Channel Estimation in MIMO-OFDM Spatial Multiplexing Using Least Square Method

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Abstract*—In this paper, channel estimation for Spatial Multiplexing (SM) is investigated for MIMO-OFDM system. Due to the channel characteristic of the transmission system is always changed by the time and its importance in wireless transmission to reconstruct the transmitted signals, the channel needs to be known as well as possible. Pilot symbols are used to gather knowledge about the channel and try to estimate it. The channel estimation based on the pilot symbol is called pilot aided channel estimation. In this research, Least Square (LS) method was chosen for initial channel estimation. By using applicable proposed system design, channel state information is estimated through the use of channel information before in subcarriers with no pilot symbols. Zero forcing (ZF) algorithm is used to detect and separate the received signal. The result shows that channel estimation would be better by increasing SNR. Normalized Mean Square Errror (NMSE) value of the channel reached 5x10^{-5} for SNR 25 dB. The value of BER reached 3x10^{-4} for SNR 25 dB. The estimated channel capacity has the values that closed to the known channel capacity.

Keywords-MIMO; OFDM; pilot symbol; channel estimation; least square; zero forcing.

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) techniques have the important merit of high spectral efficiency because the adjacent OFDM sub-carriers can partially share the same spectrum while still remaining orthogonal to one another [1]. Orthogonal Frequency Division Multiplexing (OFDM) is a technique that has been widely adopted by modern wireless communication standards such as Wireless Local Area Network (WLAN), WIMAX, Digital Audio/Video broadcasting (DAB/DVB), Integrated Services Digital Broadcasting Terrestrial (ISDB-T) and Digital Terrestrial/Television Multimedia Broadcasting (DTMB) [2].

The use of multiple antennas, both at the transmitter and receiver, has gained a lot of interest over the past decade. Various techniques have been proposed to take advantage of the diversity offered by this Multi Input Multi Output (MIMO) setup. The MIMO system that increase the benefits of diversity compared to traditional wireless system, called Space Time Block Code (STBC) [3]. In addition, the MIMO system can also increase the benefits of channel capacity and multiplexing gain in wireless system, called Spatial Multiplexing (SM) [4].

Channel estimation can be used to find out the influence of channel characteristics on the received data quality. Two approaches for channel estimation have been proposed in the literature. Blind channel estimation which relies on the exploitation of the statistical information of the received symbols, has the bandwidth-saving advantage. However, the blind technique is limited to slow time varying channels and has higher complexity at the receiver. On the other hand, pilot aided channel estimation uses pilot sequences sent as a preamble of each data frame and known at the receiver is simple to implement and can be applied to different types of channels although the use of pilots affects the data rate. In this paper we propose a pilot aided channel estimation method for MIMO-OFDM Mobile WiMax systems [5]. Channel estimation in [6] is used to analysis MIMO-OFDM for STBC technique with the block and comb pilot type. The result of this research stated that comb type methods are results poor performance than block type pilot based methods for the reason that of fast fading channels. Channel state information is required in MIMO-OFDM for space–time coding at the transmitter and signal detection at receiver. Its accuracy directly affects the overall performance of MIMO-OFDM systems [7].

This paper implements channel estimation in MIMO-OFDM system for Spatial Multiplexing technique with the aid of pilot symbols to estimate the channel. Least Square (LS) is used to get the initial estimation, whereas to define all of channel characteristics, we use the channel condition in the past in all subcarriers with no pilot symbols. The performance is measured by implementing channel estimation in applicable proposed system design and pilot type as shown in following sections.

II. SPATIAL MULTIPLEXING FOR MIMO-OFDM

A. MIMO-OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is a special technique of multi-carrier modulation which is transmitted through several subcarriers with low symbol rate [1]. Bandwidth efficiency is obtained by overlapping subcarrier and utilizing the orthogonality properties between subcarriers.

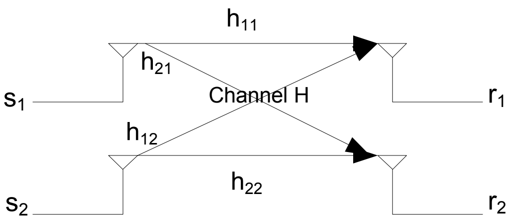

Figure 1. A 2x2 MIMO Channel [8]

Orthogonality between subcarriers will not cause interference problems. This is due to the frequency of each subcarrier is harmonic.

