Downlink Spectral Efficiency of Mobile WiMAX System

Mohamad Iskandar b. Saian

Faculty of Electrical Engineering

Universiti Teknologi Mara (UiTM), Shah Alam

Selangor, Malaysia

iskandarsaian@gmail.com

***Abstract* — The IEEE 802.16 is the working group on broadband wireless access standards. The Mobile WiMAX was introduced in the final standard, IEEE 802.16e-2005. The mobile WiMAX makes changes and give benefits in mobility and flexibility for the user. Mobile WiMAX is a cost-effective approach to significantly extend the coverage and enhance the throughput and capacity especially the downlink part. This project investigated the performance of advanced antenna such as Single Input Single Output (SISO) and Multiple Input Multiple Output (MIMO) techniques in the downlink of mobile WiMAX. The OPNET modeler software is used to evaluate the performances including throughput, spectral efficiency, SNR and Modulation Coding Scheme (MCS). Results of simulation show that higher MCS (e.g. 64-QAM) which deployed MIMO antenna has better performance as compared to lower MCS (e.g. QPSK) with SISO antenna.**

***Index Terms* — *Mobile WiMAX, OFDMA, SISO, MIMO,* throughput, delay, spectral efficiency, HTTP.**

I. INTRODUCTION

A. *Overview of Study*

The demand of the internet has increased recently especially for mobile internet services which is to give the best coverage experience comparable to existing fixed internet [1]. The enhancement of performance in mobile WiMAX compared to the existing mobile radio system because the usage of scalable OFDMA and advanced antenna system. The large channel bandwidth will offer the possibility of higher throughput for the user [2]. The cost-effective application of MIMO technology gives lots of advantages especially in a wireless channel in order to increase the throughput over the same frequency [3].

The mobile broadband wireless access which has been standardized by IEEE 802.16-2005 [4] supports time division duplexing (TDD) and Quality-of-Service (QoS) which are flexible and provide seamless solution for the multimedia services [5]. The applications of fixed internet include video streaming, file transfer protocol (FTP) and web browsing are also demanded in wireless internet (mobile). The aimed of mobile WiMAX system is to receive and transmit the application without any distortion by overcoming several weaknesses such as flexibility, packet losses, throughput, delay in any transmission condition.

The Adaptive Modulation Coding (AMC) and MIMO techniques are very popular in recent years for capacity and coverage improvements. The AMC allows for the dynamic allocation of Modulation and Coding Schemes (MCS) based on wireless channel conditions. It extends the range of the network and also increase the system level capacity as it allows for real time tradeoffs between throughput and robustness on each link [6]. MIMO technology employs the space dimension to increase spectral efficiency through Spatial Multiplexing (SM) and improved link reliability through Spatial Diversity (SD). Mobile WiMAX also supports dynamic MIMO switching to maximize spectral efficiency with no reduction in coverage area. In this project, the evaluation of mobile WiMAX in the downlink (DL) direction is investigated using OPNET simulator.

a) *Mobile WiMAX Overview*

The initial WiMAX system based on the IEEE 802.16-2004 standards. First the WiMAX targeted to fix broadband wireless application by installation of Customer Premises Equipment (CPE). Past year, on December 2005, WiMAX tried to make an evolution in network technology which is IEEE completed the 802.16e-2005with new features to support mobile application.

The mobile WiMAX systems are modified by extending the original OFDM PHY layer to get more efficient multiple-access by using scalable OFDMA. The data streams to and from individual user equipment are multiplexed to groups of subchannels on downlink and uplink. By deploying a scalable PHY architecture, mobile WiMAX is able to support a wide range of bandwidth. The varying of FFT size from 128 to 512, 1024 and 2048 to support channel bandwidth of 1.25 MHz, 5 MHz, 10 MHz and 20 MHz respectively *b) MIMO Block Diagram*

