Evaluation of Filtering Techniques in Channel Estimation for MIMO - OFDM Systems

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Abstract. Noise in a signal is an unwanted distribution occurred which disrupts the original signal during transmission, depuration or conversion. Also noise may be random, with an unspecified mean or white noise with an independently interleaved distribution, zero mean by the processing algorithms. Performance degradation of Orthogonal Frequency Division Multiplexing system with Multiple Input and Multiple Output would have ensued due to the noise distribution in an original signal, so it is inevitable to reduce the unwanted noise distribution in an original signal to recover the original information which is sent at the transmitter. Various filtering techniques in channel estimation have been proposed in this literature to denoise a signal in Multiple Input Multiple Output – OFDM system effectively. The main intent of this survey is to provide the better insight of various denoising techniques in channel estimation to reduce unknown noise distributions in a signal with the tradeoff complexity in MIMO – OFDM systems.

Keywords: Multiple Input Multiple Output (MIMO); Orthogonal Frequency Division Multiplexing (OFDM); Least Mean Square (LMS); Recursive Least Square (RLS); Minimum Mean Square Estimator (MMSE);

1. Introduction

With the addition of more number of antennas and larger bandwidths in OFDM and due to the simplified equalization technique in MIMO systems make the OFDM-MIMO combination is useful. Due to the possibility of parallel transmission of signals in MIMO and OFDM systems in time and frequency domains leads to the increased data rate and increased spectral efficiency. Generation of the OFDM signal is generated initially and which are transmitted through a number of antennas, since achieving diversity or to improve gain while transmitting in a higher rate in the MIMO-OFDM system. It is assumed that, at the sending end the no. of antennas is expressed as sk and at the receiving end the no. of receiving antennas is expressed as xk as discussed in [1] by HauWo, et al in IEEE Transactions on Communications. Data is transmitted through the coding block from there it is coded and divided into sk different symbol blocks that are sent from different antennas. Each signal which are used have used the OFDM modulation.
The cyclic prefix length added in a signal would be larger than that of the channel multipath delay. At the receiving end each antenna receives a superposition of transmitted signal from sk transmitting antennas which is at the input side. Fast Fourier Transform (FFT) and the Inverse Fast Fourier Transform (IFFT) is performed at the transmitter and receiver side respectively for the conversion of the signal from one domain to other in the MIMO-OFDM system after encoding and before decoding. The allocation of number of users i.e., subcarriers will purely rely on bandwidth and the requirement of increased transmission rate. As cited in [2], the implementation of FFT/IFFT introduces guard bands to avoid interference between the subcarriers. Shijian Gao, et al., discussed in [3] that precoded modulation will increase the data transmission in MIMO OFDM system with the unknown noise distributions in the signal.

To denoise the signal, channel estimation must be chosen effectively for the MIMO-OFDM system, that has been depended on the application which were discussed in [4], [5]. Reliable channel estimators had been made use of channel training symbols or ‘Pilot symbols’. These pilot symbols are known transmitted data in predetermined locations in the subcarriers allocated in the channel. The performance of filtering techniques in channel estimation got benefitted from more training data. However, this training represents overhead in the communication systems. Hence, there is a trade-off between accuracy in channel estimation, computational complexity and spectral efficiency of a system.

2. Filtering Techniques

A. Kalman filter

Kalman filter in channel estimation in MIMO OFDM systems is easily implemented and also it can be computed quickly. The measurements taken from the subcarriers in the channel are used to make the certain hypothesis regarding the unknown value which is in the Non-Gaussian term. Kalman filter is used to obtain the information of the subcarrier measurements between the unknown state variables from the distribution free referred state variables. To estimate the state variables, kalman filter is efficiently used and also it could be implemented effectively for the systems which have more number of state variables. Kalman filtering, is an algorithm that utilizes continuous series of measurements taken which would be spotted over time of a signal which contains statistical noise presence and in other ambiguities, and it would give more accurate information of the signal by taking continuous measurements to produce the unknown state variables estimate rather than the measurement taken once in which joint probability distribution is performed over the unknown variables for each of the timeframe in a signal which was discussed in [6]. Mukeshpathela, et al., discussed in [7] that channel
estimation by kalman filtering leads to retrieve the original signal effectively from the unknown noise distributions.