There are two types of MIMO, Space Time Block Coding (STBC) and Spatial Multiplexing (SM). The principle of STBC is sending multiple replicas of the signal information on the independent channel fading in orthogonal signal format, so that at least one received signal which did not destroyed by the worst fading. In SM, the total symbols to be transmitted are split into several parallel of symbols and then transmitted simultaneously with the same bandwidth at each antenna. This technique increases capacity, proportional to the number of antennas.

By using MIMO Spatial Multiplexing, the transmitted signal (S), received signal (R), noise signal (N) and MIMO channel (H) can be expressed as [4]

$$\mathrm{R} = \mathrm{H}.\mathrm{S} + \mathrm{N} \tag{1}$$

Based on Fig.1, input-output relationship of a 2x2 MIMO system can be written as [2]

$$\begin{bmatrix} \mathrm{r}_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \tag{2}$$

Each channel is a multipath fading channel which has a distribution that independent and identically distributed (i.i.d), namely the Rayleigh distribution.

B. Channel Characteristics and Channel Modeling

Channel characteristic that will be referenced in this research is the multipath channel based on ITU-R standard as shown in table I. Channel characteristic is generated in the frequency domain. It's because the simulation is not use the IFFT nor FFT that change the signal from frequency domain to time domain and vice-versa.

Signal that pass through the channel would be distorted due to the channel characteristic. In this study, Rayleigh fading modeling was chosen because of the tendency of wireless communication channel currently does not have a dominant line of sight (LOS) path. In this research, the channel is modeled by Rayleigh fading with exponential power delay profile (PDP) that performed as [8]

$$\mathrm{P}(\tau) = \frac{1}{\sigma_t} e^{-\tau T_s / \sigma_t} \ , \quad \tau = 0,1,...,\tau_n \tag{4}$$

where τ is time delay, Ts is sampling period and σ_t is root mean square (RMS) delay.

TABLE I. PDP : ITU-R STANDARD [6][7]

	Path	#0	#1	#2	#3	#4	#5
P	$\lvert\alpha k\rvert^2$ (dB)	0	-9.7	-19	-23	-	-
A	τk (μs)	0	0.1	0.19	0.41	-	-
P	$\lvert\alpha k\rvert^2$ (dB)	0	-0.9	-4.9	-8	-7.8	-24
B	τk (μs)	0	0.2	0.8	1.2	2.3	3.7
V	$\lvert\alpha k\rvert^2$ (dB)	0	-1	-9	-10	-15	-20
A	τk (μs)	0	0.3	0.71	1.09	1.7	2.51

Channel can be modeled in frequency domain

$$\mathrm{H(f)} = \sum_{\mathrm{k=0}}^{\mathrm{k=L}} \alpha_{\mathrm{k}} e^{-j2\pi\tau_k} \tag{3}$$

where α_k is amplitude attenuation in each tap delay and τ_k is multipath delay time.

Channel impulse response based on Rayleigh fading can be simulated by adding two random variables which is normally distributed with the PDP as a variance. The index of last path delay, that is $\tau_n = \tau_{max}$/Ts [4][8]. Refers to the ITU-R Standard from Table I, the distributions of the maximum delay spread (τ_{max}) is 3.7 μs with RMS delay (σ_t) is equal to 0.74 μs, assuming $\tau_{max} = 5\sigma_t$ [4].The problems of synchronization and ISI can be solved perfectly by the addition of cyclic prefix (CP) which is equal to or greater than the maximum delay spread [9].

C. Least Square and Zero Forcing Method

Pilot aided channel estimation is the simplest technique of channel estimation, by implementing Least Square (LS) method, which is the division between received symbols with transmitted symbols. This method is applied to the four elements of channel matrix H, and can be expressed as

$$\mathrm{H_{LS} = H_p = Y_p / X_p} \tag{5}$$

where Yp is received pilot symbols, Xp is transmitted pilot symbol which known at the receiver, and Hp is pilot channel estimation using LS method.

Channel detection algorithm is important because the signals that arrive at the receiver antenna are the sum of various signals from different transmitter antennas.

In this research, the zero forcing algorithm (ZF) is used, where multiplier matrix W is an inverse or pseudo inverse (PI) matrix of the channel matrix H, namely:

$$\begin{aligned} &\mathrm{W = H^{-1}} && \text{for M=N} \\ &\mathrm{W = (H^H H)^{-1} H^H} && \text{for M}\neq\text{N} \end{aligned} \tag{6}$$

with ^{H} is complex conjugate transpose matrix H.

