Performance Analysis of MIMO OFDMA at IEEE 802.16e Standard

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Abstract- The used of MIMO has been believed to increase the system performances. One of the MIMO scheme is Spatial Multiplexing, which is a scheme that offers benefit such data rate increment. For modulation technique, OFDMA is employed. Because the system works for more than one user, it has multi user behaviours, that is why OFDMA chosen. The combination of MIMO and OFDMA was expected to provide a better performance to the system. The standard employed is IEEE 802.16e standard.

In this research, the MIMO OFDMA system will be analysed based on IEEE 802.16e standard. The parameter used is BER, where the system will be observed from both downlink and uplink side. At the downlink side, the influence of user movement in certain speed toward the BER, so is the allocation of more than one sub-channel will be seen. Meanwhile at the uplink side, how is the influence the number of the user whom accessing the system at once.

Keywords: MIMO, OFDMA, Spatial Multiplexing, IEEE 802.16e and BER

1. INTRODUCTION

The greater need toward the broadband wireless access with a high speed data recently (and predicted keep increased for the upcoming years, whether the user stay in one certain place or while mobile in accessing the system), demanding a reliable digital wireless communication system that able to fulfilled the abovementioned challenge which are providing a high data rate and also the reliable QoS.

One of the Broadband Wireless Access is WiMAX, a technology with a high speed internet access, which exceed the Wi-Fi speed and also with a larger coverage than Wi-Fi [1]. The WiMAX standard has been stated by IEEE, in which IEEE 802.16d for fixed and nomadic wireless broadband and IEEE 802.16e for full mobility wireless broadband [1].

To bolster the above services, it needs a system that able to provide the optimum performance in order that the user (especially the one who making a movement in accessing the system) obtained a quality of service that match with IEEE 802.16e standard. That is why the system employs a modulation technique called OFDM. Due to it is in a multi user environment, so it will be added the multiple access technique called OFDMA. OFDMA is a multiple access technique base on OFDM (a multi carrier modulation in which the channel bandwidth is divided into several sub-channels, 1 sub-channel consist of several sub-carriers, which allocated to each different user) [1]. In OFDM system only a single user that able to transmit at the whole sub-carriers while in OFDMA multiple users could transmit at once at the different sub-carrier in OFDM symbol [3].

OFDMA is also compatible with MIMO technology. MIMO (Multiple Input Multiple Output) is a technique of employing more than one antenna whether at the transmitting or at the receiving side. MIMO scheme used is Spatial Multiplexing, which has an ability to increase the system data rate [4].

At this research, the performance of MIMO OFDMA at IEEE 802.16e standard will be analysed based on BER (Bit Error Rate) depict by the graphic.

2. BASIC THEORY

2.1 IEEE 802.16e Standard [1][14]

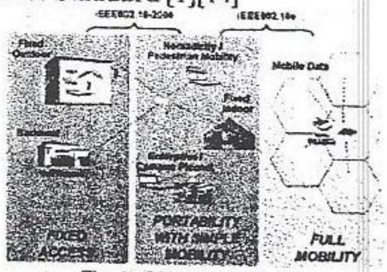

Fig. 1. 802.16e Application

WiMAX (Worldwide Interoperability for Microwave Access) as a Broadband Wireless Access (BWA) has many benefits rather than the previous BWA standard such as the ability to be implemented in NLOS (Non Line of Sight) condition whether for fixed, nomadic, portable and mobile application. The focus of WiMAX is standardization, so among any brands able to interoperate. Interoperate ability also intends to combine fixed and mobile communication service through one licensed band. And also scalable, means that the system could flexibly works in the different

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bandwidth, considering the bandwidth regulation in each country is different one and another.

802.16 is a standard developed by IEEE for a broadband service need such as voice, data and video. There is 802.16d for fixed WiMAX and 802.16e for mobile WiMAX. Based on the standard used, mobile WiMAX could provide a capacity until 10Mbps per channel for each base station in a basic configuration.