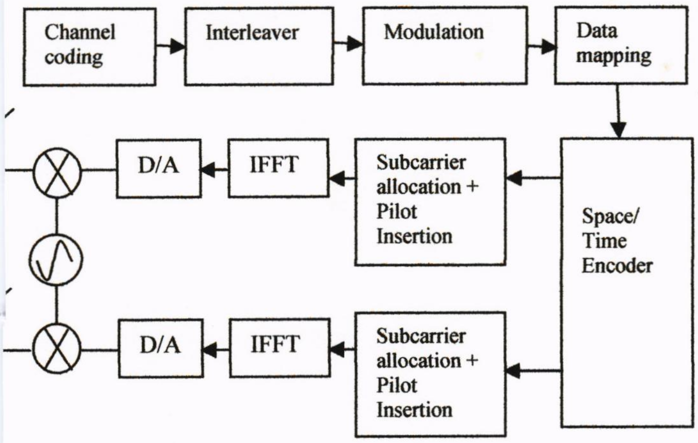

Figure 1. Mobile WiMAX functional stages

Figure 1 shows the block diagram of a MIMO system [7] and the explanation of each block is as follows:-

Channel coding - The stage includes randomization, coding and puncturing.

Interleaving – use a block interleaver to interleave the encoded bits.

Modulation – convert the sequence of interleaved bits into a sequence of complex symbols depending on the chosen modulation scheme (QPSK, 16QAM and 64QAM)

Data mapping – First steps of the process is to segment the sequence of modulation symbol into a sequence of slots. Each slot contains a number of modulation symbols. Second step is to map the slots into a data region.

Space / Time Encoder – converts one single input data stream into multiple output data streams.

Subcarrier allocation / Pilot insertion – In this stage all data symbols are mapped to a data region and assigned to their corresponding logical subcarriers.

IFFT and Digital-to-Analog – convert the data into analog form (in time domain) for use in the radio front end.

c) Spectral Efficiency and MCS

The important performance evaluation metrics for mobile WiMAX is spectral efficiency and is shown in Table 1 [8]. When deploying higher modulation scheme, the spectral efficiency is better and the throughput will be increased [9].

MCS	Spectral Efficiency	Code rate
QPSK	1	½
16-QAM	2	½
64-QAM	3	½

Table 1. Modulation and Coding Scheme

d) QoS traffic flow

In this project, the QoS is set as Best Effort (BE) for HTTP application. There is no strict latency requirement. The HTTP traffic workload pages [10] for small page is 5 kB, medium page is 25 kB and large page is 100 kB. The average packet loss for HTTP at end-to-end is less 10% [11].

B. Problem Statement

In this project, it investigates the performance of downlink spectral efficiency of mobile WiMAX with Hyper Text Transfer Protocol (HTTP) application. To achieve the best performance, several specifications of HTTP application are needed to satisfy the performance metrics of the application such as the throughput, packet drop, SNR, pathloss and spectral efficiency.

C. Objective and Scope of Study

The theory of mobile WiMAX [12] is AMC improved the capacity, peak data rate, coverage and allow the MSC to average the channel condition for each user because MCS is dynamic. When MCS is set to 64-QAM, it means that the mobile station is near to the base station and able to transmit and receive more bit per symbol and achieve higher throughput. Combining the MIMO and highest MCS is the best way to improve on capacity and coverage.

The performance of the system can be degraded when the MS and BS is far each other [13]. The modulation is set to a QPSK where the throughput, coverage and capacity is less than the 64-QAM performance. Besides that, employing MIMO can improve the system throughput to more than 50% than SISO [14]. Furthermore, MIMO technique has less packet loss as compared to SISO. In MIMO techniques, there are several modes which are SM and space time coding (STC) where STC gives the best performance as compared to SM at high SNR. The throughput also increases when STC is combined with AMC. This will improve the spectral efficiency and SNR [15].

The outline of the paper is as follows. In Section II, the description of the methodology and the network design is described. Simulation results and discussion are described in Section III. Finally, the conclusion in Section IV.

II. METHODOLOGY

In this project, the OPNET Modeler version 14.5 is used for simulation and referred to WiMAX Module specification. The scenario was designed which consists of HTTP application with different BS and QoS. Figure 2 shows the flow chart and the steps of the network topology design.

A. Network Topology Design

a) Flow Chart

To design the network topology, OPNET modeler® version 14.5 is used to create the simulation design.

