Channel Estimation of MIMO-OFDM using TVLMS Filter

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Abstract- In wireless communication systems, Multiple-Input Multiple-Output (MIMO) has a major impact because of its high performance. Recent research has shown that MIMO systems can significantly increase the data rates without increasing much transmit power or bandwidth. Further, Orthogonal Frequency Division Multiplexing (OFDM) is designed to combat the effect of multipath reception. That is the reason why with OFDM, MIMO makes a promising communication systems due to its high transmission rates, improved information carrying capacity and robustness against multi-path fading. Performance of wireless systems improves greatly when the receiver has the knowledge of the influence of channel on the received signal. Channel estimation is the estimation of the transmitted signal using the corresponding received signal bits by various different techniques. In MIMO-OFDM system, the change in channel parameter is significant. Hence to overcome this problem, an appropriate channel estimation method would be the one which follow these changes in channel parameter to give increased performance. In this paper an adaptive algorithm based on TVLMS filter is presented for channel estimation in MIMO-OFDM system. Evaluation of system performance is carried out by plotting bit error rate (BER) vs. signal to noise ratio (SNR) under different channels. Based on simulation results, it is concluded that the proposed system enhances the channel estimation performance by providing much less BER even at lower SNR.

Keywords - MIMO-OFDM, Channel Estimation, TVLMS filter

I. INTRODUCTION

There has been an intense research on modulation techniques that provide high data rates over wireless channels which can support ever increasing number of users, multimedia, wireless Internet services, and future generations of mobile communication systems. In communication system, there are various modulation schemes such as Frequency Division Multiple Access(FDMA), Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). The disadvantages of these methods led to evolution of OFDM. In the case of single carrier transmission, higher bandwidth is required to support the faster data rates. Further, if the bandwidth of the signal becomes larger than the coherence bandwidth, the channel suffers from inter-symbol interference due to multipath fading. Multipath fading adaptive equalizers are used. But the complexity of the adaptive equalizer increases as the data rate increases. This means for higher data rates highly complex equalizers are required. So we can conclude that for high data rate transmission with single-carrier may not be possible due to too much complexity of the equalizer at the receiver. Due to failure of single carrier transmission at higher data rates, multiple carrier transmission was developed to work at higher data rates [1].

With the combination of OFDM-MIMO, we can have a wireless system which have higher channel capacity and which can support higher data rates .Channel estimation is an important part of the receiver designs in MIMO-OFDM systems. In MIMO-OFDM systems it is necessary to have a reliable knowledge of channel impulse response between the transmitter and the receiver for a coherent signal detection at the receiver end [3]. In wireless communication system the transmitted signal passes through channel, which get distorted due to channel characteristics and noises. In order to recover the transmitted bits, the channel effect must be estimated and compensated in the receiver. The orthogonality allows each subcarrier component of the received signal to be expressed as the product of the transmitted signal and channel frequency response at the subcarrier. Thus, the transmitted signal can be recovered by estimating the channel response. Channel estimation can be avoided by using the differential modulation techniques. But this results in lower data rates. There is an approximate loss of about 3-4

dB of SNR. Hence, systems with a channel estimation block are needed for the current and future need of higher data rate [5].

II. MIMO SYSTEM

Multiple input multiple output (MIMO) systems have multiple transmit antennas and multiple receive antennas which increases the channel capacity significantly. The wireless communication link is ever varying. As discussed earlier, use of adaptive equalizer is a potential solution to this problem. Another solution would be the use of diversity. Diversity also help in combating multipath fading. When the signal power drops significantly, the channel is said to be in a fade. This results in high BER (Bit Error Rate). Many diversity techniques were evolved such as temporal diversity which include assigning different timeslots along with time interleaving strategies and channel coding, another one is frequency diversity. Spatial diversity include the use of multiple antennas at receiver end or at transmitting end or at both the ends. Such system deploying antenna diversity at both the ends of communication link is known MIMO systems [4][6].

