A Study of Spectrum Sensing based Channel Estimation for MIMO–OFDM over Noisy Channel

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Abstract: As the world move in to the future, there is a rising demand for high performance, high capacity and high bit rate wireless communication systems to integrate wide variety of communication services such as high-speed data, video and multimedia traffic as well as voice signals. Orthogonal Frequency Division Multiplexing (OFDM) has made tremendous improvement possible in wireless technology. OFDM is a multicarrier system that provides an efficient means to handle high-speed data streams over a multipath fading environment. Orthogonal frequency division multiplexing (OFDM) is a powerful technology to increase the data rate transmission over mobile wireless channels. Spectrum sensing finds spectrum hole for transmission which enables wireless radio systems coexist with the authorized wireless systems without harmful interference. The resource of radio frequency spectrum is not efficiently managed, and the increased dependence on wireless devices in the modern era just adds to the problem by helping to achieve improved spectral management, utilization, and efficiency. One of the ways to improve the efficiency and utilization of an available frequency spectrum is to share it between the users. One of the most important steps for spectrum sharing is spectrum sensing. There are many spectrum sensing algorithms available for wireless network. This paper reviews about spectrum sensing and channel estimation techniques. In this paper, a review is performed for spectrum sensing based channel estimation algorithm. In the presence of a primary user (PU), the algorithm estimates the channel and the noise variance. If the PU is not active, the algorithm returns a very accurate estimation of the noise level. By comparing the noise variance to the second moment of the received signal estimation (useful signal with noise or only noise), it is then possible to determine if the PU is present or absent. So, it is advantageous to performs a PU detection, the noise variance, and the channel estimation if the PU is active and it returns the noise level in the frequency band when the PU is absent.

Keywords: MIMO-OFDM, Spectrum Sensing, Channel Estimation, AWGN

I Introduction

A typical digital communication system showing, in Figure 1, how a communications signal is transmitted from an information source, through a transmitter, through a channel, into a receiver, and to a final destination [1]. Due to ever-increasing demand of bandwidth in the future wireless services, the radio frequency band is more and more in demand. The major requirements of the communication systems are:

- To have a better coverage.
- To have better quality.
- To be more bandwidth efficient.
- To deploy in diverse environment.

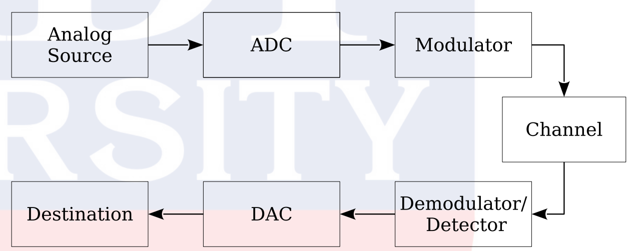

Figure 1: A Typical Digital Communication System

Multi-carrier Modulation schemes divide the input data into bands upon which modulation is performed and multiplexed into the channel at different carrier frequencies so that information is transmitted on each of the sub carriers, such that the sub channels are nearly distortion less [2].

In Todays communication environment, a demand for high data rate, reliable high speed. These requirement place indicative challenges to the parallel data transmission scheme which removes the problems faced with serial systems. High spectral efficiency and resilience to interference caused by multi-path effects are the fundamentals to meet the requirements of today's wireless communication. The Orthogonal Frequency Division Multiplexing (OFDM) is a wide-band multi-carrier wireless digital communication technique that is based on block modulation [3]. With the wireless multimedia applications becoming more and more popular, the required bit rate/high speed are achieved due to OFDM multi-carrier transmissions. The distribution of the data bits over many carriers means that fading will cause some bits to be received in error while others are received correctly.

By using an error-correcting code, which adds extra bits at the transmitter, it is possible to correct many or all of the bits that were incorrectly received. The information carried by one of the vitiated carriers is corrected, because other information, which is related to it by the error correcting code, is transmitted in a different part of the multiplex [4]. OFDM is one of the powerful Multi-Carrier Modulation (MCM) techniques having high speed transmission capability with bandwidth efficiency and robust performance in multipath fading environments. Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation technique which divides the available spectrum into a number of parallel subcarriers and each subcarrier is then modulated by a low rate data stream at different carrier frequency [5].

The capability of OFDM system is improved using MIMO technique, which spatially multiplexes data streams via multiple antennas [6]. MIMO–OFDM, the combination of both OFDM and MIMO technologies, is currently under study and is one of the most propitious candidates for future communication systems, ranging from wireless LAN to broadband access [7]. TheMIMO communication systems use multiple transmit and receive antennas, increase the data rate without increasing the bandwidth, increase the diversity, and improve the performance against fading channels using space-time codes [8]. It has been found that the capability of MIMO– OFDM systems grow linearly with the number of antennas, when optimal knowledge of the wireless channel is available at the receiver.