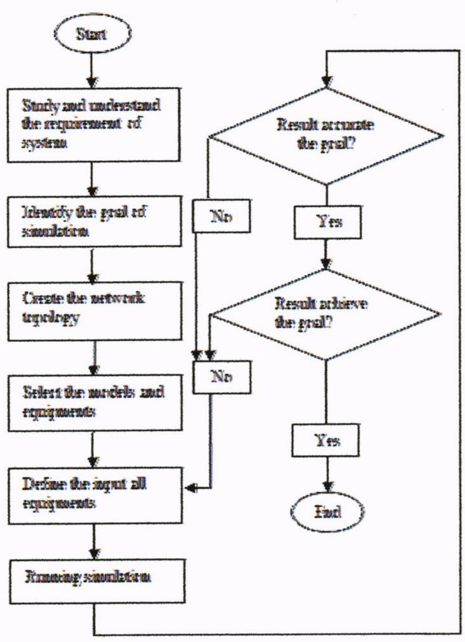

Figure 2. OPNET modeler simulation design flow chart.

From Figure 2, it shows the flow of creating the network of mobile WiMAX, configuring the network, run the simulation and analyzing the results. If the result is not satisfied, repeat the previous steps by adjusting the parameters accordingly.

b) Create Network Topology

The network topology of the model is designed and shown in Figure 4. In this project, the measurement is focused on HTTP application in the downlink spectral efficiency. With modern technology and smart phone, most of the users spend time with their gadget which is surfing the internet using the HTTP application. The downlink performance is important for HTTP because the protocol of request, response and acknowledgement from server to user for downloading the pages in few seconds is required by the users.

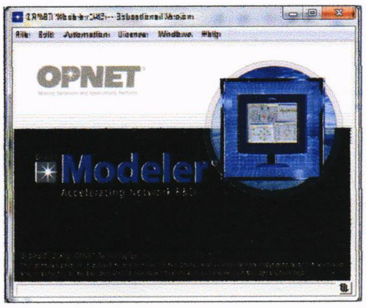

Figure 3. OPNET Modeler 14.5 simulator

Figure 3 shows the software that was used to create and simulate the network designed. The steps to create the subnet of network topology are:-

File ⟶ New ⟶ Create project ⟶ Ok

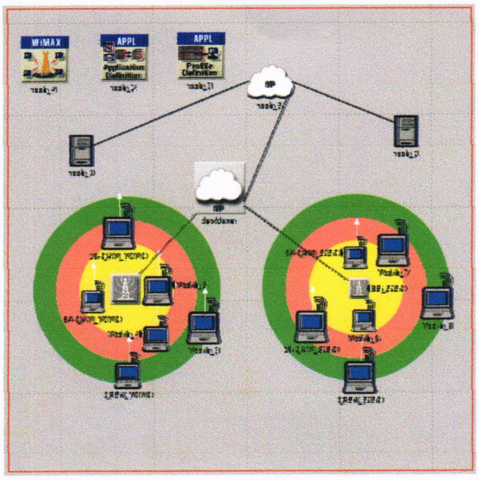

Figure 4. Top view of the network topology

Figure 4 shows the network that has been designed and simulated. The network consists of MIMO and SISO base station (BS) with 12 mobile stations (MS). In this subnet, the setting of three different distances from the BS which are 6 km, 4 km and 2 km. Each radius is set with its own MCS which is QPSK ½, 16-QAM ½ and 64-QAM ½ (for 2 km, 4 km and 6 km respectively). The BS is connected to the IP backbone and the IP cloud by using Digital Signal (DS3).

The scenario is HTTP application and mobile WiMAX. To make MS is moved, the parameter of pathloss needed to set as Vehicular as shown in Figure 5. The trajectory is set as a Vector with a speed of 70 km/s.