Let us consider a MIMO system with m transmit antennas and n receive antenna as shown in fig. 1. MIMO system can mathematically characterized as:

$$\vec{y} = H.\vec{x} + \vec{n} \tag{1}$$

where, vector y and vector x are received and transmitted vectors respectively. H is the impulse response of the channel and n is noise vector.

The direct connection from antenna 1 to 1 is specified as h11, etc., while the connection from antenna 1 to 2 is specified as h21, etc. From this we can obtain transmission matrix or channel matrix H with the dimensions n x m.

$$\begin{pmatrix} h11 & h12 & h.. & h1m \\ h21 & h22 & h.. & h2m \\ h.. & h.. & h.. & h.m \\ hn1 & hn2 & hn. & hnm \end{pmatrix}$$
(2)

Compared to SISO i.e. single antenna system, the channel capacity of a multiple antenna system with Nt transmit and Nr receive antennas can be increased by the factor of min(Nt, Nr), without using additional transmit power or spectral bandwidth [1]. Data to be transmitted is divided into independent data streams. The number of streams M is always less than or equal to the number of antennas (when number of transmit antenna are equal to number of receive antennas i.e. Nt=Nr). Now for the case of asymmetrical (Nt not= Nr) antenna constellations it is always smaller or equal the minimum number of antennas. Theoretically, the capacity C increases linearly with the number of streams M. In other words, the capacity of an orthogonal MIMO channel is therefore M times the scalar channel capacity [2].

$C = MBlog_2(1 + SNR)$ (3)

Let us consider the space diversity technique. Basically the effectiveness of any diversity scheme lies in the fact that at the receiver we must provide independent samples of the basic transmitted signal. We make use of spatial diversity because of the fact that signal will not suffer the same level of attenuation as it propagates along different paths. Replicas of the same transmitted signal are provided across different antennas of the receiver. This is applicable in cases where the antenna spacing is larger than the coherent distance to ensure independent fades across different antennas.



Figure 1. MIMO system

III. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

OFDM is a multi carrier transmission technique. Orthogonality ensures that the modulation symbol can be recovered from the transmit signal without ISI. Furthermore, successive orthogonal symbols can be separated by guard band to reduce the effect of ISI. This makes OFDM system more robust. OFDM divides the available spectrum into a number of overlapping but orthogonal narrowband subchannels, and hence converts a frequency selective channel into a non-frequency selective channel. Discrete fourier transform (DFT) and Inverse fourier transform (IDFT) are used to implement such orthogonal signals. All the subcarriers are of the finite duration T and the spectrum of the OFDM signal can be considered as the sum of the frequency-shifted sinc functions in the frequency domain. If the number of sub channels are large enough, then each subchannel can be considered as flat fading channel [1][7].

The bandwidth of each channel is given by:

$$Fsc = 1/Ts = f_{somp}/N \tag{4}$$

where f_{samp} is the sample rate and Ts is sample time.

Fig. 2 represent the bock diagram of OFDM system. The binary information data are grouped and mapped into multi-amplitude-multi-phase signals according to modulation. There are various modulation techniques available such as BPSK, QPSK, 8-QAM, 16-QAM etc. any of these techniques can be used. Consider the total number of subcarriers be N. Due to modulation, the symbol rate get reduced to R=log2M, where M is constellation size. After modulation serial binary data is converted into parallel by using serial to parallel converter. Each parallel stream corresponds to small bandwidth in whole spectrum.



The modulated data is converted into time domain signal x(n)

$$\mathbf{x}(\mathbf{n}) = \mathrm{IDFTX}(\mathbf{k}) = \sum_{k=0}^{N-1} \mathbf{X}(\mathbf{k}) e^{-f \mathbf{i} \pi k \mathbf{n} / N}$$
(5)

where n = 0...N - 1. Cyclic prefix or guard band can be added here. Then again the signal is converted back in serial form and transmitted over multipath fading wireless channel. The signal received at the receiver is of form:

$$y(n) = x(n)^* h(n) + w(n)$$
 (6)

where h(n) is the impulse response of channel and w(n) is the additive white Gaussian noise. The signal is converted into frequency domain by applying DFT on received signal to demultiplex the multicarrier signal.

$$Y(k) = DFT \ y(n) = \frac{1}{N} \sum_{n=0}^{N-1} y(n) e^{-f 2\pi k n / N}$$
(7)

where, k = 0....N - 1.

