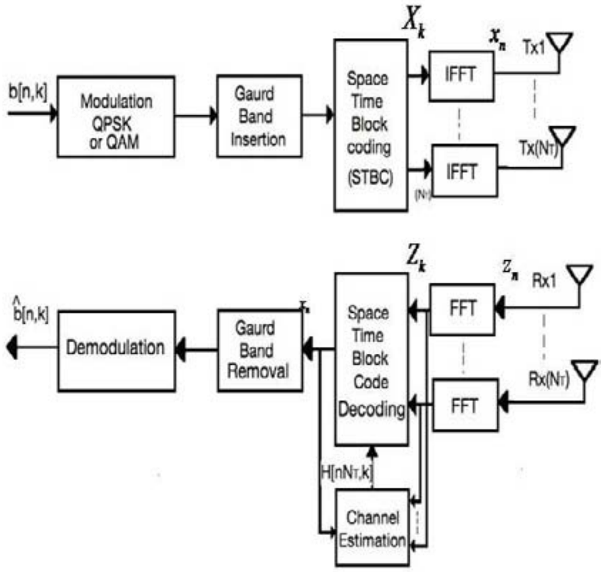

Figure 1: Block Diagram of MIMO-OFDM System

As Figure 1 shows, we use N_T transmit antennas, N_R receive antennas, *n* OFDM symbols and *K* subcarriers in a MIMO-OFDM system.
The transmitted symbol vector is given as

$$x[n,k]=\left[x^{(1)}[n.k]\ldots x^{(N_T)}[n.k]\right]^T$$
$$n\in Z, k=0\ldots\ldots K-1,$$

Where $x^{(i)}[n.k]$ indicates the symbol transmitted at the symbol time *n*, subcarrier *k*, and antenna *i*. The n^{th} OFDM symbol $X_n[m]$ can be acquired by performing an inverse fast discrete Fourier transform (IFFT) to the $x[n,k]$ and inserting a CP of length L_{CP}

$$X_n[m]=\begin{cases}\dfrac{1}{\sqrt{KN_T}}\sum_{m=0}^{K-1}x[n,k]e^{j2\pi mk/K}, m=-L_{CP}\ldots K-1\\ 0, else\end{cases} \quad (1)$$

Thus the duration of each OFDM symbol is *cp* $N=K+L_{CP}$. The overall baseband transmitted signal is

$$X_n[m]=\sum_{n=-\infty}^{+\infty}x_n[m-nN] \quad (2)$$

The signal from each receiver is formed by the parameter matrix $H[m,l]$ of the fading MIMO $N_T\times N_r$ channel [11], the transmitted signal $X_n[m]$, and the noise $\eta[m].\eta[m]$ is stationary white Gaussian noise which distribution is expressed by N $(0,\sigma_\eta^2)$. The receiver signal $z[m]$ is demodulated by removing cyclic prefix and performing fast Fourier transform (FFT).

$$Z[n,k]=\frac{1}{\sqrt{K}}\sum_{m=0}^{K-1}z[nN+m]e^{-j2km/K} \quad (3)$$

If $N\ f_{Doppler} << 1$ and $H[m,l] = h_l[n]$ (Here n=m) varies negligibly within one OFDM symbol, the input/output relation can be expressed as below,

$$Z[n,k]=\hat{H}[n.k]x[n.k]+\hat{\eta}[n.k] \quad (4)$$

Here $Z[n,k]$, $\hat{H}[n.k]$ and $\hat{\eta}[n.k]$ are all $N_T\times N_r$ matrices, and $\boldsymbol{x}[n,k]$ is $N_T\times N_r$ matrix.

III. Combined Orthogonal Pilot Scheme

Use of pilot symbols for channel estimation introduces overhead and it is desirable to keep the number of pilot symbols as minimum as possible. The completely orthogonal pilot data symbol among the different subcarriers position of different transmitting receiving antenna pair [15, 17]. And the pilot data symbols are distributed in the entire time-frequency grid of the channel for each transmitting antenna of the OFDM transmitter, the pilot symbols are coded, so that the antenna is unique. The coded pilot symbol was inserted into the OFDM frame, in order to form the diamond grid, and the diamond grid used for different antenna will use the same frequency, but in the time domain will deviate a single symbol from each other.

At the OFDM receiver, the channel responses are estimated through the use of two dimensional interpolations according to the diamond center symbol of each of the diamond grid and the estimated channel response in frequency domain is smoothed. The channel response of the rest symbols are estimated through the interpolation in the frequency domain.The arrangement of the pilot patteren is shown in the figure.2 [15].