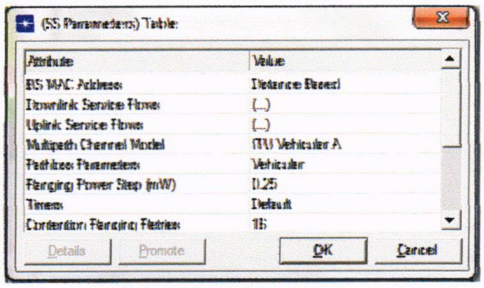

Figure 5. SS parameter

c) *WiMAX configuration*

In the subnet network topology, MS, BS, WiMAX Configure, Application Definition and Profile Definition need to set the specification and HTTP application profile. The WiMAX configure is important because it is needed to define the service classes with the QoS requirements of the service flow where the service flow is represented by traffic flow between the BS and MS. In this project, the downlink service flow is important because most of the users browsing the web each hour and second. By doing the research, the improvements of spectral efficiency, throughput can be analyzed.

The service flows are defined by type of MAC Service Class and it allows the mobile WiMAX configure to support the QoS and determine the delay sensitive traffic such as video conferencing and VoIP application. In this study, the HTTP application and the QoS is set to BE as shown in Figure 6.

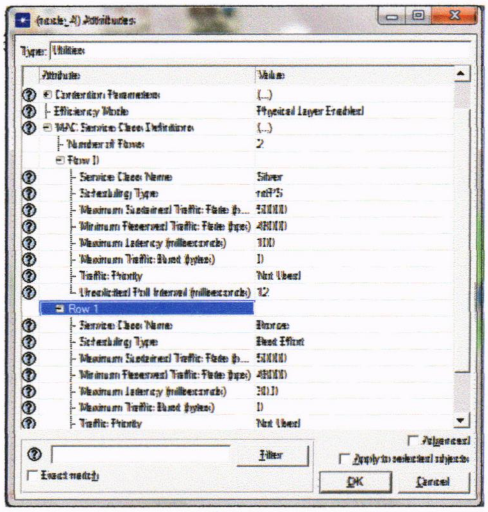

Figure 6. Setting the QoS

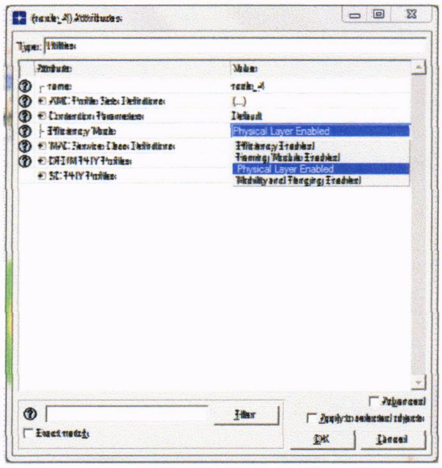

Figure 7. Efficiency Mode

Figure 7 shows the selection of efficiency mode by selecting Physical Layer Enable. The air interface or PHY layer access was configured with OFDM with 2.3 GHz base frequency using a 10 MHz channel bandwidth and 1024 subcarriers. The WiMAX MS transmit power was configured to 2 watts and using -1 dBi gain antennas. The BS transmit power was configured to 3.8 watts with 15 dBi gain antenna and is shown in Table 2.

Parameter		Value
Duplex Mode		TDD
Frequency		2.3 GHz
Frame Length		5 ms
Bandwidth		10 MHz
BS	Antenna Gain	15 dBi
	Tx Power	3.8 W
MS	Antenna Gain	-1 dBi
	Tx Power	2 W
Pathloss		Vehicular

Table 2. OFDM parameter

III.RESULT

The results are shown for the 64-QAM ½ , 16-QAM ½ and QPSK with the MIMO and SISO BS.

Symbols:-
Mobile_3 for QPSK_MIMO BS
Mobile_4 for 16-QAM_MIMO BS
Mobile_5 for 64-QAM_MIMO BS
Mobile_6 for 64-QAM_SISO BS

