

A Novel Channel Estimation Technique of MIMO-OFDM System based on Modified Kalman Filter

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Abstract

Objectives: Novel channel estimation technique of MIMO-OFDM system based on Modified Kalman Filter (MKF). The performance metrics are bit error rate, types of modulation method, size of the antenna, types of the Kalman filter. **Methods:** The performance methods considered are MKF, Single Kalman Filter (SKF), Double Kalman Filter (DKF). We have evaluated channel effect with respect to QPSK modulation technique and Rayleigh channel. Using MATLAB simulation tool, we have plot the bit error rate versus signal to noise ratio graph for MKF, SKF and DKF method. **Results:** The proposed channel estimation method improves the bit error rate performance compare to conventional channel estimation method. We have compared the proposed MKF method with the SKF and DKF method. Theoretical analysis and simulation results shows that the proposed channel estimation and tracking method based on MKF offer the excellent improvement in bit error rate compare to conventional channel estimation method. **Improvements:** We have achieved lowest bit error rate in the proposed MKF method compare to SKF and DKF method. As we increase the number of antenna at transmitter and receiver side we have also achieved the lowest bit error rate in the proposed MKF method.

Keywords: BER (Bit Error Rate), Channel Estimation, DKF (Double Kalman Filter), MIMO-OFDM (Multiple Input Multiple Output - Orthogonal Frequency Division Multiplexing), MKF (Modified Kalman Filter), SKF (Single Kalman Filter)

1. Introduction

For wideband digital communication OFDM is adopted. OFDM is used in various application such as wireless networking, digital TV, audio broadcasting. OFDM is also applicable in 4G service to provide the data rate of 100 Mbps for mobile users and 1 Gbps for fixed users¹. OFDM is basically a frequency division multiplexing with multi-carrier technique. The performance of OFDM system is excellent in multipath fading environment².

In current generation scenario, there is a huge requirement of high data rates in wireless communication system. This requirement is fulfill by Multiple-input Multiple-output (MIMO) techniques. MIMO system provides the high data rate by sending data in a simulcast manner from various antennas. A technique which is used in the

MIMO system is OSTBC³. It provides the antenna array spatial diversity and channel coding.

The previous study is based on flat fading and time invariant channel characteristics. But practically majority times the channel characteristic is based on the frequency selective fading and time variant behaviour. But for frequency selective fading point of view efficient equalizer is require which remove the ISI effect. To reduce this effect for that OFDM technique is applicable in MIMO system. The mixture of MIMO and OFDM technique, which is called a MIMO-OFDM system, is mostly used in current generation wireless system. This system is used to provide high data rate and diversity³.

In wireless system, channel estimation is the most important issue. In this paper we have proposes a channel estimation technique using a MKF under the frequency

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selective fading and time varying behaviour of the channel for MIMO-OFDM system. The proposed method tracks the channel in the fast fading environment that is Doppler spread is high^{4,5}. We have presented the performance of our proposed method based on the MATLAB software. The simulation results of proposed method are compared with the conventional method.

2. System Model

2.1 Block Diagram of MIMO-OFDM Transmitter

Figure 1 shows the basic block diagram of OFDM transmitter with interleaver. The data source is a kind of digital data. Digital data is fed to the QPSK modulator. The data is handled by a large number of orthogonal sub-carriers. By using serial to parallel converter the data is divided into several parallel streams^{6,7}. After that data is fed to the IFFT block in which frequency domain signal is converted in to the time domain signal. Then adding cyclic prefix into the time domain signal and then convert the parallel data stream into the serial data stream and finally using DAC the analog signal is generated which is passed to the wireless channel^{8,9}.

2.2 Block Diagram of MIMO-OFDM Receiver

Figure 2 shows the block diagram of an OFDM receiver with channel estimation. The signals which are received from the wireless channel are fed to the ADC which provides the digital signal^{10,11}. After that cyclic prefix

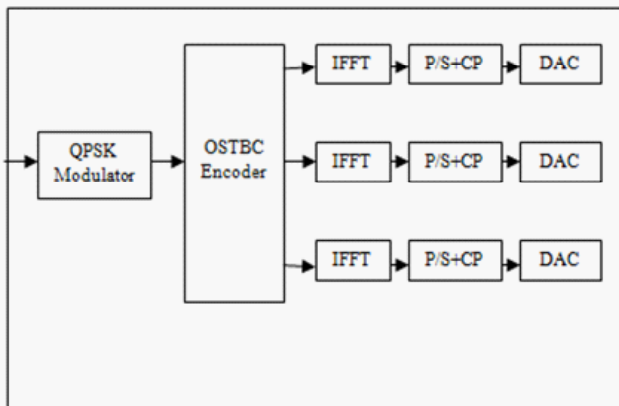


Figure 1. MIMO-OFDM transmitter block diagram.

