CHANNEL ESTIMATION DESIGN OF MIMO-OFDM SYSTEMS USING MMSE FOR IEEE 802.11N WLAN STANDARD

Rima Raissawinda
Undergraduate Student of Diploma 4 Telecommunication Engineering
I Gede Puja Astawa
Lecturer of Graduate Diploma 4 Telecommunication Engineering
Yoedy Moegiharto
Ahmad Zainudin
Imam Dui Agusalim
Member of PENS Wireless Communication Research Group Department of Electronic Engineering Politeknik Elektronika Negeri Surabaya, Indonesia

Abstract

IEEE 802.11n is the latest development of IEEE 802.11 WLAN communication standard that provides higher significant throughput than IEEE 802.11a/g. With various of transmission channels in wireless communication, has decreased performance of the receiver antennas caused by noise interference and fading channel. Hence, there is a need to analyze channel estimation method to estimate and discover the real condition of channel information between transmitter and receiver for IEEE 802.11n WLAN communication standard. This research simulated the channel estimator using *minimum mean squared error* (MMSE) algorithm in MIMO-OFDM systems with 2x2 and 2x4 schemes. Rectangular shaping filter assumption in time domain is used for the channel approximation due to the multipath Rayleigh fading channel distribution. System performance value is shown in channel impulse response of Tx transmitter to Rx receiver. The simulation results indicate that channel estimator has been working on purpose in MIMO-OFDM system with antenna scheme of 2x2 and 2x4 as well.

Keyword: MIMO-OFDM, channel estimation, MMSE.

Background

In development of communication systems, the needs to access high data rate is incredibly increased. To support user requests and create a reliable system performance, wireless communication system is supported by a modulation technique called *orthogonal frequency division multiplexing* (OFDM) combined with *multiple-input multiple-output* (MIMO) as an important technology of IEEE 802.11n WLAN communication development. With the various transmission channels increasement of wireless communication, receiver performance becomes obviously severe due to high noise and fading in the channel communication. Therefore, we need a method to predict channel estimation and obtain information about the channel conditions between the sender and the receiver.

Channel estimation in OFDM system using comb-type pilot with MMSE algorithm (Meng-Han *et al*. 1998) resulted in the channel impulse response comparison between the use of Rician and Rayleigh channel. The use of comb-type pilot for channel estimation is to generate better channel impulse response than using block-type pilot. However, to estimate the real condition of wireless communication channel, this research applied MMSE channel estimator only in OFDM system which signal reception quality is quite low, so that the resulting channel estimation was not so good. Hence, the MMSE channel estimator should be combined with channel interpolation algorithm.

A thorough discussion (Sinem Coleri *et al.* 2002) of Block-type and Comb-type pilot for channel estimation had been conducted. Channel estimation using block-type pilot preparation is done with and without decision feedback equalizer. While the comb-type pilot is performed with insertion pilot method and channel insertion in the data frequency. Comparison of changes in each parameter indicate that the comb-type pilot with combination of MMSE and a low-pass interpolation showed the best results among all the used parameters. For a low value of doppler, performance degradation can be minimized even though channel estimation result using comb-type pilot combined with low-pass interpolation gives better effect to doppler frequency upgrading.

An effective channel correlation technique had finally solved bad synchronization occurance of MMSE channel estimation in OFDM wireless communication systems (Chandranath R. N. Athaudage *et al*. 2004). It is an incorporation of time performance adjustment of the OFDM block with MMSE channel interpolation matrix that does not require additional computing when compared to deterministic block-by-block estimation for time error adjustment. The computing result showed that the technique can minimize the decline of MMSE channel estimator performance caused by block error timing.

Estimation paper which had discussed in MIMO-OFDM systems (Eric Pierre Simon *et al*. 2011) use the pilot symbols insertion in time domain channel. It used *L-path* method to estimate *complex amplitude* (CA) path and by calculate carrier frequency offset, while the data recovery is processed using QR equalizer. Comparison with the conventional method shows a better fading for 0.1 doppler value.

