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State Space Model Based Channel Estimation using Extended Kalman Filter for Superposition Coded Modulation OFDM System

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Abstract – In this work Extended Kalman Filter(EKF)is implemented for Orthogonal Frequency Division Multiplexing-Superposition Coded Modulation(SCM) scheme. Due to time varying nature of Rayleigh fast fading channel which vitiates the performance of data detection which in turn degrades the performance of OFDM system. An efficient channel estimation technique is necessary. An Extended Kalman filtering algorithm is proposed which is low in computational complexity. The Jakes process is modeled as Autoregressive model and approximated to Rayleigh fading channel. This estimator algorithm is bandwidth efficient and requires less computation contrast to data-based only estimators. The results obtained prove that the proposed algorithm can be used to obtain the channel estimation with low computational complexity at the receiver.

Index Terms - SCM (Superposition Coded Modulation), EKF(Extended Kalman Filter),Orthogonal Frequency Division Multiplexing(OFDM), AR model (Auto regressive)model.

1.0 INTRODUCTION

OFDM is multicarrier, bandwidth efficient modulation technique, but it suffers from Peak average Power Ratio(PAPR) and Inter carrier Interference(ICI).Due to high speed mobility of the transceiver, the channel characteristics vary rapidly. An efficient channel estimation technique is required to estimate the channel impulse response. In wireless communication system field the main efforts have been directed towards the channel estimation. Since the transmitted data are prone to the channel noise. The error controlled codes are used to minimize channel noise but these codes are bandwidth inefficient.

In order to solve these problems several coded modulation schemes are proposed in literature [1-4, 19]. To match the channel conditions both coding and modulation are combined in coded modulation schemes.

Superposition Coded Modulation (SCM) is one among the Coded modulation schemes [5-6]. The SCM system is explained in detail in section II. In this paper we are proposing channel estimation technique for the SCM –OFDM system. In most of the applications, the estimated parameters are used to detect the data transmitted. The efficient channel estimation techniques are essential for the equalizer to work efficiently. The channel state information is very crucial in the wireless communication system. In order to maximize the SNR at the receiver, several channel approximation algorithm was proposed for rapid convergence and for improving MSE performance[7]. The channel estimation using pilot sequences were proposed in both time and frequency domains[8]. The decision direct channel estimation technique has been proposed in[9]which are based on Kalman filter. The technique mentioned in[9] has no overhead pilot symbols. But the decision direct method adopted in the[9] has delay problem. This leads to slow channel tracking in fast fading channel.

The wireless communication channel with multipath fading and Doppler effects can be approximated as a Jakes process and can be model using an Autoregressive (AR)model with white Gaussian process input. The Extended Kalman Filter (EKF) is used to extract the fast fading channel parameters [10][17].

This paper is organized as follows: section II: Describes the SCM-OFDM system. Section III:Describes Kalmanfilter based channel estimation and tracking. Section IV: Extended Kalman Filter algorithm implementation. SectionV: Simulation Results and finally SectionVI: Conclusion was made.

2.0 SCM SYSTEM

In recent years, the demand for high data rate has been increasing. Several high rate systems were proposed Superposition Coded Modulation (SCM) is one among them. In this system serial to parallel conversion of serial data stream is done, each paralleled data stream is considered as K number of data streams, each K stream is considered as individual k layer. Each k layer is encoded, interleaved and mapped. For simplicity we considered Binary Phase Shift Keying.

$$\{x_{i1,}x_{i2,\dots\dots}x_{ik}\}, \text{i.e., } \beta_k x_{i,k}$$

$$X_i = \sum_{k=1}^{K} \beta k x i, k \qquad (1)$$

Where each $x_{i,k}$is from a binary phase shift keying(BPSK) constellation and $\{\beta_k\}$ are a set of weighting constants[11][18].