We use Least Square channel estimation technique and Zero Forcing symbol detection method in this study due to more emphasis on analysis of channel characteristic that influence on the capacity of the system with known channel that compared to the systems with estimated channel.

III. CHANNEL ESTIMATION SCHEME

A. System Design of MIMO-OFDM Spatial Multiplexing

This research has proposed the channel estimation system design for a 2x2 MIMO-OFDM Spatial Multiplexing in the frequency domain with 128 subcarriers, so that the model does not need the IFFT/ FFT. Channel esrtimation system design, in detail, is shown in Fig. 2.

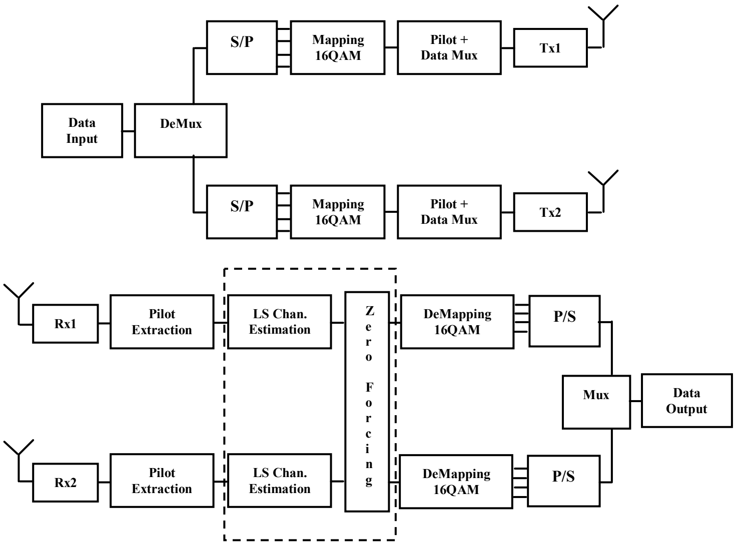

Figure 2. Channel Estimation Scheme in MIMO-OFDM Using Least Square Method

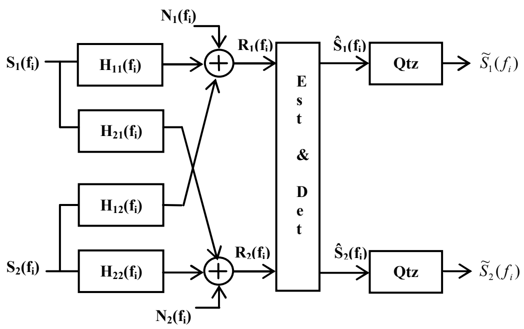

Figure 3. Design of a 2x2 MIMO-OFDM models in frequency domain

Propagation channel matrix contained in each signal path generated by the channel coefficient for Rayleigh model and assuming that the cyclic prefix is always sufficient in every OFDM symbol transmission, to avoid interference.

In the data transmission, each output data symbol in all transmitters is multiplied by the channel matrix H. For the proposed 2x2 MIMO-OFDM in frequency domain shown in Fig 3, channel matrix H consists of 4 elements such as H_{11}, H_{12}, H_{21}, and H_{22}. This process is performed simultaneously for all data in each OFDM symbol transmission with AWGN noise addition.

B. Pilot Aided Channel Estimation

One of the channel estimation methods is by using pilot symbols as reference signal. The pilot symbol does not carry information, but it is known by both of the transmitter and receiver. Characteristic of estimated channel that approach to the true value provides a good reference to make equalization at the receiver.

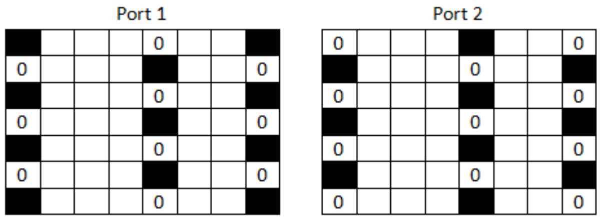

Figure 4. Design of pilot pattern in a 2x2 MIMO-OFDM

In MIMO-OFDM systems, channel estimation processed in each channel that connects each transmitter (M) and receiver (N). In the other words, the channel estimation is performed on each element in the matrix channel, according to the dimensions of the channel matrix in a MIMO system (M x N channel matrix). The channel estimation process will be as many as the number of channels that built in the MIMO system.

The addition of pilot symbol with the specific pilot pattern used for channel estimation often called the pilot-based channel estimation).