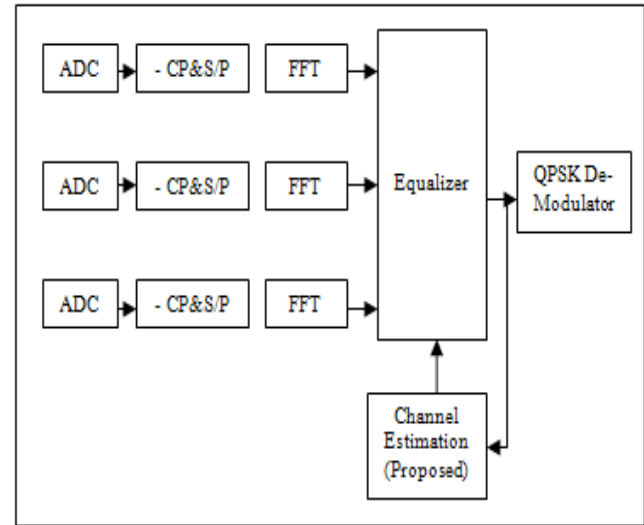


Figure 2. MIMO-OFDM receiver block diagram.

are removed and then equivalent signal is applied to the serial to parallel converter which provides parallel data stream¹². Then using FFT block time domain signal is converted into the frequency domain signal and then it is fed to the parallel to serial converter which provides serial data stream¹³. The QPSK demodulation techniques which demodulate the signal and then finally receive the original signal^{14,15}.

3. Mathematical Model

In this section, we have mentioned the mathematical model of the channel estimation based on Kalman filter method and proposed MKF method.

3.1 Channel Estimation based on Kalman Filter

It is a tool which estimates the states of the linear system. Out of all possible filters, Kalman is the one that minimizes the standard deviation of the calculated error.

Channel estimation based on Kalman filter is divided into mainly three steps.

Step 1: State Equation is given as: $\mathbf{g}_{k+1} = \mathbf{D}\mathbf{g}_k + \mathbf{E}\mathbf{v}_k$ + process noise ($\mathbf{p}_k$) where $\mathbf{D}$ transition matrix, $\mathbf{E}$ input matrix and $\mathbf{F}$ measurement matrix.

Step 2: Measurement equation is given as: $\mathbf{m}_k = \mathbf{F}\mathbf{g}_k$ + measurement noise ($\mathbf{q}_k$).

Step 3: Kalman filter equations are given as follows: (Estimator Equation) [9]

$$K_k = DP_k F^T (FP_k F^T + S_q)^{-1} \quad (01)$$

$$\tilde{g}_{k+1} = (D\tilde{g}_k + Ev_k) + K_k (m_{k+1} - F\tilde{g}_k) \quad (02)$$

$$P_{k+1} = DP_k D^T + S_p - DP_k F^T S_z^{-1} FP_k D^T \quad (03)$$

where, K_k is the Kalman gain, $\tilde{g}_{k+1}$ is the next state estimator, P_{k+1} is the estimation error covariance, D , E and F are matrices, k is the time index, u is the known input to the system, m is measured output of the system, S_p and S_q are the process noise (acceleration noise in a vehicle) covariance and measurement noise (instrumentation noise) covariance respectively.

Figure 3 shows the channel estimation method of Kalman Filter. There are two types of equations are used: one is predictor equation and second is corrector equation. The function of predictor equation is to predict the channel state. The function of corrector equation is to correct the error in the prediction state.

3.2 Channel Estimation based on Modified Kalman Filter

The Kalman filtering problem is valid for a case where state vector in a linear model of a dynamical system. But in real time the model is not always linear. In the case where the model is nonlinear that is channel is varying nonlinear in nature then the resulting filter is known as the MKF.