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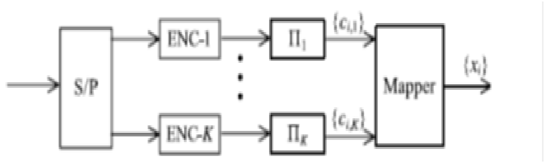

Figure 1a: Transmitter of MC-SCM

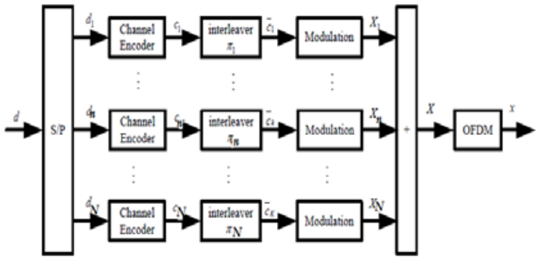

Figure 1b: Transmitter of MC-SCM-OFDM.

The output signal X is a linear superposition of N independently coded symbols. Then the superposition signal is fed into an Inverse Fast Fourier Transform (IFFT**)** modulator. After IFFT and the cyclic prefix, the signal is represented in the time domain as in equation (3)[26].

$$X(m) = \sum_{n-1}^{N} X_n(m),\ 0 \le m \le N-1 \qquad (2)$$

$$x(n) = \frac{1}{N}\sum_{m=0}^{N-1} X(m) e^{\frac{j2\pi mn}{N}} \quad -N_g \le n \le N-1 \qquad (3)$$

Where,
N = the total number of subcarriers

Ng = the length of CP.

The received signal $Y_n(k)$ is given by

$$Y_n(K) = \sum_{l=0}^{L-1} x_n(k-1)h_n(k-1)+w(k),\ k=0,1,\ldots N-1 \qquad (4)$$

Where $h_n(k,l)$ and w(k) represents l^{th} the complex time varying fading channel path with length L and additive noise at the k^{th} instant of SCM-OFDM symbol respectively. W (k) is assumed to be white Gaussian noise with zero mean and variance σ_n^2.
In this paper we investigate on the state space approach in modeling dynamics of the systems. In order to inference about a dynamic system and analyze the same, we require two models firstly a model which describing the state of the process with time(the system mode) and second a model relating the noisy measurements to the state (the measurement model)[21].

3.0CHANNELSTATE ESTIMATION USING EXTENDED KALMAN FILTER FOR SCM-OFDM SYSTEM.

Channel estimation is one of the major signals processing technique in wireless receivers. The channel estimation methods are classified into two types of channel estimation namely 1) Blind channel estimation: requires no training sequences, utilizes deterministic or statistical information from the received signal to estimate the channel impulse response. Advantage of this method is that it is bandwidth efficient but exhibit a draw backs such as slow convergence rate and computationally intensive 2) the second category in the channel estimation techniques to estimate the channel impulse response uses pilot symbols and previous state of the channel. The semi blind channel estimation techniques are spectral inefficient and high in computational complexity. Kalman filter attains superior estimation with few numbers of pilot symbols. Kalman filter uses an underlying channel model for channel estimation. Thus it is spectral efficient and low in computational complexity[15,16].The estimator that Kalman filter uses are of two types -channel model based estimator and data based estimator[7].

3.1 Channel model based estimator

The wireless channel is modeled as the Jakes model. Jakes model is approximated as an auto-regressive process. By solving the Yule-Walker set of equations the weights for the AR modelare determined(5). Using the relation of auto correlation'R' of the autoregressive process and the autoregressive co-efficient'r_{ss}'can be written as[15].

$$\Phi = R^{-1} r_{ss} \qquad (5)$$

Kalman algorithm uses the AR co-efficient obtained by above equations aids to model channel in a state space form [12][15].

3.2 Data based estimation

Data based estimator uses a pilot sequence of length M, transmitted with superposition coded frame. Pilot sequences are known to both transmitter and receiver. Assuming the channel is invariant along the length of the symbol.
The vector form of Pilot sequence is:

$$X=[x_0,x_1,x_2,\ldots x_{M-1}]^T \qquad (6)$$

Where 'T' represents the transpose operator.