The pilot pattern in MIMO-OFDM system is slightly different. This system requires insertion symbol 'zero' that is located alternately with the pilot symbol and apply across the transmitter. It means that when the Tx1 transmits the pilot symbol (reference signal) then Tx2 does not send anything or in the other words Tx2 transmit symbol 'zero' and vice versa. By using the implementation of the pilot pattern, then the next pilot symbol can be detected separately by using the previous pilot symbols. Channel estimation process is based on the result of a merger between the before-period and after-period of pilot symbols. Design of pilot pattern is shown in Fig 4.

By using the implementation of pilot pattern according to the Fig 4, pilot symbols can be detected separately until unknown symbols values can be obtained [10].

IV. SIMULATION RESULT AND ANALYSIS

A. Channel Estimation in MIMO-OFDM

The original channel is multiplied by the data symbols from both of the transmitter including a pilot symbols. Estimated channel which is obtained by using Least Square method is called as the initial estimated channel. It said the initial estimated, because only a few channel characteristic are known at the receiver, based on pilot symbols subcarrier. Furthermore, based on the initial estimated channel, we can obtain the overall channel estimation through the use of channel information before, in all subcarriers with no pilot symbols.

The result of comparison between original channel and estimated channel for MIMO-OFDM system in the frequency domain at SNR 3 dB and SNR 25 dB are shown in Fig 5 and Fig 6.