2.2 MIMO [2][4][5][6]

MIMO is a system that employs more than one antenna weather it is at the transmitting or at the receiving side. The MIMO technique is able provide the diversity gain and the multiplexing gain.

Diversity gain could be achieved by implementing diversity technique at the wireless digital communication system. The basic idea is diversity sent several information signal replica at independent fading channel, in order at the receiving side at least one signal has not experienced a deep fade.

Multiplexing gain could be achieved by using spatial multiplexing or space division multiplexing (SDM) at the signal that going to be sent.

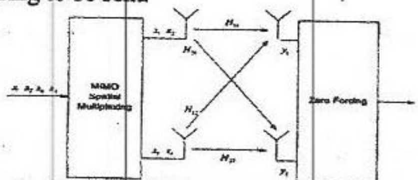

Fig. 2. MIMO with *Spatial Multiplexing Scheme*

The basic principal of spatial multiplexing is a stream of symbol will be divided into several parallel stream of symbol then transmitted simultaneously with the same bandwidth at each antenna, so this technique offers a data rate increment.

2.3 MIMO Detection (Zero Forcing)[2][4][5][6]

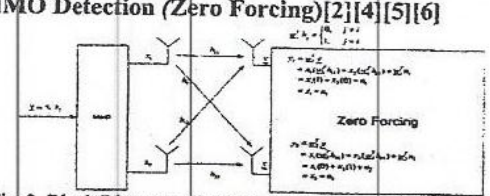

Fig. 3. Block Diagram of MIMO with detection (*Zero Forcing*)

The basic principle of zero forcing is each sub-stream believed as the desired signal, meanwhile another signal considered as an interfere signal. Nulling of interferes was done by giving a linier weighted toward the received signal, in order that another interferers could be eliminated. For zero forcing, nulling of interferer could be achieved by selecting the vector weight $\underline{d_i}$, $i = 1, 2, \ldots M_T$, as follow:

$$\underline{w}_i^T h_j = \begin{cases} 0, & j \neq i \\ 1, & j = i \end{cases} \qquad (1)$$

Where T represent transpose operation and j referred to column j and $\check{H}$ channel matrix. From the equation (1), nulling of interferer makes a null process if the weighted index is not the same as the index of transmitted signal antenna.

$$\begin{aligned} y_i &= \underline{w}_i^T \underline{y} \\ &= x_1(\underline{w}_i^T h_1) + x_2(\underline{w}_i^T h_2) + \ldots x_i(\underline{w}_i^T h_i) \ldots + w_i^T n \end{aligned} \qquad (2)$$

- For MIMO 2x2, i=1 and 2

$$\begin{aligned} y_1 &= \underline{w}_1^T \underline{y} \\ &= x_1(\underline{w}_1^T h_{11}) + x_2(\underline{w}_1^T h_{12}) + \underline{w}_1^T n \\ &= x_1(1) + x_2(0) + n_1 \\ &= x_1 + n_1 \end{aligned}$$

$$\begin{aligned} y_2 &= \underline{w}_2^T \underline{y} \\ &= x_1(\underline{w}_2^T h_{21}) + x_2(\underline{w}_2^T h_{21}) + \underline{w}_2^T n_2 \\ &= x_1(0) + x_2(1) + n_2 \\ &= x_2 + n_2 \end{aligned}$$

The signal received at the 1st antenna $= x_1 + n_1$
The signal received at the 2nd antenna $= x_2 + n_2$

2.4 OFDM [6][7]

OFDM (Orthogonal Frequency Division Multiplexing) is multi carrier modulation technique, where between one and another sub-carrier is orthogonal. Because of that, the side by side sub-carrier could be made overlapped without any inter carrier interference (ICI) effect arose. It will make OFDM has an efficiency of spectrum higher than any other conventional multi carrier modulation, such as showed below.