Let the impulse response of the channel be:

$$h= [h1,h2,h_3\ldots\ldots..h_{l-1}]^T \qquad (7)$$

Where L is the process length to be tracked[13][16].
The received signal is the convolution of impulse response of the channel and transmitted pilot sequence in presence of noise as shown in equation (8). Using transmitted and received signal an estimate of the channel is found.

$$Y=X * h + n_c \qquad (8)$$

Where X is the transmitted pilot signal. Y is the received signal after passing through the channel with h as the impulse response of the channel. The $n_c$with zero mean and variance σ_c^2 with E_b=1 energy of the symbol, the SNR of the channel is given by:

$$\frac{Eb}{No} = \frac{1}{2\sigma c2} \quad (9)$$

The estimate of the channel is found by linear regression method as given below:

$$h=(X^TX)^{-1}(X^TY) \quad (10)$$

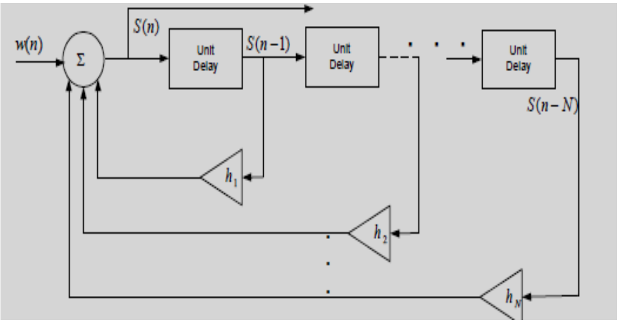

Figure 2: The Auto regressive (AR) model.

The figure represents AR process model truncated to N-taps[25].

The AR process is represented as below:

$$S\,(n)=\sum_{i=1}^{N} \emptyset i S(n-i)+w(n) \quad (11)$$

S (n): The complex Gaussian process.
$\varphi_{i:}$ AR modelparameters.
N=the number of taps delays.
W(n): Zero mean Complex Gaussian random variables.

The N^{th} order difference equation in the form of vector for state space model is written as:

$$\bar{S}(n) = F\bar{S}(n-1)+\bar{W}(n) \quad (12)$$

Where $\bar{S} and\ \bar{W}$ are column matrix of size (N X 1) and F is an (NXN) matrix [16][20].The mean and variance of autoregressive process are zero and

$$\text{Variance}= \sum_{i=1}^{N} \emptyset i Rss(i)+\sigma_n^2 \quad (13)$$

Autocorrelation is given by

$$\begin{aligned} R_{ss}(m) &= E\{S(n-m)S(n)\} \\ &= E\{[\textstyle\sum_{i=1}^{N} \emptyset i S(n-i)+w(n)]S(n-m)\} \\ &= \textstyle\sum_{i=1}^{N} \emptyset i Rss(m-i) \end{aligned} \quad (14)$$

The autocorrelation co-efficient is:

$$\begin{aligned} rss(m) &= \frac{Rss(m)}{S2x} \\ &= \textstyle\sum_{i=1}^{N} \emptyset i rss(m-i), \quad m\geq 1 \end{aligned} \quad (15)$$

The above equation in matrix form is called Yule-Walker equation.

$$\bar{R}\emptyset = \bar{r}ss \quad (16)$$

Since Ris invertible, we obtain

$$\emptyset = \bar{R}^{-1}\bar{r}ss \quad (17)$$

The equation (17) can be used to express the underlying process model which in turn can be used to express a Kalman filter to estimate the process.[13][16].