In this paper, channel estimation using MMSE technique in MIMO-OFDM systems with 2x2, 2x4 antennas is studied in accordance of the IEEE 802.11n WLAN standard. The MIMO-OFDM systems generate more profits, which can eliminate *intersymbols interference* (ISI) dan *intercarrier interference* (ICI) caused by multipath channel and also strengthening the OFDM signal reception due to the use of more than one antennas in both the sending and receiving side.

The presentation structure of this paper comes as follow: in Section 2 is System Model, describes the system model of MIMO-OFDM and channel estimation using MMSE technique. Section 3 describes the design of channel estimation, and Section 4 explains the simulation results and discussion. And section 5 is the conclusion.

System Model

IEEE 802.11n WLAN System

IEEE 802.11n WLAN communication is the latest development of IEEE 802.11(a/g) which is constantly increasing and improving throughput. WLAN IEEE 802.11n (Thomas Paul *et al*. 2008) has been applied in a system with many transmitter and receiver antennas and also combined with multiple carrier modulation technique known as MIMO-OFDM system. WLAN IEEE 802.11n is capable to support the needs of user through a good quality video streaming for multiple users (ex: video conference in a WLAN network) and still produce a high throughput (*gigabyte*) as well as to fix the *quality of service* (QoS) network better than other WLAN standards. The IEEE 802.11n WLAN standard based on MIMO-OFDM system is also able to provide higher data rate throughput than the original data rate which can reach from 54 Mb/s to 600 Mb/s.

MIMO-OFDM System

MIMO-OFDM system in this research using 2x2 and 2x4 antenna schemes as shown in Fig. 1:

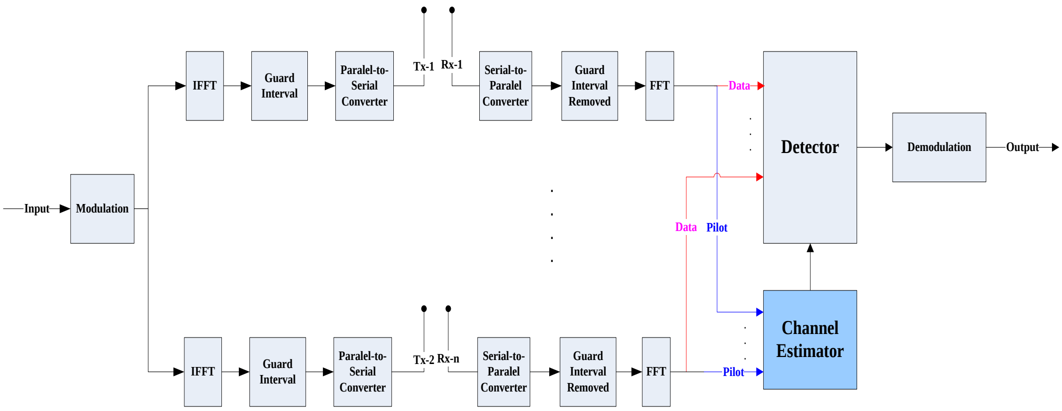

Figure 1 . Channel estimation system design in MIMO-OFDM.

On the transmitter side, a row of symbols in frequency domain is inserted in parallel way and being modulated with 16-QAM mapping. Then, in IFFT block, added *zero padding* symbols correspond to the use of IFFT size and the rows are also inserted by the pilot symbols, one symbol for each subcarrier, so that the IFFT block produces symbols equals to the IFFT size in time domain. Next step is adding cyclic prefix (CP) as the guard interval as much as 25% of the IFFT size with the aim to eliminate the ISI and ICI. Rows of symbols then serialized and transmitted through a multipath channel. Rows of symbols transmitted over a Rayleigh channel and Gaussian distributed and received by the receiver. At the receiver, the symbol stream in time domain is then paralellized. After conversion, the symbols pass the CP removal block to enter the FFT block. The FFT block results are the symbols and their pilots. While the symbols enter the detector block, the pilots are processed by channel estimator. Output from channel estimator is received by the detector to be processed together with the FFT symbols. Furthermore, demodulation block with 16-QAM demapping demodulate the results from detector and it finally produce the same symbols as the input in transmitter side.