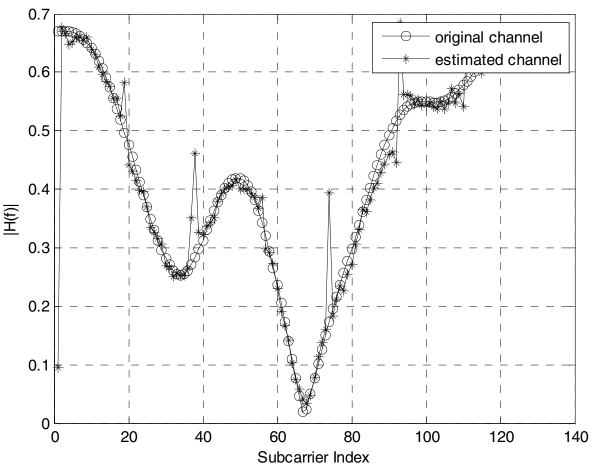

Figure 5. Comparison result of channel H(f) at SNR 3 dB

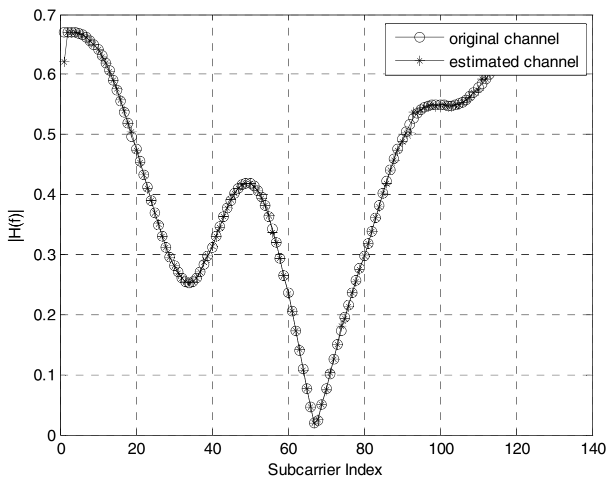

Figure 6. Comparison result of channel H(f) at SNR 25 dB

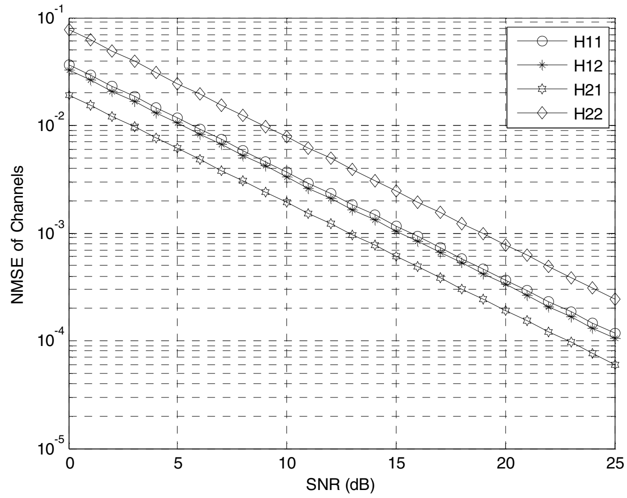

Figure 7. Normalized MSE of MIMO Channel

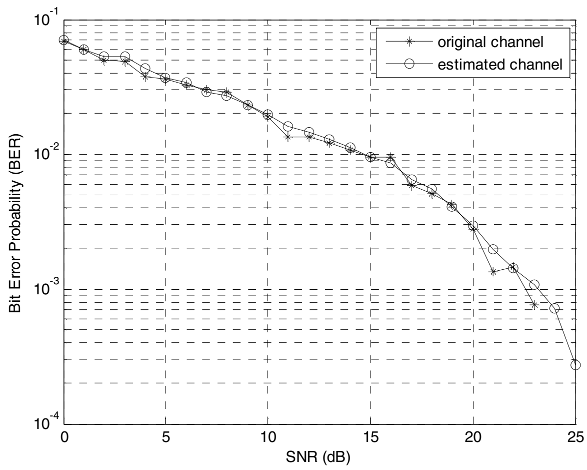

Figure 8. Bit Error Rate (BER) of MIMO-OFDM

It showed that in a small SNR, the comparison between original channel and estimated channel contained many inaccuracies. While at large SNR values, it obtained accurate channel estimation or in the other words the estimated channel is very close to the original channel.

Basically, the channel estimation result is not exactly the same as original channel, so we need parameters to express the number of error in channel estimation, namely Normalized Mean Square Error (NMSE) of the channel. The result of NMSE of the four channels is shown in Fig 7.

The result of NMSE of channel showed that the greater SNR, the smaller error will be. It means that the estimated channel get closer to the original channel.

The value NMSE of channel reached $5x10^{-5}$. Accuracy of the estimation result is quite good if the NMSE value get close to zero.

B. Channel Estimation Performance

Channel estimation performance is also measured based on the value of Bit Error Rate (BER). The greater the SNR is given then the smaller the BER values obtained. Fig 8 shows that at SNR 25 dB can be achieved the BER value up to $3x10^{-4}$.

This research also compares the BER performance in the system that use original channel and system that use estimated channel. The results showed that BER on system using the original channel are better than that using the estimated channel. This is because the using of channel in the past.

System performance can also be analyzed based on channel capacity. Fig 9 showed the simulation result of channel capacity for estimation MIMO systems compared with MIMO and SISO systems based on Shannon's theory.

The simulation result shows that the channel capacity in systems with channel estimation is relatively smaller than MIMO system based on theory, but it's bigger enough than SISO system. It reached 14 bps/ Hz at SNR 25 dB.

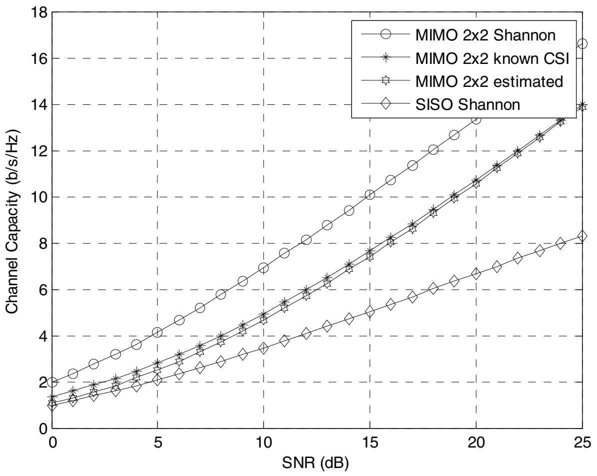

Figure 9. Channel capacity

V. CONCLUSION AND RECOMMENDATION

The result of channel estimation is affected by the SNR value. The larger the SNR the higher accuracy of the estimation will be. Accuracy of the estimation process is known from the value of NMSE of the channel. The value NMSE of channel reached $5x10^{-5}$. It can be concluded that the channel estimation are good enough. It relates to the selection of channel estimation and detection techniques.

The estimation results also affect the value of BER that would be decrease by increasing the value of SNR. At SNR 25 dB can be achieved the BER value up to $3x10^{-4}$. The results showed that BER on system using the original channel are better than that using the estimated channel. The BER values through the original channel have lower value than the estimated channel. It can be concluded that systems with the original channel has performance better than systems with estimated channel.

Performance based on channel capacity shows that the increasing SNR value cause greater value of channel capacity as well. Channel capacity for the estimated system is smaller than MIMO Shannon systems and MIMO channel known CSI, but larger than the SISO Shannon.

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