3.3 System model:

The system model for the first order process is given by:

$$S(n)=\varphi_i\, S(n-1)+w(n) \quad (18)$$

S (n):The complex Gaussian process.
$\varphi_{i:}$AR modelparameters.
W(n): Sequences of i.i.dcomplex Gaussian random variables withzero meanwith variance σ_w^2[16]

3.4 Observation model

The data aided estimate creates estimates of the noisy version of the Complexprocess[16].
The observation model of the estimate can be written as:

$$X(n)=S(n)+v(n) \quad (19)$$

Where S(n)= The complex Gaussian process at time n.
X(n)=The data based estimate of S(n)
V(n)=Error of the data based estimate[16,20].

Algorithm to track the process is as follows:

Step 1: The initial conditions are:

$$\hat{S}(0) = E\{S(n)\} = 0$$

$$P(1) \geq \{\sigma_w^2 \text{ and } \sigma_v^2\}$$

Step 2: The Kalman gain is given by:

$$K(n) = \frac{P(n)}{P(n)+\sigma v2\,(n)}$$

Step 4: The current estimate of the process, after receiving the data estimate is given by:

$$\hat{S}\,curr(n) = \hat{S}\,(n) + k(n)[X(n) - \hat{S}\,(n)]$$

Step5: the predict estimate of the process is given by:

$$\hat{S}\,(n+1) = \emptyset 1\{\hat{S}\,curr(n)\}$$

Step6: the current error co-variance is given by:

$$P_{curr}(n)=[1-k(n)]P(n)$$

Step7: the prediction error covariance is given by:

$$P\,(n+1)=\emptyset_1^{\,2}\{P_{curr}(n)\}+\sigma_w^2$$

4.0 THE ITERATIVE EXTENDED KALMAN FILTER IMPLEMENTATION

The simulation setup parameters are as follows:
System equation:

$$S(n)=0.9S(n-1)+w(n) \tag{20}$$

Observation equation:

$$X(n)=S(n)+v(n) \tag{21}$$

M=8: The pilot training sequence length.
The SNR of the channel for unit energy, E_B=1 is:

$$\frac{EB}{No}=\frac{EB}{2\sigma c2}=6dB$$

Thus σ_c^2=0.1256

The data estimate variance

$$s_v^2=\frac{\sigma c2}{M}=0.0157$$

The variance of the noise is

$$s_w^2 = 2\sigma_v^2=0.0314$$

Channel estimation algorithm using theKalman filter is as follows:
{Initialize:
Time:n=1

Assuming initial predicted error covariance and initial prediction as P(1)=1,$\hat{S}(1)$=0; respectively.
{Start iteration:
Perform data based estimation, i.e. get X(n)[15,16,22].

Calculate Kalman gain:

$$K(n) = \frac{P(n)}{P(n)+1}$$

Calculate current estimate:

$$\hat{S}curr(n) = \hat{S}(n) + k(n)[X(n) - \hat{S}(n)]$$

Calculate current error covariance:

$$P_{curr}(n) = [1-k(n)]P(n)$$

Predict ahead:

$$\hat{S}(n+1)=0.9\{\hat{S}curr(n)\}$$

Predict the error covariance:

$$P\,(n+1) = (0.9)^2\{[1-k\,(n)]P(n)\}+1$$

Time :(n=n+1)
End loop}

5.0 SIMULATION RESULTS

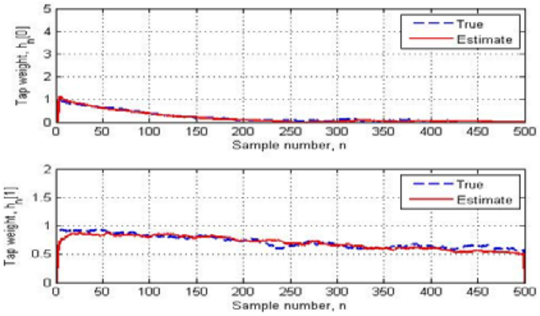

Figure 3: Shows channel estimation for time varying channelwith different tap gain.