Prediction and Estimation are the two steps involved in this algorithm. Prediction is carried out by making current state variables estimation along with their ambiguities. Then the next measurement is spotted along with the intentionally added random noise, by weighted average the current state variable estimates are updated along with more weight are provided to the estimation of the current state variables with more precision, and it is performed recursively to get best results. As Cited in [8] that the essence of Kalman filter estimation approach is to provide how ambiguity regions could be mingled to the current state variables of the kalman filter that are correctly taken into account for the Non-Gaussian terms and also the dynamic estimation of the current state variables has to be carried out. The Discrete form of the state space is contemplated here as

\[ x_k = F_{k-1} x_{k-1} + w_k \text{(State)} \] (1)

\[ y_k = H_k x_k + v_k \text{(Measurement)} \] (2)

\( k = 1, ..., n \), where \( x_k, H_k \) and \( v_k \) have the Non-Gaussian distributions term i.e., (Say xo = 0; No loss), and \( F \) represents the state transition matrix and \( H \) represents the measurement matrix, both are time-varying. Kalman filtering in channel estimation in various systems were discussed in [9]. Kalman filter would give better estimate for a system of signals which have noises along with the unknown ambiguities, modeling by a state space.

B. Wiener Filter

Wiener filtering is to compute the estimate of an unknown signal by using a fundamental signal as an input and filtering that related signal to produce the estimate for the unknown signal as an output. The Wiener filter is utilized to filter out the unwanted distributions in a signal i.e., noise to provide an estimate of the fundamental signal of interest. By the statistical approach, and a more statistical account of the theory, wiener filter can be given in the minimum mean square error (MMSE) estimator. As Cited in [10], Linear Minimum Mean Square Estimation (LMMSE) through wiener filtering has been showed that it would provide best estimation of the desired signal than other linear estimation methods. For the Rayleigh fading channel, to get précised Channel Side Information (CSI), LMMSE is implemented. Obviously, the LMMSE has many advantages. Out of which it provide 1 dB gain than other linear estimation methods in MIMO systems. The noise in the transmitted signal is greatly reduced at the receiver by the both domain estimation, and thus the BER performance is also increased than other linear estimation methods. Pilot and CP aided estimation would result in increased denoising but with increased system complexity and pilot contamination analysis were discussed in [11], [12]. Yu Zhang, et al., discussed in [13], that by tracking the angle joint delay subspace, system complexity could be reduced also could attain increased Gain performance. When the frequency characteristics of the signal and also the additive noise are known, at least some extent, wiener filter can be used very effectively.

C. Adaptive Filters

It is also coined as variable filter, since the transmitted signal which contains the unknown distribution of the desired signal is allowed to adjust until the unknown distribution is minimized to obtain the fundamental signal of interest. The Recursive Least Square (RLS) filter and Least Mean Square (LMS) filter are two adaptive filter types. When the adjustment made is successful to reduce the error, the noticed output at the filter is the exact estimation of the transmitted signal. Yongmin Liang, et al., discussed in [14] that, Mean Square Estimation performance of the Recursive Least Square filter is better in terms of SNR, but the Linear Mean Square estimation is better in terms of BER. By minimizing the ambiguities in the transmitted signal by performing the adaption recursively to obtain the exact replica of the fundamental signal of interest which were discussed in [15], [16], [17].Due to the its SNR performance RLS is used where the power is taken into account despite of its computational complexity. Exploitation of Pilot signals is carried out in RLS while estimating the fundamental signal of interest in the MIMO-OFDM systems. Results show that the RLS filter has much performance and also less computational complexity than the LMS.
D. Hampel Filtering

Hampel filter is categorized under the decision filters that alters the mid value of the arranged data as the median value if that mid value is away from the median which is considered as an outlier. As cited in [18], the mid value in the entire arranged data is considered as an outlier and that are changed if that appears more than t number of times. The estimate of the entire arranged data

\[ y_k = \begin{cases} x_k & \text{if } |x_k - m_k| \leq tS_k \\ m_k & \text{otherwise,} \end{cases} \]

Here, \( m_k \) is the median of \( w_k \) and

\[ S_k = 1.4826 \times \text{median}_{j \in [-K,K]} \{ |x_k - j - m_k| \}, \]

\( m_k \) is the standard median filter output, since the Hampel filter would reduce its value to \( S_k \) (i.e., Standard Median Filter) if \( t = 0 \). It is discussed in [19], that the quality of the signal would be improved without distorting the original signal. Many Median Filters are fall under the class of Hampel filtering by replacing the value of its respective standard median. Some of the filters which would fall under this class by doing so are Median filters and the recursive filters.