MMSE Channel Estimation

At the receiver, the signal obviously has been distorted by the channel. So, to recover the received signal there has to be a channel estimation and compensation by the receiver. Generally, the data signals and the training signals can be used for channel estimation. Several aspects that need to be considered for channel estimation such as the expected performance, calculation complexity, changes of time on the channel, and so on. In general, channel estimation method with *minimum mean square error* (MMSE) is designed as in Fig. 2:

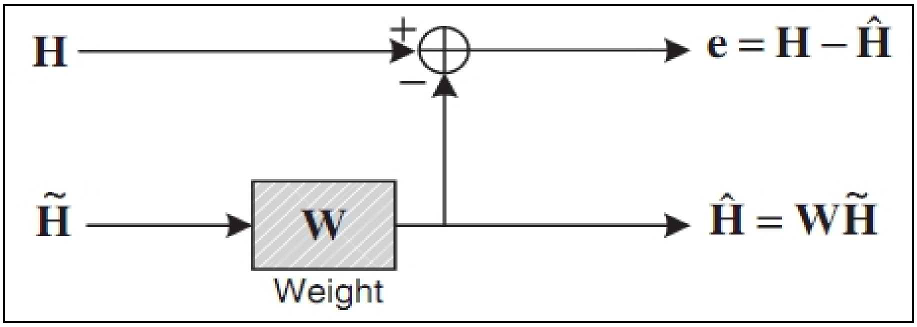

Figure 2. MMSE channel estimation.

According to Fig. 2, the mean square error (MSE) in the estimated value of channel H is given in the following equation:

$$J(\widehat{H}) = E\{\|e\|^2\} = E\left\{\left\|H - \widehat{H}\right\|^2\right\} \quad (1)$$

The purpose of MMSE estimation is to get better estimation value, in this case is the selection of the proper weight (W). So, Eq. 1 needs to be minimized. By utilizing the orthogonality properties of the error vector estimation $e = H - \widehat{H}$ to be orthogonal to $\widehat{H}$, it can be written in Eq. (2):

$$\begin{aligned} \{e\widehat{H}^H\} &= E\left\{(H - \widehat{H})\widehat{H}^H\right\} \\ &= E\left\{(H - W\widehat{H})\widehat{H}^H\right\} \\ &= E\{H\widehat{H}^H\} - WE\{\widehat{H}\widehat{H}^H\} \\ &= R_{H\widehat{H}} - WR_{\widehat{H}\widehat{H}} \\ &= 0 \end{aligned} \quad (2)$$

In this case, $\widehat{H}$ is *least square* (LS) channel estimation which is given as Eq. 3:

$$\widehat{H} = X^{-1}Y = H + X^{-1}Z \quad (3)$$

Then, the W obtained as in Eq. 4:

$$W = R_{H\widehat{H}} R_{\widehat{H}\widehat{H}}^{\ \ -1} \quad (4)$$

Where $R_{\widehat{H}\widehat{H}}$ is the auto-correlation matrix of $\widehat{H}$, and given as follow:

$$\begin{aligned} E\{e\widehat{H}^H\} &= E\{\widehat{H}\widehat{H}^H\} \\ &= E\{X^{-1}Y(X^{-1}Y)^H\} \\ &= E\{(H + X^{-1}Z)(H + X^{-1}Y)^H\} \\ &= E\{HH^H + X^{-1}ZH^H + HZ^H(X^{-1})^H + X^{-1}ZZ^H(X^{-1})^H\} \\ &= E\{HH^H\} + E\{X^{-1}ZZ^H(X^{-1})^H\} \\ &= E\{HH^H\} + \frac{\sigma_z^{\ 2}}{\sigma_x^{\ 2}} I \end{aligned} \quad (5)$$

While, $R_{H\widehat{H}}$ is the cross-correlation matrix between real channel vector with the temporary channel vector in frequency domain. Furthermore, MMSE channel estimation can be given as in Eq. 6 below:

$$\widehat{H} = W\widehat{H} = R_{H\widehat{H}} R_{\widehat{H}\widehat{H}}^{\ \ -1}\widehat{H} = R_{H\widehat{H}}\left(R_{HH} + \frac{\sigma_z^{\ 2}}{\sigma_x^{\ 2}} I\right)^{-1}\widehat{H} \quad (6)$$