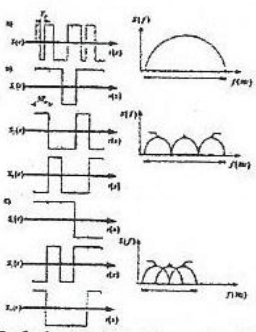

Fig. 4. Modulation Technique (a) *Single carrier* (b) *Multi carrier* (c) OFDM

The concept of OFDM is dividing the wideband information signal data rate become a parallel data stream with a lower data rate, so we will obtained the parallel signal streams with a low data rate. Afterwards, the parallel data

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modulated with the orthogonal sub-carrier. The usage of DFT at the OFDM will reduce the complexity level of transmitting and receiving system. DFT is used to create the orthogonal sub-carrier, to decrease the computation time. The algorithm of Fast Fourier Transform (FFT) will be implemented.

2.5 Orthogonal Frequency Division Multiple Access (OFDMA) [1]

Multiple access technology has been facing several phases of advancement after AMPS (Advanced Mobile Phone System) as the 1stG invented, which using the FDMA (Frequency Division Multiple Access) technology, in which FDMA is a technology used in the radio system by allocating one bandwidth with a certain wide for one user, so it will need wider bandwidth allocation if another user exists. All the frequencies will be sent once at a same time. This system was looked inefficient since the bandwidth resource is limited and expensive. The further research is directed to the development of 2nd generation that using TDMA (Time Division Multiple Access) as a method. In TDMA, one frequency will be allocated to several users but sent with a different time. Meanwhile at the 3rd generation there is CDMA (Code Division Multiple Access), where among the user are differentiate by codes.

OFDMA is a multiple access based on OFDM as the modulation technique. OFDM as a modulation technique basically will pass one bit stream at one communication channel with one OFDM symbol by dividing the one user bit stream into a lower rate in parallel, and then loaded to the sub-carrier before finally combined again. For a multi user environment, OFDM needs to be combined with multiple access technique such as OFDM-TDMA, OFDM-CDMA, and OFDMA. At the OFDM-TDMA, the multiple access technique was done by placing the user at the available bandwidth in one frame. A time slot consists of several OFDM symbol, in another word, each user will be modulated at the whole sub-carrier in the spectrum before placed at certain time slot. While at OFDMA, one user would be OFDM modulated at one certain sub-carrier. User in OFDMA is differentiate by sub-carrier frequency as used in FDMA, but the benefit compared to FDMA is about the guard band between the sub-carrier that allocated to each user is tighter because it could be overlapped. So in the end the frequency spectrum is more efficient and could increase the capacity. In this research, multiple access technique discussed is OFDMA that likely make several users transmit and receive simultaneously without modulated through the whole spectrum

2.6 QPSK Modulation[6]

At QPSK modulation, there are four levels of signals which are "00", "01", "11", "10". Each of the signal level is symbolized with the phase difference about 90 degree. Every one QPSK symbol can carry 2 bits of data. The output of QPSK is a complex number with data rate R/2, where R is data rate. Figure 5 shows QPSK constellation, used a grey mapping technique, which will be used in this research.

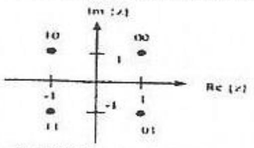

Fig. 5. QPSK constellation

2.7 Guard Time and Cyclic Prefix [13]

The influence of multi path channel could cause Inter symbol Interference (ISI). To combat that, it introduced a guard interval technique which will be added for every OFDM symbol [3]. The selected guard interval is several last symbols from one OFDM symbol in order the sub-carrier orthogonally maintained. The guard interval length needed is depends on channel delay spread condition, but the guard interval is supposed to exceed the delay spread. The chosen guard intervals, is copied to become a prefix one OFDM symbol, and this thing called cyclic prefix.