The channel condition is not known in practical application. Thus, the channel estimation, i.e., channel identification plays a major role in MIMO–OFDM system [9]. Channel estimation is one of the most salient processes in communication system [10]. A perfect channel estimation algorithm should comprise both the time and frequency domain characteristics of the OFDM systems [11].

The channel estimation in MIMO-OFDM is very applicable because at the receiver side there is a multiple users interference can be occurred so in order to eliminate these interferences channel estimation is required [9]. The channel estimation can be done by the proper knowledge of channel at the receiver side [10]. Mostly the channel can be estimated by providing the pilot symbols along with the transmitting signal which is known by the receiver [12]. There is various methods to transmit the pilot symbols along the transmitting data. The pilot symbols are of two types; block type pilot symbols and comb type pilot symbols [13]. In block type pilot the symbols are send periodically along each OFDM symbol and it can be used for slow fading. The pilots are inserted into all of the subcarriers of one OFDM symbol with a certain period of time. In comb type pilot the symbols are inserted over all sub channels in each OFDM symbols. In this method channel estimation can be based on least square and minimum mean square error [14].

II MIMO OFDM

MIMO-OFDM system plays an important role in the fourth generation of communication system so that it can increase the data rate and the system capacity and removing the multiple paths fading. The block diagram of MIMO-OFDM consist of T_x transmit antenna, R_x received antenna and N is the number of subcarriers.

2.1 OFDM

OFDM is a wideband wireless digital communication technique that is based on block modulation. With the wireless multimedia applications becoming more and more popular, the required bit rates are achieved due to OFDM multicarrier transmissions. Multicarrier modulation is commonly employed to combat channel distortion and improve the spectral efficiency. Multicarrier Modulation schemes divide the input data into bands upon which modulation is performed and multiplexed into the channel at different carrier frequencies so that information is transmitted on each of the sub carriers, such that the sub channels are nearly distortion less [4]. A typical OFDM system is presented in Figure 2.

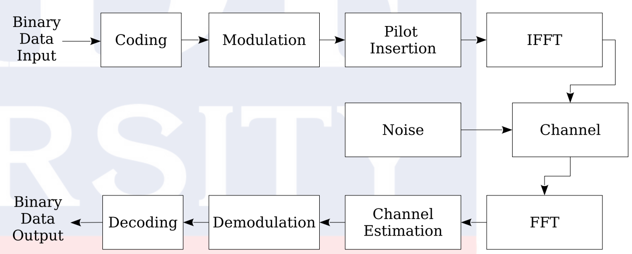

Figure 2: OFDM System

At the OFDM transmitter end, the $N-$point IFFT is taken for transmitted symbols. Taking the $N-$point FFT of the received samples, the noisy version of the transmitted symbols can be obtained in the receiver. N point FFT is used to convert the signal from time to frequency domain [5]. The input data is first mapped into a modulation scheme. The complex plane data is transformed to parallel format and IFFT transform is obtained to produce OFDM signal. The output data is converted to serial format and cyclic prefix is added. Reverse operations are carried out at the receiver end. Cyclic prefix is removed and $N-$point FFT is taken to retrieve the transmitted data.

Following equation can be used for computing FFT and IFFT:
FFT

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-j2\pi nk/N} \tag{1}$$

where $(k = 0, 1 \ldots, N-1)$
IFFT

$$X(n) = \frac{1}{N} \sum_{n=0}^{N-1} x(k) e^{j2\pi nk/N} \tag{2}$$

where $(n = 0, 1 \ldots, N-1)$

2.2 MIMO

Wireless channel that is selective fading caused Multipath Fading channels will cause a decrease in the performance of the communication system, to resolve the issue of diversity techniques used. MIMO diversity is one technique that uses multiple antennas at the transmitter and receiver [14]. The illustration of MIMO antennas is represented in Figure 3.

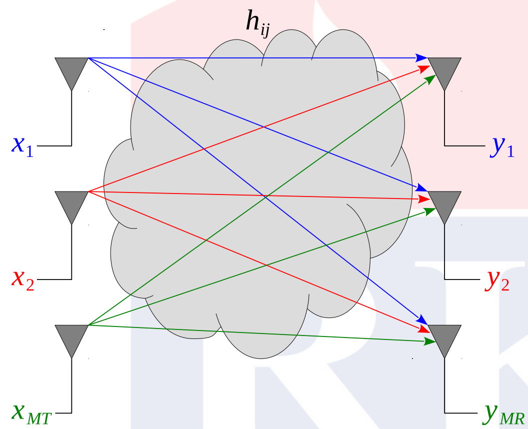

Figure 3: Illustration of MIMO Antennas

III Wireless Transmission Channels

Signals in a digital communication system must get from transmitter to receiver via a transmission channel. A channel is therefore some kind of a physical medium that connects the transmitter and receiver. For analytical purposes, it is sometimes convenient to model the transmission channel as noiseless which means that the signal received is only the signal that was sent, nothing more and nothing less. However, communication channels introduce noise, fading, interference, and other distortions into the signals that they transmit. Simulating a communication system involves modeling a channel based on mathematical descriptions of the channel. Different transmission media have different properties and are therefore modeled differently [6].