Design of Channel Estimation in MIMO-OFDM System for IEEE 802.11n WLAN Standard

Diagram block of channel estimator in MIMO-OFDM system for IEEE 802.11n WLAN standard as shown in Fig. 3:

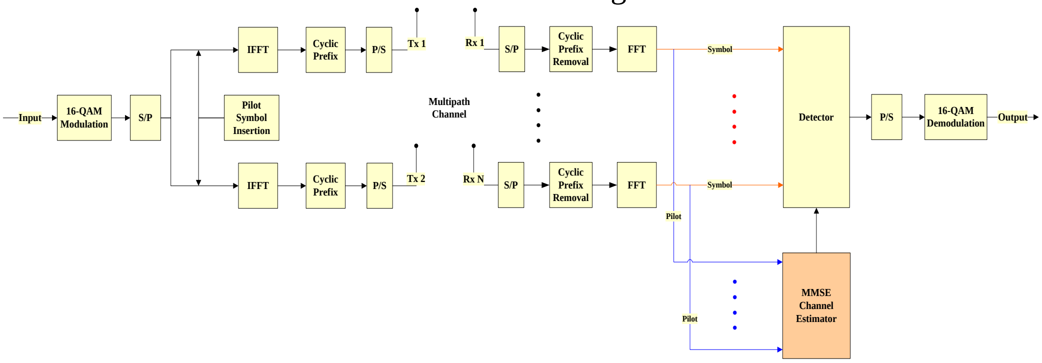

Figure 3. Design of MMSE channel estimator in MIMO-OFDM 2x2 and 2x4.

Channel estimation algorithms have been discussed in Section 2 and Section 3 describes the use of approximation channel model, so that the MMSE method can process it. In this research, *rectangular shaping filter* is used for Rayleigh fading channel (I Gede Puja Astawa *et al*. 2012). Equation of rectangular shaping in time domain is shown as Eq. 7:

$$p_r(\tau) = \begin{matrix} 1 & ; & 0 \leq \tau \leq T_1 \\ 0 & ; & otherwise \end{matrix} \quad (7)$$

Where T1 shows the root-mean-squared delay spread. To obtain a rectangular shaping in frequency domain is derived as follows:

$$R_p(\Delta_f) = \int_{-\infty}^{\infty} p_r(\tau) e^{-j2\pi\Delta_f\tau} d\tau$$

$$= \int_0^{T_1} \tau e^{-j2\pi\Delta_f\tau} d\tau \quad (8)$$

$$= T_1 e^{-j\pi\Delta_f T_1} \frac{sin(\pi\Delta_f T_1)}{\pi\Delta_f T_1}$$

Furthermore, Eq. 8 is used to obtain the covariance matrix as written in Eq. 4.

Discussion

Parameter System

In this research, the symbols are transmitted using 16-QAM modulation. The pilot sequences are inserted using High throughput Long Training Field (HTLTF) based on the IEEE 802.11n 20 MHz frequency. Other parameters as shown in Table 2.

Table 2. Parameter System

Component	Parameter	Nilai
Transmitter	Pilot sequence	HTLTF
	Modulation	16-QAM

	Number of subcarrier	56
	FFT-size	64
	Antenna schemes	2x2, 2x4
	Guard interval length	¼
Channel	Rayleigh fading	2 – rays
	Channel model approximated	Rectangular shaping
Receiver	Channel estimation method	MMSE

Performance Assesment

In this section, the results of simulation program based on design of channel estimation in MIMO-OFDM systems under approximation of Rayleigh fading channel. The simulation output are in the form of real-part impulse response and imaginary-part as well for each antenna schemes used by the system as shown in Fig. 4 to Fig. 11. For the system that uses 2 transmitters and 2 receivers, estimation results are shown in figure 4 to 7. Figure 4 and Fig. 6 show the real-part and the imaginary-part shown in Fig. 5 and Fig. 7. And for the results of system with 2 transmitters and 4 receivers with the same fixed parameters are shown in Fig. 8 to Fig. 11. Real-part are shown in Fig. 8 and Fig. 10, while Fig. 9 and Fig. 11 show the imaginary-part. The channel impulse responses then generated as input to the detector.