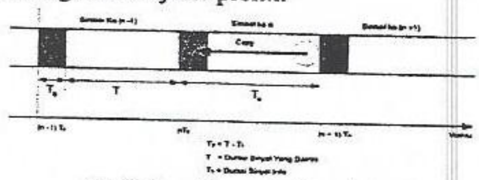

Fig. 6. *Guard Interval* with *cyclic prefix*

2.8 Channel Model

2.8.1. AWGN [9]

AWGN is a stochastic process existed in the channel with the characteristic of a spectral noise power is spread over the frequency.

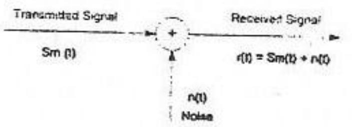

Fig.7. AWGN channel model

As seen in figure 7, the transmitted signal $s_m(t)$ will be received with equation:

$$r(t) = s_m(t) + n(t), \qquad 0 \leq t \leq T \tag{3}$$

Where n(t) is a noise existed during the signal transmitted until it arrive at the receiving side.

2.8.2 Multi path Fading [10]

Signal sent in the wireless environment, will face much of distortion such as reflection, attenuation, diffraction, scattering, etc. In the receiving side, the signal is the sum of several paths due to facing the condition above. The signals suffer a random variation of amplitude and phase through the short period of time. Signals received is a distorted signal

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because of the channel effect or widely known as a small scale fading.

These are several important parameters in analysing the channel characteristic:

1. Doppler shift

It is caused by a relative movement between the transmitter and the receiver because of the channel objects movement. It caused a broadening of signal spectral received. It is showed as follow:

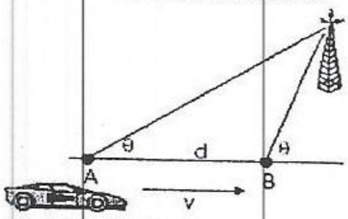

Fig. 8. Doppler effects illustration

if f_d is *doppler shift*, so f_d stated:

$$f_d = \frac{v}{\lambda}\cos\theta \qquad (4)$$

2. Delay Spread and Coherence bandwidth

Delay spread

The signal will arrive with a different time of arrival depend on the path distance. An impulse sent will be received as no more impulse instead a pulses with widespread called delay spread. Delay spread is a size of each path delay interval passed by signal with certain amplification or attenuation value. Delay spread causing interference inter symbol, because each symbol will collided. The level of interference is determined by bit transmission speed.

Coherence bandwidth

Coherence bandwidth is a channel statistical parameter in one certain range of frequency that considered flat, which are all spectrum component in that frequency range obtained the linear gain and phase. Coherence bandwidth could define fading behaviour as a selective frequency or flat fading. If transmitted in a bandwidth smaller than coherence bandwidth, so the signal will treat as a flat fading, and if happens in turn called frequency selective fading. As an approach, coherence bandwidth measured with this equation:

$$B_c \approx \frac{1}{T_m} \qquad (5)$$

In another word, base on delay spread channel facing:

- Flat fading, if a. BW signal < BWc
  b. Delay spread <symbol period
- Frequency Selective Fading, if
  a. BW signal > BW c
  b. Delay spread > Symbol Period

3 SYSTEM MODELLING

3.1 MIMO OFDMA System

The model and simulation of MIMO OFDMA covered the downlink and the uplink side. At the figure 9 the block diagram shows the downlink side. While at figure 10 the uplink block diagram.