IV. CHANNEL ESTIMATION

The transmitted signal travel through channel and get modified due to channel characteristics. To receive the symbol correctly, the receiver must be able to estimate the channel. The performance of an OFDM system can be significantly influenced by the accuracy of the channel estimation. Transmitted signal can be reproduced at the receiver with the help of channel impulse response and the received signal [9].

Use of the adaptive filters to calculate the channel response is one of the major methods used. Channel can be estimated using other methods too like pilot aided channel estimation or blind or semiblind channel estimation techniques. Following is the brief description of channel estimation techniques.

Training based channel estimation is done by inserting pilot carriers in OFDM data block. Based on the position of insertion, this type of channel estimation is divided in two categories: 1) Block type pilot carriers and 2) Comb type pilot carriers. Block type pilot signal is assigned to a particular OFDM block only and Symbols are transmitted periodically. The estimation of channel response is usually obtained by LS or MMSE estimate of training pilots. In comb type arrangement Interpolation is required because it is sensitive to frequency selectivity [3][9].

By inserting pilot carriers spectrum is wasted. That is why to avoid this wastage, a technique was introduced which estimate the channel without pilot carriers. This technique is known as blind channel estimation technique. Blind channel estimation depends on the statistical information of the received symbol. The performance is not comparable to that of pilot-based channel estimation. In semi blind estimation technique, there's a trade off between accuracy and usage of spectrum. Semi-blind channel estimation uses training symbols together with neighboring unknown data symbols for channel estimation. Compared to purely training based schemes, the number of training symbols can be saved a lot. And compared to blind channel estimation technique, performance is improved [4][8].

V. MOBILE RADIO CHANNELS

The statistical model of wireless channels is very important to achieve the reliable communication. The transmitted signal is seriously affected by the multipath propagation due to which the wave is scattered, diffracted and reflected. The signals that reaches receive antenna is time delayed with different value. Due to this a interference pattern is created that depends the frequency and the time. In other words, the mobile radio channel is characterized by time variance and frequency selectivity. This process can be characterized using Gaussian Wide sense stationary uncorelated scattering (GWSSUS) process. Gaussian processes are completely characterized by their properties up to second order which include the mean and the autocorrelation. For a GWSSUS process with zero mean, every sample H(f,t) for fixed frequency and time is a complex Gaussian random variable given by:

From the property,

$$H(f,t) = X + jY \tag{8}$$

$$E\{H(f1+f,t1+t)H(f1,t1)\} = 0$$
(9)

We conclude that, X and Y are uncorrelated, independent and have the same variance. The probability density function of X and Y is given as:

$$p_{\chi}(x) = \frac{1}{\sqrt{2}} e^{-x^2}$$
 (10)

$$p_{\rm Y}(y) = \frac{1}{\sqrt{\pi}} e^{-y^2} \tag{11}$$

Converting the above equation in polar co-ordinate and calculating the joint probability function in terms of amplitude and phase.

$$\mathbf{F}_{\mathbf{\hat{A}},\mathbf{\varphi}}(\mathbf{a},\mathbf{\varphi}) = \frac{1}{2\pi} 2\mathbf{a} \mathbf{e}^{-\mathbf{a}^{\mathbf{\varphi}}}$$
(12)

PDF in phase is given by:

$$P_{\phi}(\phi) = \frac{1}{2\pi} \tag{13}$$

Now, we will have the PDF in term of amplitude alone.

$$P_A(a) = 2ae^{-a^2} \tag{14}$$

The probability density function of amplitude is known as Rayleigh distribution. And this zero mean GWSSUS is known as Rayleigh fading channel. For Rayleigh channel the power is exponentially distributed. Rayleigh distribution provides the a good approximation to fading that are observed in practical cases. For a channel with line of sight (LOS) component, GWSSUS channel defined above has constant mean value. Therefore, the PDF of amplitude for Gaussian function with non zero mean is given by:

$$P_A(a) = 2a(1+K)e^{-(K+\alpha^2(1+K))} I_0(2a\sqrt{K(1+K)})$$
(15)