In wireless communication systems, signal propagation between the transmitter and receiver has gone through different path. The channel variation indicates that environmental conditions are always changing (multipath). The existence of this multipath causing strong difference signal reception at the receiver. Therefore applied a MIMO-OFDM system for data transmission in a multipath channel modeling using Rayleigh fading channel. In addition, the channel model approximation using additive white gaussian noise (AWGN) is also performed in AWGN channel where the transmitted information is disturbed by white noise using Gaussian distribution.

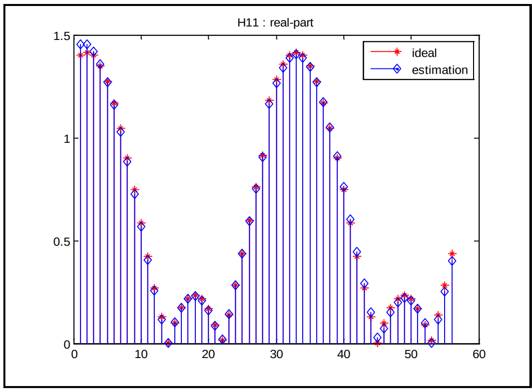

Figure 4. Real-part channel estimation of MIMO-OFDM 2x2 from Tx=1 to Rx=1.

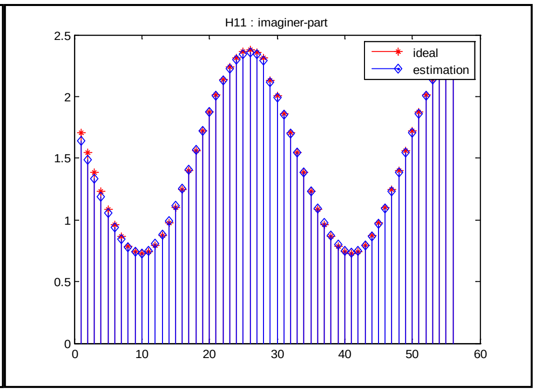

Figure 5. Imaginary-part channel estimation of MIMO-OFDM 2x2 from Tx=1 to Rx=1.

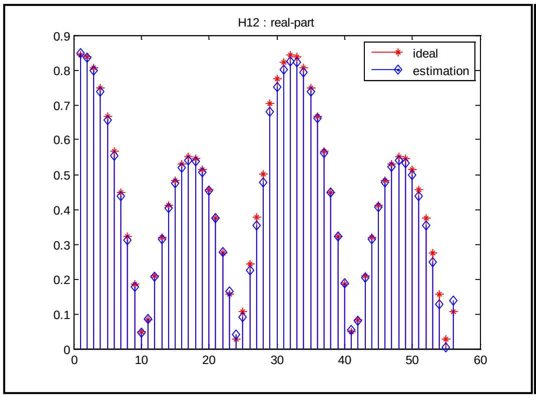

Figure 6. Real-part channel estimation of MIMO-OFDM 2x2 from Tx=1 to Rx=2.

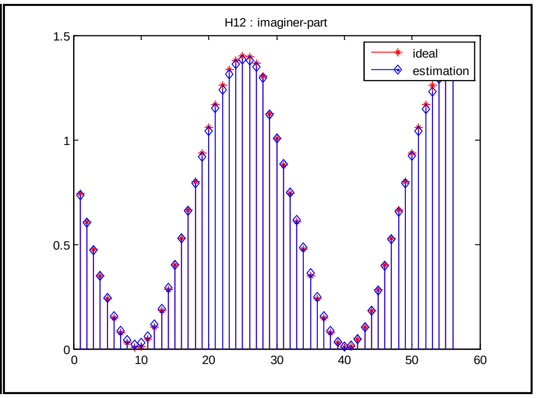

Figure 7. Imaginary- part channel estimation of MIMO-OFDM 2x2 from Tx=1 to Rx=2.

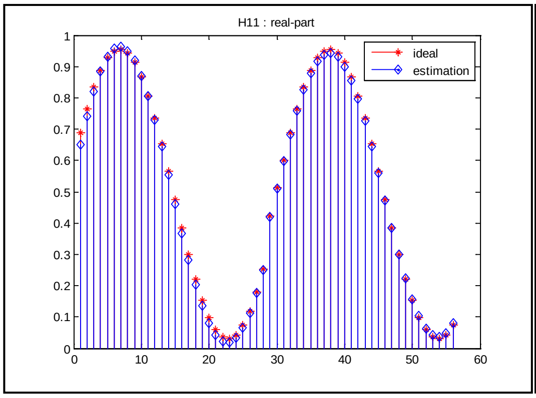

Figure 8. Real-part channel estimation of MIMO-OFDM 2x4 from Tx=1 to Rx=1.