The MKF algorithm is given in the following way:

Step 1: The system equations are given as,

$$\text{State equation: } g_{k+1} = f(g_k, v_k) + p_k \quad (04)$$

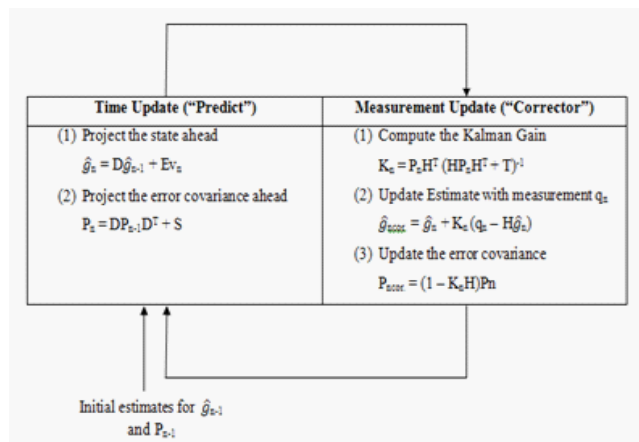


Figure 3. Channel estimation method of Kalman filter.

$$\text{Output equation: } m_k = h_k(g_k) + w_k \quad (05)$$

Step 2: At each time step, compute the following derivative matrices, evaluated at the current state estimate:

$$D_k = f'(\hat{g}_k, v_k) \quad (06)$$

$$F_k = h'_k(\hat{g}_k) \quad (07)$$

Note that the derivatives are taken with respect to x_k , and then evaluated at $g_k = \hat{g}_k$.

Step 3: Execute the following Kalman filter equation:

$$K_k = P_k F_k^T (F_k P_k F_k^T + R)^{-1} \quad (08)$$

$$\hat{g}_{k+1} = f(\hat{g}_k, v_k) + K_k [m_k - h_k(\hat{g}_k)]$$

$$P_{k+1} = D_k (I - K_k F_k) P_k D_k^T + Q \quad (09)$$

The term $h_k(\hat{g}_k)$ is the single stage predicted output $\hat{m}_k$ and $m_k - h_k(\hat{g}_k)$ is the single stage prediction error sequence, also referred to as the innovation sequence, generally denoted as i and defined as:

$$i_k = (m_k - h_k(\hat{g}_k)) \quad (10)$$

The weighted innovation, $K_k [m_k - h_k(\hat{g}_k)]$ acts as a correction to the predicted estimate $\hat{g}_k$ to form the estimation g_k , the weighting matrix K_k is commonly referred to as the filter gain or the Kalman gain matrix.

4. Simulation Results and Discussion

Here we have evaluated the channel estimation of proposed MKF for MIMO-OFDM system with QPSK modulation technique. We have calculated mean square error value of proposed MKF method and single and double Kalman filter method. In this section we have discussed the simulation results of MSE V/S SNR and BER V/S SNR of MIMO-OFDM system with MKF, SKF and DKF method. We have compared the proposed MKF method with single and double filter method.

Simulation results show that in proposed MKF method, the BER value is lowered compare to SKF and DKF method. At the 16 dB SNR value the BER value is around 10^{-5} for proposed MKF method and around 10^{-4} for SKF and 10^{-3} for DKF method. So, the lower value of

BER is achieved in the proposed MKF compare to single and double Kalman filter.

We have compared the MKF, SKF and DKF statistics. Figures 4, 5 and 6 shows the simulation results of MIMO-OFDM system with single and double Kalman filter method. As the order of the Kalman filter increase the BER is also increased. But higher order Kalman filter is applicable in nonlinear analysis of the system. SKF is applicable for linear analysis. So due to non-linearity in the system the BER value is also increased. The mobile velocity is unknown; it is varying with the time. So due to this sometimes non linearity exists. For that Double Kalman Filter is applicable. Figures 7, 8 and 9 shows the simulation results of MKF, SKF and DKF method. The simulation parameters are mentioned in Table 1.

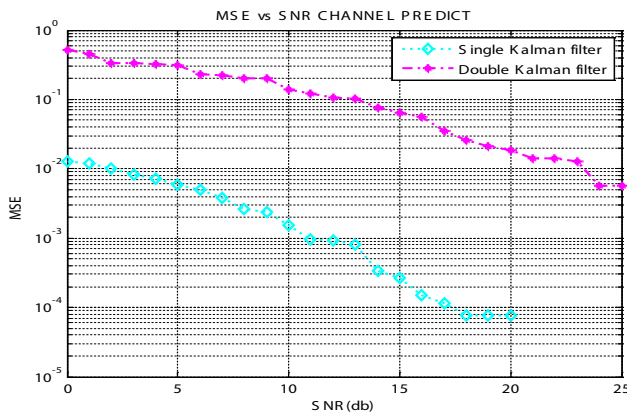


Figure 4. MSE v/s SNR for MIMO-OFDM system with Kalman Filter (Predictor).