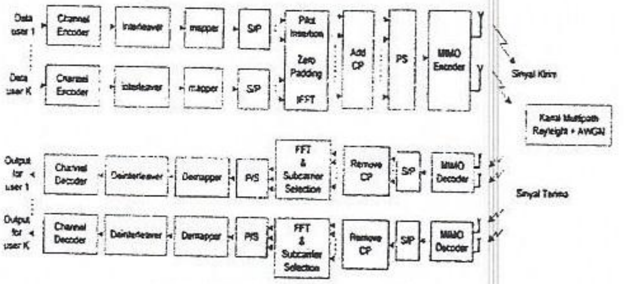

Fig. 9. Block diagram for downlink

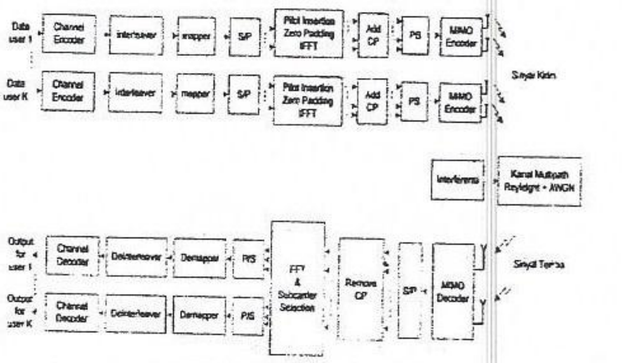

Fig. 10. Block diagram for uplink

The part of the block will be explained as follows:

a. Channel Encoder

To correct the wrong bit accepted base on the information from another bit.

b. Interleaver

To combats the burst error.

c. Mapper

To maps the digital data into an in phase symbol.

d. S/P Converter

The serial output of the data generator will be converted into parallel output.

e. Zero Padding

The additional carriers add in purpose to complete the number of IFFT subcarrier.

f. Pilot Insertion

The subcarrier to estimate the channel

g. IFFT

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To generates the orthogonal sub carrier.

h. Cyclic Prefix Addition

The interval guards to combat the ISI and ICI.

i. P/S Converter

To combined several signals into one serial symbol stream.

j. MIMO Encoder

MIMO encoder used is Spatial Multiplexing.

k. MIMO Decoder

MIMO Decoder used is Spatial Multiplexing.

l. Remove Cyclic Prefix

To remove the Cyclic Prefix that being added at the transmitting side.

m. FFT and Subcarrier selection

To select the subcarrier that belongs to the user.

n. Demapper

To reconstruct the data accepted to become the stream of bit that the same with the transmitting side.

o. Deinterleaver

Restore the data accepted after being interleaved.

p. Channel Decoder

To regain the information bit that being coded at the transmitting side.

3.1 IEEE 802.16e Standard [1]

IEEE 802.16e Standard used in the research is as follow:

- Frequency : 2,5 GHz
- Bandwidth : 5 MHz
- FFT Size : 512
- Symbol period : 91.4 μs
- Guard Time : 11.4 μs
- OFDMA Symbol duration : 102.9 μs
- Sampling Frequency : 5.6 MHz
- Space between sub-carrier : 10.94 KHz

4. SIMULATION RESULT ANALYSIS

4.1 The influence of user speed toward the system performance at a certain SNR value.

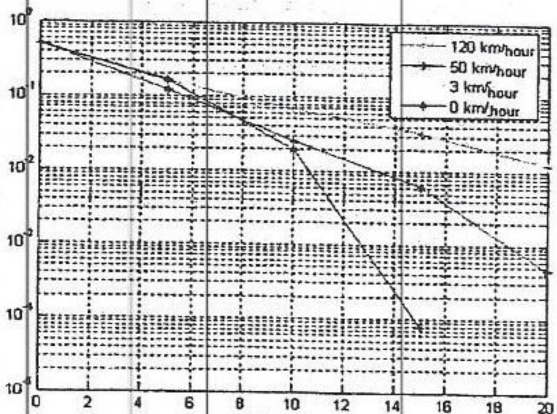

Fig. 11 MIMO OFDMA performance with the user speed influence at the downlink side

From the picture above, the user moves with a speed of 0 km/hours, 3 km/hours, 50 km/hours and 120 km/hours. The faster the user moves, the higher also BER achieved. It means that, the performance of the system is decreased.

4.2 The influence of allocation of sub-channel to one specific user toward the system performances that received at AWGN channel and Reyleigh channel.