E. Wavelet Filtering

The basis function of a \( \Psi(t) \) is

\[ \Psi_{a,b}(t) = \frac{1}{\sqrt{a}} \Psi\left(\frac{t-b}{a}\right) \]

Here \( a, b \) is constant and \( a > 0 \).

The wavelet transform of the \( x(t) \) is given by

\[ \text{WTx}(a,b) = \int \frac{1}{\sqrt{a}} x(t) \Psi^*\left(\frac{t-b}{a}\right) \]

The basic steps to filtering signals using wavelets are given below.

- Decomposing the desired signal.
- Filtering the signal using thresholding.
- Reconstructing the original signal.

The fundamental signal of interest is decomposed into detailed coefficient parts and approximated coefficient parts by applying Discrete Wavelet Transform. By applying the thresholding technique to remove or approximate to zero of the detailed coefficient parts of the decomposed signal, since the detailed coefficient parts contains the insignificant values when compared with the fundamental signal of interest.
The basic steps to filter out the signals by decimation and interpolation are discussed in [20]. Three methods are given by different authors to denoise the signal through wavelet filtering. The first is method is based on only taking the maximum values. The second method is based on the correlation between the past and present values. The third method is based on thresholding.

The three methods in wavelet thresholding technique are efficient way to select the value depends on the amount of signal to be retrieved. From that we could conclude that the thresholding technique has to be chosen for the requirement. The thresholding techniques are Hard and Soft Thresholding.

Soft thresholding is nothing but by setting a threshold value the entire coefficients parts are manipulated. The values above the threshold value are approximated to zero to obtain the fundamental signal of interest in the process of denoising by wavelet filter. But through this method the value that lies above the threshold may contain some significant values but that are compromised in this case. Whereas in case of Hard thresholding the value above the threshold are kept as it is and the filtering process is carried out. But it would bring system and computational complexity with accurate information as the result of denoising the signal.

Among so many wavelet coefficients, it has been made that the coefficients which are below the threshold value are approximated to zero, the values above the threshold are kept as it is, and it is reversed depending on the information. From the information obtained as a result of wavelet filtering would produce the fundamental signal of interest effectively.

System complexity is more in case of hard thresholding technique; as well improved retrieval of original signal could be achieved in adaptive wavelet thresholding which was discussed in [21]. From this we could conclude that the thresholding technique chosen has to be depended on the system’s requirement.

### 3. Results And Discussion

![Fig.3 Perfect Reconstruction of filter bank in wavelet](image)

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| S.No | Filtering Technique             | EER | SNR (dB) |
|------|---------------------------------|-----|----------|
| 1    | Kalman                          | 10.28 | 15.5    |
| 2    | Wiener                          | 10.29 | 10      |
| 3    | LMS                             | 10.26 | 6       |
| 4    | RLS                             | 10.16 | 10      |
| 5    | Wavelet (Soft thresholding)     | 10.29 | 11      |
| 6    | Wavelet (Hard thresholding)     | 10.3  | 10      |

Table 1 Performance comparison of various filters

The table shows the evaluated results of the various filtering techniques which have been performed on the 2.4 GHz frequency band signal. And the performance comparison among those have been tabulated for the 16 QAM modulated signal transmitted in an AWGN channel. Out of which the kalman filtering has outperformed among all these filtering techniques. Soft thresholding is performed as a
thresholding technique in the wavelet filtering, by approximating the value beyond the threshold value as zero. If the Hard thresholding is performed as a thresholding technique in the wavelet filtering, by keeping the value beyond the threshold value as same then the performance of the system in terms of BER and SNR would be better than the soft thresholding technique. Hampel filtering is required number of time series measurements to identify the outliers. Trade off among system complexity, BER, SNR have to be analyzed the selection of the filtering technique to denoise a signal.

4. Conclusion

MIMO OFDM system is one of the most required for high data rate applications. And this system also provides high spectral efficiency. But it has a limitation of unknown noise distribution in the fundamental signal of interest during transmission. Lots of channel estimation filtering techniques is discussed in this review paper. All of the above mentioned filtering techniques to estimate the fundamental signal of interest methods have the capability to denoise the signal effectively but at the tradeoff among system complexity, SNR, BER, and computational complexity. Thus, depending upon the system requirement the filtering techniques in channel estimation have to be selected to meet the demands.

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