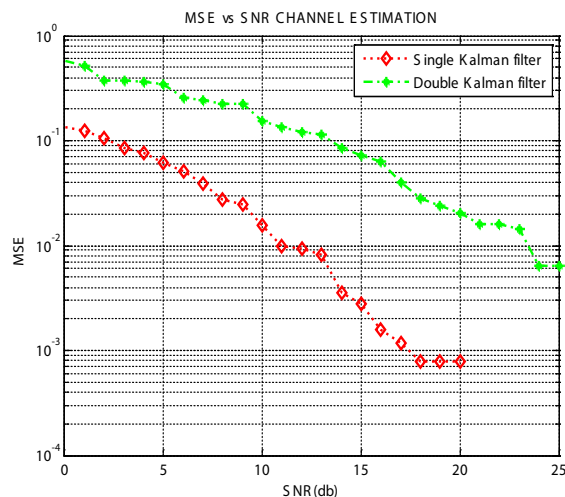


Figure 5. BER v/s SNR for MIMO-OFDM system with Kalman Filter (Estimator).

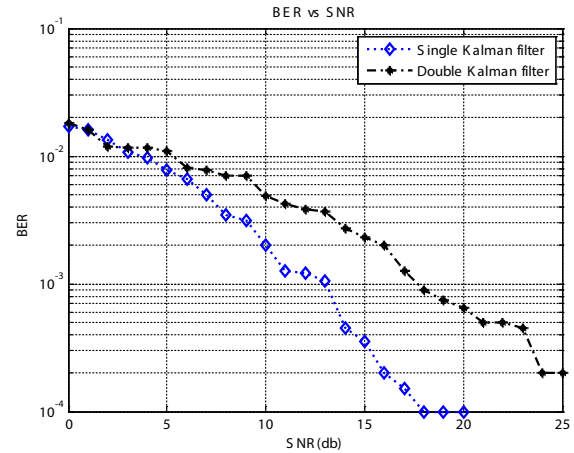


Figure 6. BER v/s SNR for MIMO-OFDM system with Kalman Filter.

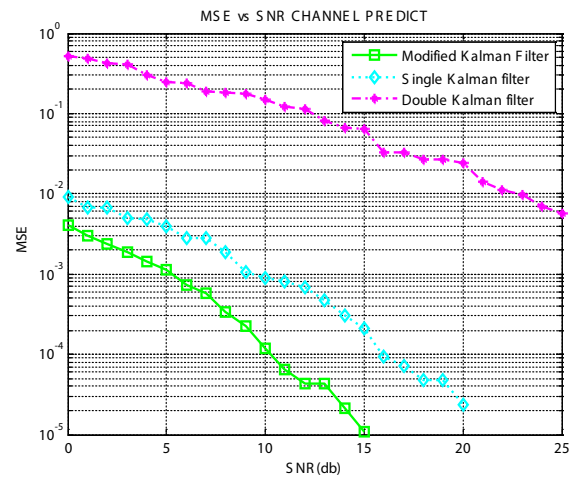


Figure 7. MSE v/s SNR for MIMO-OFDM system with Kalman Filter (Prediction).

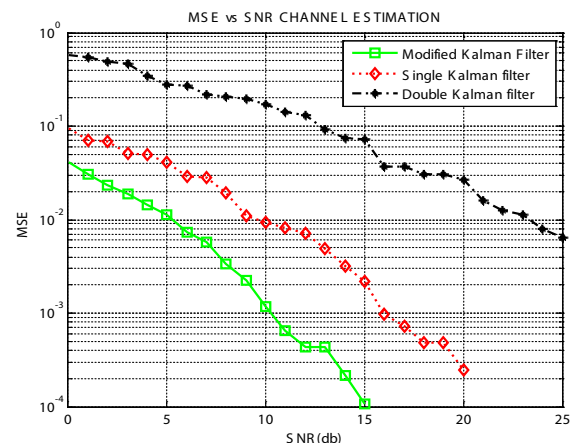


Figure 8. MSE v/s SNR for MIMO-OFDM system with Kalman Filter (Estimation).