- **At AWGN Channel**

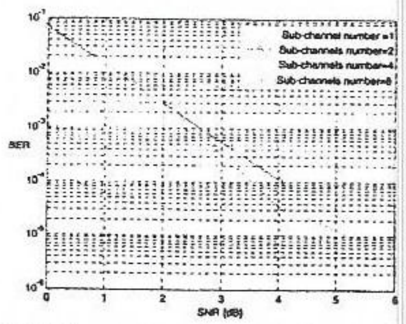

Fig. 12. MIMO OFDMA system performance with influence of allocation of sub-channel to one user at AWGN channel at downlink side

One certain user will be allocated with one certain number of sub channels. The condition of channel is fully occupied. Means that, if there is one user has two sub-channels, the remaining sub-channels will be allocated to another six users, with each user obtained one sub channel. The graphic shows the lines are tight with each other. It means that no significant influence existed in the system due to the allocation of sub channel. This analysis was done in AWGN channel.

- **At Rayleigh Channel**

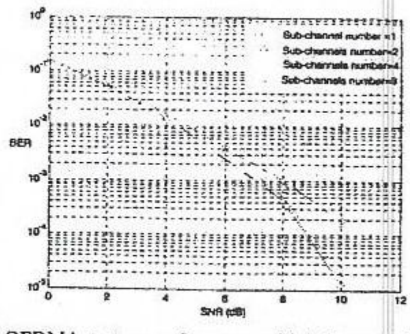

Fig. 13. MIMO OFDMA system performance with influence of allocation of sub-channel to one user at reyleigh channel when user moving at 3 km/hours at downlink side

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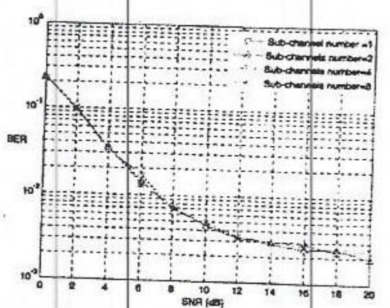

Fig. 14. MIMO OFDMA system performance with influence of allocation of sub-channel to one user at reyleigh channel when user moving at 50 km/hours at downlink side

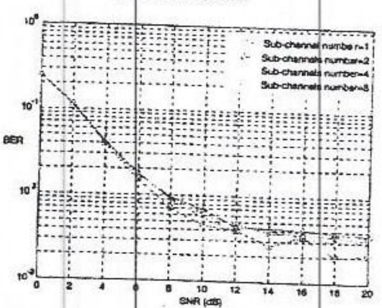

Fig. 15. MIMO OFDMA system performance with influence of allocation of sub-channel to one user at reyleigh channel when user moving at 120 km/hours at downlink side

These three figures (fig 13, 14 and 15) was analysed at the reyleight channel, with the user moves with 3 km/hours, 50 km hours and 120 km/hours. One certain user will be allocated with one certain number of sub channels. The condition of channel is fully occupied. Means that, if there is one user has two sub-channels, the remaining sub-channels will be allocated to another six users, with each user obtained one sub channel. The graphic shows almost the same with the user at AWGN channel. The lines are tight with each other. It means that no significant influence existed in the system due to the allocation of sub channel at reyleigh channel.

4.3 The influence of multiuser toward the MIMO OFDMA performance

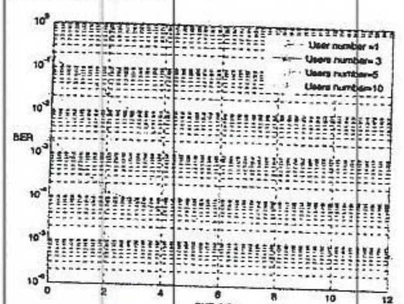

Fig. 16. MIMO OFDMA system performance with influence of multiuser at uplink side

This figure shows the influence of the number of users whom accessing the system. The more users accessing the system at the same time, the higher also the BER value achieved. The performance of the system will be decreased when the more users accessing the system at the same time.