3.1 Additive White Gaussian Noise (AWGN) Channel

The noise analysis of communication systems is often based on an idealized noise process called additive white Gaussian noise (AWGN). In this type of channel, the noise distorting our signal is a wide sense stationary random process that is independent of frequency. In fact, AWGN is defined in terms of its power spectral density which is given as

$$S_W(f) = \frac{N_0}{2} \tag{3}$$

where N_0 is a constant and the factor $1/2$ has been included to indicated that half the power is associated with positive frequencies and half with negative frequencies. The word Gaussian in the phrase additive white Gaussian noise is due to a Gaussian distribution of the amplitude of the noise (i.e., it has a normal "bell curve" distribution). AWGN leads to simple, tractable mathematical models useful for gaining insight into the underlying behavior of a system [7].

3.2 Fading Channels

When dealing with satellite and other communications systems where there is line of sight between the transmitter and receiver, the free-space propagation model gives simple theoretical explanations for propagation loss. However, with ground communications many obstructions can interfere with the transmission of a signal. Objects like mountains, buildings, densely wooded areas and rough terrain cause the signal to be reflected (i.e., bouncing off) and diffracted (i.e., bending around) these various surfaces in order to arrive at its destination. These obstacles cause signals to scatter and these delayed versions to arrive at slightly different times. This phenomenon is known as multipath propagation and causes a phenomenon in real-world communications known as fading [8].

3.3 Ricean Multipath Channel

A Ricean fading model is used to describe a channel where there is a dominant Line of Sight (LOS) wave component between the transmitter and the receiver, as well as existence of multiple waves that experience random multipath fluctuations that cause fading. Therefore, the Ricean fading model is a combination of the Rayleigh fading and LOS component [6]. The ratio between the deterministic signal power and the power of the non-dominant wave is defined as the Ricean factor, k.

IV Spectrum Sensing Techniques

Spectrum Sensing is a key aspect of wireless network. The objective of wireless network is to utilize the empty channels in the spectrum to reduce the traffic in congested areas. Proper sensing of the spectrum is the integral part of this software defined radio. Also, communication should not be obstructed or hindered by fading. Spectrum sensing in wireless network is applicable to radio frequencies only. Observing the unused spectrum of a licensed user is crucial for the concept of wireless network to be a success. So, the primary user is sensed perpetually to allow channel mobility of SU to another part of the spectrum; in case the primary user initiates to transmit.

This requires an efficient hardware with minimum possible error. The threshold for detection forms the crux. This should be in consideration of the interference in the worst-case scenario. Future spectrum analysis and decision-making processes are dependent on sensing the primary user correctly. This is defined as managing the spectrum dynamically [15]. There are various spectrum sensing techniques which are employed for spectrum sensing; such as:

4.1 Matched-Filter Detection

The matched-filter (also known as coherent detector), can be considered as a best sensing technique if CR has prior knowledge of the PU. It is very accurate because it maximizes the received signal-to-noise ratio (SNR). Matched-filter correlates the received signal with its time shifted version. Comparison between the final output of the matched-filter and a pre-determined threshold will determine the presence of primary user. Hence, if this information is not accurate, then the matched-filter will operate weakly [16].

4.2 Cyclostationary Feature Detection

Implementation of a Cyclostationary feature detector is a spectrum sensing technique which can differentiate the modulated signal from the additive noise. A signal is said to be Cyclostationary if its mean and autocorrelation are a periodic function. Cyclostationary feature detection can distinguish PU signal from noise, and used at very low Signal to Noise Ratio (SNR) by using the information present in the PU signal that are not present in the noise [17].

4.3 Energy Detection

Energy detection is the most popular way of spectrum sensing because of its low computational and implementation complexities. The receivers do not need any previous knowledge about the primary users. An energy detector (ED) simply treats the primary signal as noise and decides on the presence or absence of the primary signal based on the energy of the observed signal [18].

V Channel Estimation

Channel Estimation is the method of characterizing the effect of the physical medium on the input sequence. It is an essential function for wireless systems. Even with a limited knowledge of the wireless channel properties, a receiver can achieve insight into the data sent over by the transmitter. The main goal of Channel Estimation is to measure the property of the channel on known or partially known set of transmissions [19].