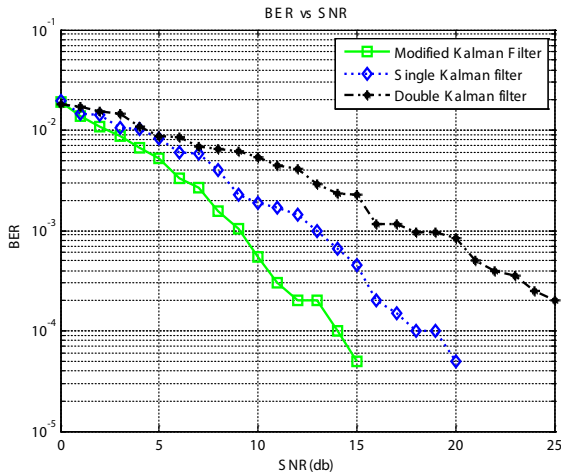


Figure 9. BER v/s SNR for MIMO-OFDM system with Kalman Filter.

Table 1. Simulation parameters

Sr No.	Name of the Parameters	Value of the parameters
1	Modulation Technique	QPSK
2	Available BW of the system	2 MHz
3	FFT Size	256 point
4	No. of subcarriers per user	64
5	No. of OFDM blocks for iteration	7000
6	No. of the antenna	2 TX, 2 RX
7	Types of Kalman filter	SKF, DKF, MKF

Figure 4 shows the MSE V/S SNR plot for MIMO-OFDM system with predicted Kalman filter. The predictor and corrector equations are given in Figure 3. Based on that equation MSE value is predicted. As the SNR value is increased, the MSE value is decreased. The lowest value of MSE is achieved in the case of SKF method.

Figure 5 shows the MSE V/S SNR plot for MIMO-OFDM system with estimated Kalman filter. The estimator equation is given in equation (01), (02) and (03). Based on that equation MSE value is calculated. As the SNR value is increased, the MSE value is decreased. The lowest value of MSE is achieved in the case of SKF method.

Figure 6 shows the BER V/S SNR plot for MIMO-OFDM system with increasing the order of the Kalman filter method. As the order of the Kalman filter increased, the BER value is also increased because as the order of the filter increased, the nonlinearity of the system is also increased and due to this nonlinearity BER value is increased.

Table 2. Simulation results of MIMO-OFDM SYSTEM with SKF, DKF and MKF based channel estimation

SNR (dB)	BER of Single Kalman filter (SKF)	BER of Double Kalman filter (DKF)	BER of Modified Kalman filter (MKF)
3.0	0.045	0.065	0.025
4.0	0.040	0.060	0.020
5.0	0.037	0.055	0.018
6.0	0.031	0.050	0.015
7.0	0.023	0.045	0.010
8.0	0.016	0.040	0.009
9.0	0.008	0.038	0.006
10.0	0.0045	0.035	0.005
11.0	0.0040	0.030	0.003
12.0	0.0035	0.025	0.001
13.0	0.0020	0.002	0.0007
14.0	0.0025	0.009	0.0004
15.0	0.0009	0.001	0.0001

Figure 7 shows the MSE V/S SNR plot for MIMO-OFDM system with predicted Kalman filter. As the SNR value is increased, the MSE value is decreased. The lowest value of MSE is achieved in the case of proposed MKF method (equation (04) to (07)).

Figure 8 shows the MSE V/S SNR plot for MIMO-OFDM system with estimated Kalman filter. As the SNR value is increased, the MSE value is decreased. The lowest value of MSE is achieved in the case of proposed MKF method (equation (08) and (09)).

Figure 9 shows the BER V/S SNR plot for MIMO-OFDM system with proposed MKF, SKF and DKF method. As the order of the Kalman filter increased, the BER value is also increased because as the order of the filter increased, the nonlinearity of the system is also increased and due to this nonlinearity BER value is increased. But in proposed MKF method BER value is decreased, as we increase the nonlinearity in the system. So, the proposed MKF method is better in terms of nonlinearity of the system.

5. Conclusion

This work was devoted to the channel estimation of MIMO-OFDM system with MKF method in which we have proposed the algorithm to minimize the probability of error or BER compare to SKF and DKF method. Simulation

results shows that lowest BER value is achieved in proposed MKF method (Figure 9) compared to SKF and DKF method. From Figure 4 to Figure 9, we have concluded that as the order of the Kalman filter is increased, the BER and MSE value is also increased. Because higher order of the Kalman filter include the non-linearity of the system and due to this non linearity the BER value is also increased. But in the proposed MKF BER is reduced as the non-linearity increased. So, the proposed MKF works better for nonlinear system compare to SKF and DKF method.

6. References

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