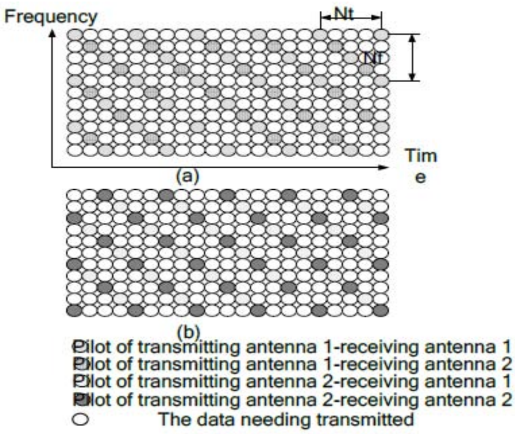

Figure 2: Pilot Arrangemet in Combined Orthogonal Scheme

IV. Time Varying Channel Model

a) Tapped delay line channel Model

A multiplicative channel model with an additive Gaussian white noise (AGWN) model is used sometimes it also refers as Gauss-Markov process represented [5] above as equation (2) i.e.

$$y(t,\tau)=\sum_r h_r(t)x(\tau-\tau_r) \tag{5}$$

The function $y(t,\tau)$ in the above equation is just same as Finite Impulse Response (FIR) filter which has time-varying coefficients. In real world scenario there are many factors, as disturbance, affect the medium, which leads to model the system with additive noise and result the system model become (3).i.e.

$$z(t,\tau)=\sum_r h_r(t)x(\tau-\tau_r)+v(\tau) \tag{6}$$

To design effective communication, it is necessary to have good knowledge about these coefficients. There are too many parameters to estimate in (5). As observation samples are corrupted with noise, weights of samples will rapidly change from one to others. The weighted taped channel is modeled as Gauss-Markov model. The Gauss-Markov model will be used to fix the correlation between successive values of given taped weight in time.

In channel estimation, the state vector is given as

$$h[n]=Ah[n-1]+u[n] \tag{7}$$

where

$$h[n]=\begin{bmatrix} h_n[0] \\ h_n[1] \\ . \\ . \\ h_n[p-1] \\ \\ \end{bmatrix}$$ A is a $p\times p$ matrix

and $u[n]$ is AWGN, with zero mean and variance Q. Standard assumption made that tap weights are joined Gaussian and uncorrelated with each other.

Measurement/observation model is written by rearranging (10)

$$z[n]=\left[x[n] \quad x[n-1] \quad x[n-2] \quad . \; . \; . \quad x[n-p+1]\right] h[n]+w[n] \tag{8}$$

and it can be expressed as

$$z[n]=x[n]^T h[n]+w[n] \tag{9}$$

where $w[n]$ is Gaussian white noise with variance $R=\sigma^2$ and $x(n)$ is known sequence, act as input to the channel.

b) Tapped delay line channel Model with uncertainty

In a circumstance, when there is uncertainty in the channel state vector, (7) may be written as

$$h[n]=Ah[n-1]+\Delta A+u[n] \tag{10}$$

where ΔA is a constant which arises due to channel phase rotation during coding and it is considered as a parameter modeling uncertainty in matrix A. This model is similar to case of random walk process described in [7] and in state-space domain the model

V. Channel Estimation

a) Kalman based channel estimation

The Kalman filter is a mathematical method used to use observed values containing noise and other disturbances and produce values closer to true value and calculate value [21]. The basic operation done by the KF is to generate estimates of the true and calculated values, first by predicting a value, then calculating the uncertainty of the above value and finding an weighted average of both the predicted and the measured values [20]. Most weight is given to the value with least uncertainty. The result obtained the method gives estimates more closely to true values. It is a recursive predictive filter based on the use of state space techniques and recursive algorithms. It demands the description of the dynamical problem in a state-space form which includes a system model and an observation model which is considered only for linear systems. Kalman filter is a recursive minimum mean square error (MMSE) estimator and it provides optimal estimation solution for linear and unbiased process with additive white noise. There is enough literature on KF, for example [5,21].

The implementation of KF for channel estimation problem given in above subsection is given in detail as follow steps [29].

Filter initialization

$$\hat{h}\left[n-1\middle|n-1\right]=\mu_h \text{ and } P\left[n-1\middle|n-1\right]=C_h \quad (11)$$

Prior state estimation

$$\hat{h}\left[n\middle|n-1\right]=A\hat{h}\left[n-1\middle|n-1\right] \quad (12)$$

Prior estimate error covariance

$$P\left[n\middle|n-1\right]=AP\left[n-1\middle|n-1\right]A^T+Q \quad (13)$$

Kalman Filter gain

$$K[n]=P\left[n|n-1\right]V[n]\left(V[n]^T P\left[n|n-1\right]V[n]+(R)\right)^{-1} \quad (14)$$

Posterior state estimate

$$\hat{h}\left[n|n\right]=\hat{h}\left[n|n-1\right]+K[n]\left(x[n]-V[n]^T\hat{h}\left[n|n-1\right]\right) \quad (15)$$