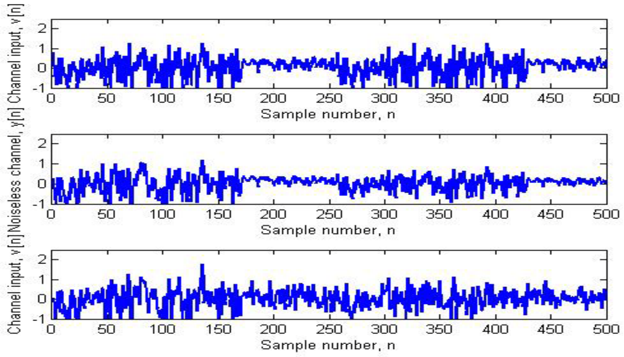

Figure 4: Input and output of the channel

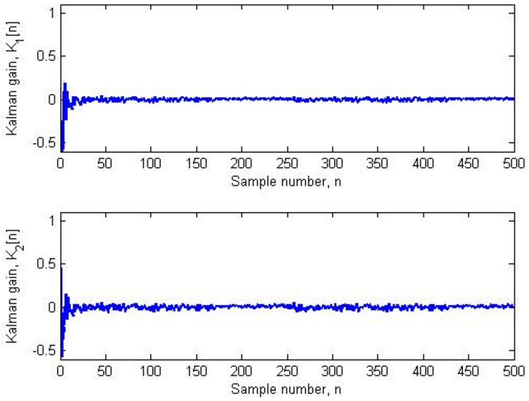

Figure 5: Kalmangain for different sample values

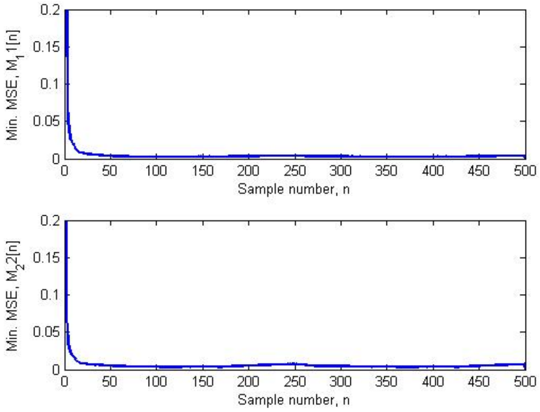

Figure 6: Variations of errors with iterations.

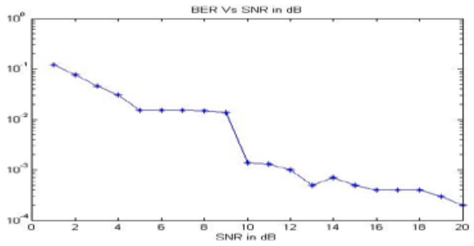

Figure 7: Bit Error Rate VsSNR(dB)

The Extended Kalman filter algorithm has been implemented for SCM-OFDMsystem with pilot sequence of 8 bits is inserted in each data block containing 200 bits with 100 iterations. Figure 4 shows the input of the channel without noise and including noise. Figure 5 shows the channel tracking capability of Extended Kalman filter for the SCM-OFDM system time varying channel. Figure 6shows Kalman gain for channel estimation using Extended Kalman filter used to estimate the SCM system with Gauss Markov channel.

Figure 7 shows MMSE variation obtained by taking actual and estimated complex tap gain using the Extended Kalman filter.

6.0 CONCLUSION

Extended Kalman filter has been implemented for the Superposition coded modulation system with OFDM systems. With the minimum length of pilot sequenceand less number of iterations,Extended Kalman filter algorithm can track the channel.

Thus it proves that EKF is a bandwidth and low complexity algorithm for SCM-OFDM system. With fewer numbers of iterations AR model demonstrates an optimum estimate of the channel impulse response. The performance of thealgorithm has been improved further by using MMSE analysis after the estimate is obtained.

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