5.1 Least Square (LS) Channel Estimation

The Least Squares Error (LSE) estimation technique can be used to estimate the system by minimizing the squared error between estimation and detection. The least square (LS) channel estimation method finds the channel estimate $\hat{H}$ in such a way that the following cost function is minimized:

$$J(\hat{H}) = \|Y - X\hat{a}\|^2 \tag{4}$$

Where, $\hat{H}$ is channel estimate.
X = Sent Data
Y = Received Data
$J(\hat{H})$ = Cost function for channel estimation

5.2 Minimum Mean Square Error (MMSE) Channel Estimation

Channel Estimation is required to determine the characteristics of a channel based on the sequence data transmitted by the transmitter. In general, channel estimation method with minimum mean square error (MMSE) is designed as :

$$J(\hat{H}) = E\left\{\|e\|^2\right\} \tag{5}$$

$$= E\left\{\|H - \hat{H}^2\|\right\} \tag{6}$$

Where, $J(\hat{H})$ = Cost function for channel estimation
e = error
$\hat{H}$ is channel estimate
The aim of the MMSE estimation is to get a better estimation, in this case is the selection of proper load (W). Thus, the above equation must be minimized.

5.3 Linear Minimum Mean Square Error (LMMSE) Channel Estimation

Linear minimum mean square error (LMMSE) is by definition the optimal channel estimator in the sense of mean square error criterion, but its practical application is limited by its high complexity. Furthermore, the LMMSE estimation method requires the knowledge of both the channel and the noise statistics, which are a priori unknown at the receiver. The LMMSE estimation is performed along the frequency axis with a pilot preamble (X_n) and is derived from the minimization of the cost function as:

$$J(\text{LMMSE}) = E\left\{\|H_n - DY_n\|^2\right\} \tag{7}$$

where D is a matrix whose coefficients have to be optimized. The estimated channel frequency response vector is J(LMMSE)

VI Neural Network based Channel Estimation

A Neuro-Estimator is designed for channel estimation and compensation. Neuro-Estimator architecture have three layer include input layer, hidden layer and output layer. In input layer received noisy data is processed. In hidden layer, we computed the output of hidden layer, that can represented as:

$$net_j^h = \sum I_i W_{ij},\ j = 1, 2, \ldots, n \tag{8}$$

where I_i is input data of i^{th} units, W_{ij} is input-to-hidden layer weights. Then hidden layer output is obtained by activation function. In output layer, the final neural network output is computed as:

$$net_o^k = \sum O_j^h W_{ij} \tag{9}$$

where W_{ij} is hidden-to-output layer weights. However, Output layer output expressed as:

$$O_k^o = f(net_k^o) \tag{10}$$

where is output layer output of kth units. In training process, the back propagation learning algorithm is based on bayesian regularization. Bayesian regularization minimizes a linear combination of squared errors and weights. It also modifies the linear combination so that at the end of training the resulting network has good generalization qualities.

VII Performance Evaluation Measures

7.1 Mean Square Error (MSE)

It measures the average of the squares of the errors, that is, the average squared difference between the estimated values and what is estimated.

7.2 Peak-To-Average Power Ratio (PAPR)

PAPR is the ratio of the maximum power to the average power of a complex signal. OFDM signal consists of large number of independent sub-carriers which may result in large PAPR when added coherently. A large PAPR is detrimental because it increases the complexity of the system and reduces the efficiency of RF power amplifier. The effect of PAPR is a serious problem in the transmitter.

7.3 Bit Error Rate (BER)

A bit error rate is defined as the rate at which errors occur in a transmission system. This can be directly translated into the number of errors that occur in a string of a stated number of bits [20].

7.4 Signal-to-noise ratio (SNR)

SNR is defined as the power ratio between a signal and the background noise (unwanted signal):

$$\text{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}} \tag{11}$$

Where, P is average power.
Both signal and noise power must be measured at the same or equivalent points in a system, and within the same system bandwidth.

VIII Conclusion

A large number of pilots are utilized to acquire channel information in traditional channel estimation for Orthogonal Frequency Division Multiplexing (OFDM) system, which leads to lower spectrum efficiency. For exploiting the sparse channel characteristics of multipath channels, the spectrum Sensing is employed. In this paper, a review is performed for spectrum sensing based channel estimation algorithm under MIMO-OFDM scenario. As it is known that in the presence of a primary user (PU), the algorithm estimates the channel and the noise variance. If the PU is not active, the algorithm returns a very accurate estimation of the noise level. By comparing the noise variance to the second moment of the received signal estimation (useful signal with noise or only noise), it is then possible to determine if the PU is present or absent.

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