Throughput

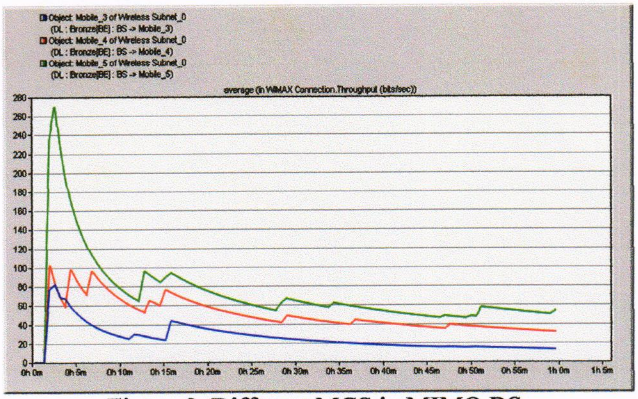

Figure 8. Different MCS in MIMO BS

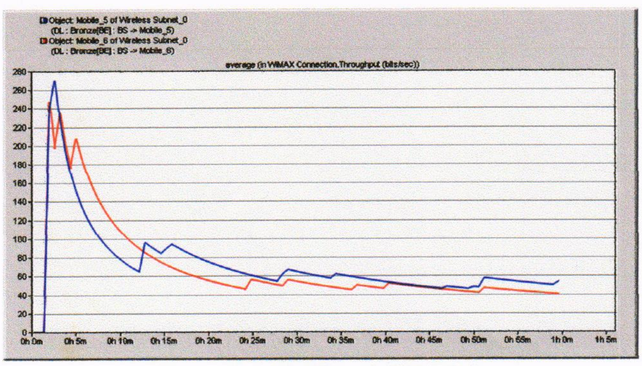

Figure 9. MIMO and SISO BS

Figure 8 and 9 show the result of throughput. According to Figure 8, the throughput of Mobile_5 by using 64-QAM ½ is higher than Mobile_4 and Mobile_3. The differences in MCS can affect the throughput performance. Even though the same MCS is configured as in Figure 9, however, the BS which is configured with MIMO is delivering higher throughput as compared to SISO.

User Cancelled Connection

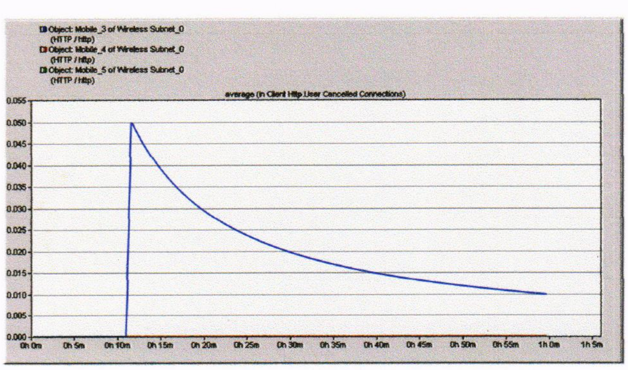

Figure 10. Different MCS in MIMO BS

Figure 10 shows that Mobile_3 is not connected to the MIMO BS since the distance is 6 km and the location is far from the BS. The user is not capable or constantly get a stable connection when the distance farther from BS.

Download Page

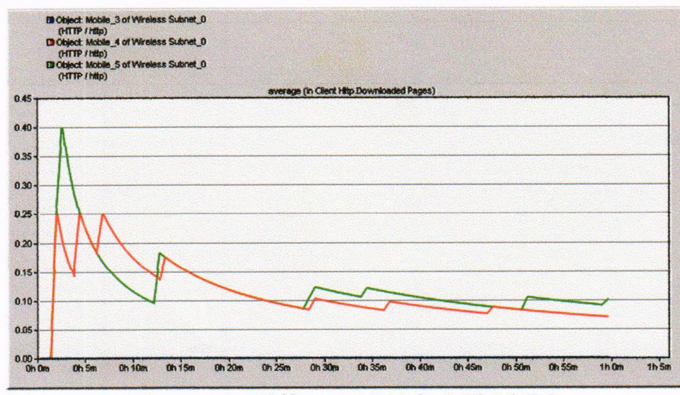

Figure 11. Different MCS in MIMO BS

It is observed from Figure 11 that Mobile_5 has lowest delay in downloading the pages as compared to other MS. The response to get the pages after browsing at Mobile_5 is faster than the other MS. The Mobile_3 does not give any response because the MS is far from BS and cancelled the connection as in Figure 10.