5. Conclusion

From the simulation result we could conclude that:

1. The faster the user moves, the system performance will be decreased. The simulation shows, when user make no movement (0 Km/hours), the minimum SNR need to achieve BER 10^{-3} is 13 dB. When user move with 3 km/hours, it need 15 dB SNR. While at 50 km/hours the minimum SNR to achieve the same BER is 19 dB and at the 120 km/hours, SNR needed is above 20 dB.
2. The sum of sub-channel that allocated to one specific user could be more than one channel. This is making the channel is always occupied. The usage of sub-channel by one certain user is not really influencing the system whether in AWGN, Reyleigh with user movement 3 km/hours, 50 km/hours and 120 km/hours.
3. The more user access the system at once will cause a degradation of performance. This is because the more interferer exists. From the simulation, at BER 10^{-3} there is a degradation of performance about 2 dB between the numbers of user is 3 compared to the 5, and 4 dB between 3 users and 10 users.

6. References

[1] Ruth, Emyana. *"Analisa dan Simulasi Sistem Orthogonal Frequency Division Multiple Acces (OFDMA) pada Standar Mobile WIMAX"*. Tugas Akhir Program Sarjana STTTelkom, Bandung, 2008.

[2] Efendi, Rustam, *"Limited Feedback Precoding dan MIMO Spatial Multiplexing Untuk Aplikasi 802.16e"*. Tesis Program Pasca Sarjana STTTelkom, Bandung, 2007.

[3] Ian C. Wong, Zukang Shen, Jeffrey G. Andrews, Brian L. Evans, *"A Low Complexity Algorithm for Proportional Resource Allocation in OFDMA Systems"*. The University of Texas, Wireless Networking and Communications Group, Austin, Texas, 2004.

[4] Hardianto, Fariz Tri. *"Analisis Performansi Algoritma Deteksi Bertingkat MIMO-OFDM Kanal Berkorelasi Pada Standar IEEE 802.16e"*. Tugas Akhir Program Sarjana STTTelkom, Bandung, 2007.

[5] Andrews, Jeffrey G. *"Fundamental Of WIMAX understandingBroadband Wireless Networking"*. Department of Electrical and Computer Engineering the University of Texas, Austin, 2007.

[6] Zulfikar, Andi. "Analisa Kapasitas Pada Sistem MIMO-OFDMA Untuk Arah *Downlink*". Tugas Akhir Program Sarjana ITT TELKOM, 2008.

[7] Lesmana, Wayan Dedy. *"Unjuk Kerja Differential Space Time Frequency Code Padu Sistem MIMO-OFDM Melalui Kanal Rayleigh Fading"*. Tugas Akhir Program Sarjana STTTelkom, Bandung, 2007.

[8] Sandy. *"Analisis Kinerja Algoritma Adaptive Beamforming pada Sistem Orthogonal Frequency Division Multiplexing"*. Tugas Akhir Program Sarjana STTTelkom, Bandung, 2006 ".

[9] Adriansyah, Nachwan Mufti, *"Diktat Kuliah Sistem Komunikasi Bergerak"*, STT Telkom, Bandung, 2003.

ISBN: 978-979-18765-0-6

[10] J Anton Parlindungan S, "Unjuk Kerja Frequency Hopping Orthogonal Frequency Division Multiple Access (OFDMA) Pada Kanal Multipath Fading", Tugas Akhir Program Sarjana STT Telkom, 2005.
[11] Hamdaner, "Kajian Performansi Pengkodean Kanal *Low-Density Parity Check Code (LDPCC)* pada sistem MIMO-OFDM", Tesis Master Teknik STT TELKOM, 2006.
[12] I r a w a n, " Analisa Performansi Sistem SVD- MIMO-OFDM Pada Kanal Fading Rayleigh", Tugas Akhir STT Telkom, 2006
[13] Eko Firdaus, "Analisa Performansi Sistem MIMO-OFDM Pada Wirreless Lan", Tugas Akhir STT Telkom, 2005.
[14] IEEE 802.16 Architecture.

ISBN: 978-979-18765-0-6