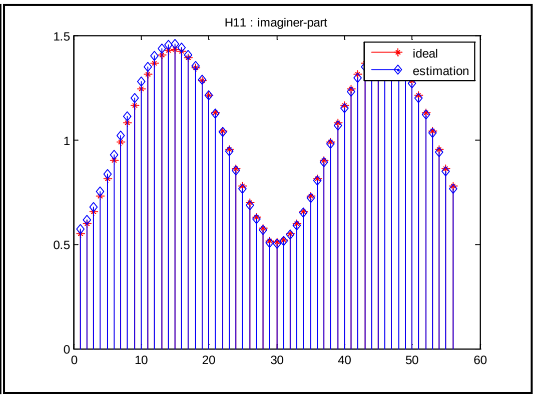

Figure 9. Imaginary-part channel estimation of MIMO-OFDM 2x4 from Tx=1 to Rx=1.

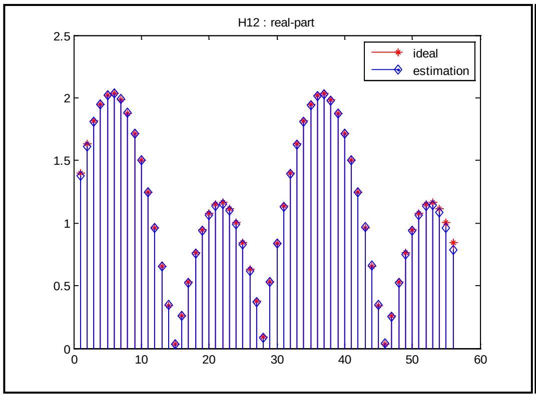

Figure 10. Real-part channel estimation of MIMO-OFDM 2x4 from Tx=1 to Rx=2.

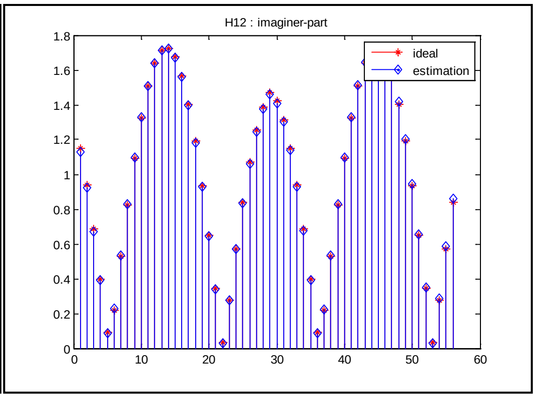

Figure 11. Imaginary-part channel estimation of MIMO-OFDM 2x4 from Tx=1 to Rx=2.

Based on the results obtained from the simulation, the output of channel estimation is shown with red dots, while the ideal channel condition is expressed by the impulse response in blue color for each real and imaginary parts. The distance of estimation points are not far from the ideal channel impulse response of system with 2 receiver antennas as well as system with 4 receiver antennas. Difference number of receiver antennas does not affect the performance of channel estimator and still accurately estimate the channel condition used at each number of antenna schemes.

The channel impulse responses are given for each subcarrier. In this research, 56 subcarriers are used based on parameter system for IEEE 802.11n WLAN standard. Therefore, for each estimation channel shows real and imaginary parts for subcarrier 1 to 56 as well as the ideal channel. The value for each subcarrier (real and imaginary parts) are different because the random input is given.

Conclusion

In MIMO-OFDM system with channel estimation technique in Rayleigh fading channel can be concluded that the channel estimator for 2x2 and 2x4 antenna scheme has been able to work well with the results expressed channel impulse response (real and imaginary parts) are estimated to approach the ideal channel impulse response.

This research is still continuing, and we are researching to observe the performance of MIMO-OFDM system for WLAN standard application and will be expressed in graph of BER vs. SNR.

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