Posterior estimate error covariance

$$P\left[n\middle|n\right]=\left(I-K[n]V[n]^T\right)P\left[n\middle|n-1\right] \quad (16)$$

b) Proposed Risk Sensitive Filter approach

A RSF which is recursively update a posteriori state and estimate error covariance as given in [23] is used here for fading channel estimation. Implementation of fading channel estimation using RSF is follows:

For linear system, the posteriori state estimate $\hat{h}$ of h at k^{th} time is obtained by the risk sensitive approach such that

$$\hat{h}\in\arg\min E[\exp\theta\{\sum_{m=0}^{k-1}l(h_m,\hat{h}_m)+l\left(h_m,\right)\}\,|\,x[n]] \quad (17)$$

Here, θ is a tuning parameter, known as risk factor or risk parameter, the function $l(h,\hat{h})$ is defined as

$$l\left(h,\hat{h}\right)=\frac{1}{2}\left(h-\hat{h}\right)^T\left(h-\hat{h}\right) \quad (18)$$

$$x[n]=\left\{x[1],\ldots,x[n]\right\} \quad (19)$$

(Notation T denotes transpose)

This is strictly filtering problems. For more details readers can refer [23-26].

As [25], the posteriori state estimation is given as

$$\hat{h}[n\,|\,n]=A\hat{h}[n-1|n-1]+P[n|n]V[n]^T R^{-1}\left(x[n]-V[n]^T A\hat{h}[n-1|n-1]\right) \quad (20)$$

Posteriori estimation error covariance is given as

$$P[n\,|\,n]^{-1}=\left[A\left(P[n-1|n-1]^{-1}-\varnothing I\right)^{-1}A^T+Q\right]^{-1}+V[n]R^{-1}V[n]^T \quad (21)$$

VI. Simulation Results

The simulation parameters are as follows. The FFT size, *N,* is 64. The data symbol X_k is based on QPSK. The channel h_n is the Rayleigh fading channel which has two paths. The space-time coding scheme is Alamouti's STBC with ½ rate and the decoding scheme used is Maximum likelihood (ML) technique with only linear processing. The number of OFDM symbols considered here are 8. The initial values of the for the KF are as follows: 0 **h** =[0 0]*T* , 0 *P* =100 *I* , 0 *S*=0 *I* , 0 **q** =[0 0]*T* , and 0 *a*=1. The comparison factor, MSE, is obtained after 100 independent trials. The linear interpolator is used as we considered slow fading channel. In contrast, the proposed RSF algorithm works well in parameter uncertainty conditions and usual performance and close to KF in absence of parameter uncertainty [22]. Although this paper focuses mainly on channel estimation under parameter uncertainty.

The graphs are plotted for Error Rate versus SNR and Mean Square Error versus SNR by taking 2x2 MIMO-OFDM systems. Performance is compared in the aspect of mean square error (MSE) LS, KF and RSF under uncertainty with 0.5 and the Bit error rate (BER) shown in Figure.3 and Figure.4 respectively.

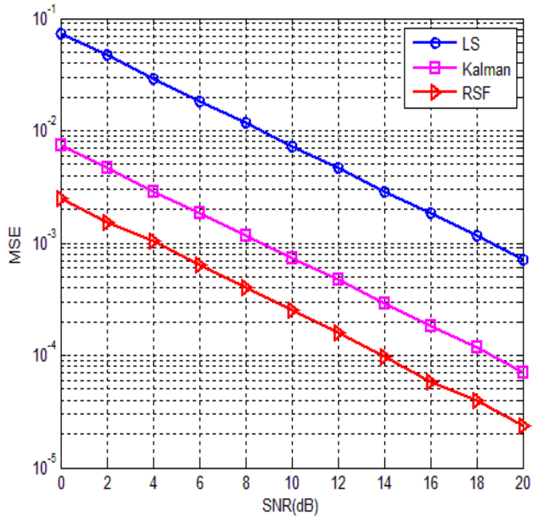

Figure 3: MSE vs SNR for LS, KF and RSF

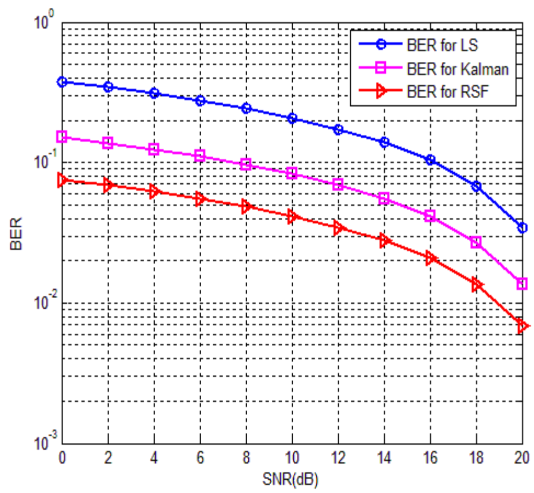

Figure 4: BER vs SNR for LS, KF and RSF

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