Where I_0 is the modified Bessel function. This pdf is called the Rice distribution. And this GWSSUS channel is called a Rician channel. The factor K is known as Rice factor. Rician fading corresponds to the dominant Line of Sight (LOS) component and a large set of i.i.d (independent and identically distributed) reflected waves. The Rician model is known to show a smaller number of deep fades. That means if the LOS component is stronger then the chances of occurrence of deep fade becomes less. If we make K=0 in PDF function of rice distribution, it becomes Rayleigh channel. K=0 signify the absence of LOS component. If $K \rightarrow \infty$ then it becomes AWGN channel, and it signifies the absence of scattering [12].

VI. PROPOSED METHOD

Fig. 3 shows the system flow used for MATLAB implementation. The main aim of channel estimation algorithm is to minimize the error. Various type of adaptive filters are used to estimate the channel like NLMS, New Variable Step Size LMS, Robust Variable Step Size (RVSS) LMS etc. In our system, we are applying Time Varying LMS (TV-LMS) Algorithm for calculation of weights. TVLMS filter is found to be effective for noise cancellation. The end purpose of deploying any adaptive filter in the system is to get impulse repose of the system as near as possible. The adaptive filter calculates its weights w so as to produce the an output as close as possible to the original output, in our case it is the transmitted signal. When MSE is minimized, the adaptive filter coefficients, w, are approximately equal to the impulse response of the system i.e. H. TVLMS filter is found to be effective for noise cancellation [10][11].



Figure 3. SYSTEM FLOWCHART

Following are the steps used for channel estimation:

1) For the first iteration we will assign the convergence factor μ to be 0.99, for next iteration updated μ will be taken.

Initialize
$$\mu$$
: $\mu(0)=0.99$

2) Calculation of error signal :

$$e(n) = D(n) - R(n)$$
 (16)

where D(n) is desired signal and R(n) is received signal.

3) Calculation of $\alpha(n)$ i.e. decaying factor for TVLMS filter :

$$\alpha(n) = C^{\frac{1}{1+\alpha N^2}}$$
(17)

where C, a, b are positive constants that will determine the magnitude and rate of decrease for α . Here we have taken value as : C=10, a=1, b=1.

Moreover, C has to be greater than 1 because if it is 1 then α will be 1, and it will act like conventional LMS algorithm.

4) Calculation of weights :

Weights(n) = weights(n-1) +
$$\mu(n)^*e(n)^*R(n)$$
 (18)

5)Calculation of $\mu(n)$ for second iteration and so on:

$$\mu(n) = \alpha(n)^* \mu(0) \tag{19}$$

6) After calculating the weights, these weights are applied to the demodulated received data i.e. After applying estimation the data becomes:

Following are the OFDM parameters taken:

TABLE I. OFDM PARAMETERS	
Modulation	QPSK
IFFT size	32
Window type	No Windowing

VII. SIMULATION RESULTS

We have implemented 2*2 MIMO system i.e. with two transmit antennas and two receive antenna. 2*2 MIMO system is compared with SISO i.e. single input single output system under same parameters using MATLAB. SNR vs BER is plotted for two different channels i.e. 1) Rayleigh 2) Rician.

Following are the graphs for SISO and MIMO system:







FIGURE 9 . MIMO-Rician

VIII. CONCLUSION

In this work performance of TVLMS filter is evaluated under different channel condition. First conclusion that we can get by observing the graphs are the Bit Error Rate can be improved greatly by implementing the MIMO system. As the order of MIMO system increases the performance is also improved. In terms of channel if we see, then BER is more for Rician channel and least for Rayleigh. Our aim is to demonstrate the behavior of TVLMS filter under different channel condition. Among the Adaptive LMS filters range, TVLMS filter gives the better BER performance than others.

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