Queue Delay

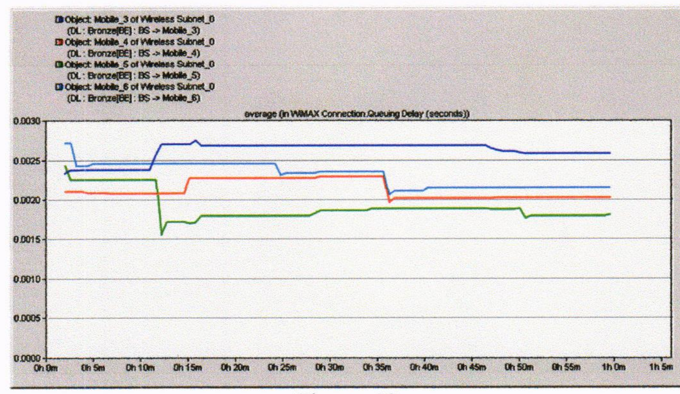

Figure 12

The queueing delay is the time a job waits in a queue until it can be executed. From Figure 12, the queue delay of Mobile_5 is less than other MS. This happened when the downloading of pages as in Figure 11 for Mobile_5 is the quickest. Even though Mobile_5 and Mobile_6 are same MCS but the diversity of the antenna which is MIMO and SISO techniques, it will affect the performance in delay time when executed and received the pages to users.

Traffic Receive

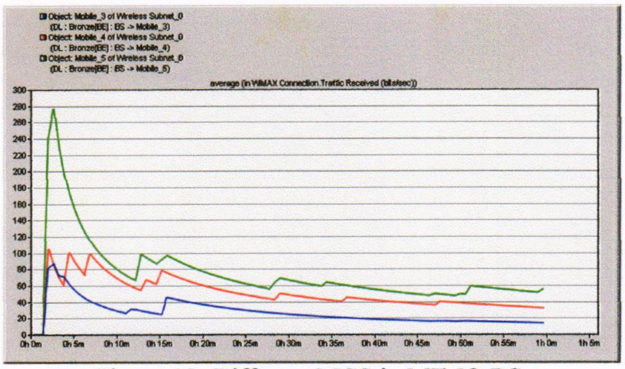

Figure 13. Different MCS in MIMO BS

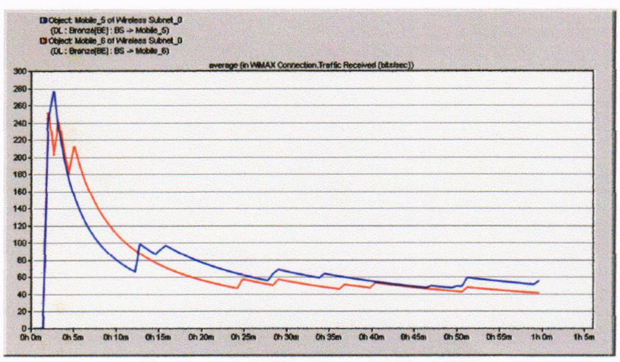

Figure 14. MIMO and SISO BS

From Figure 13 and 14 it show that the traffic received for Mobile_5 is higher than other MS. The higher MCS (64-QAM ½) with combination of MIMO antenna make the traffic received for Mobile_5 are stable connection, less delay and less distortion or error when browsing the web page.

Pathloss

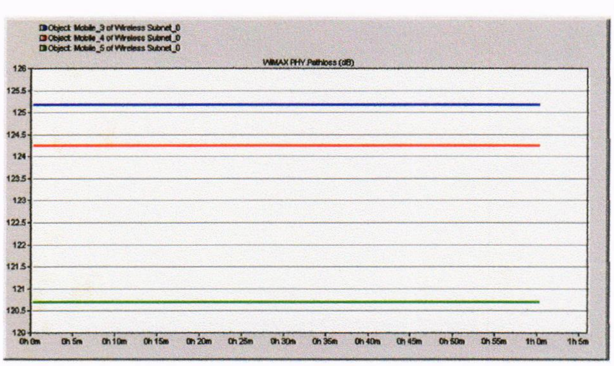

Figure 15. Different MCS in MIMO BS

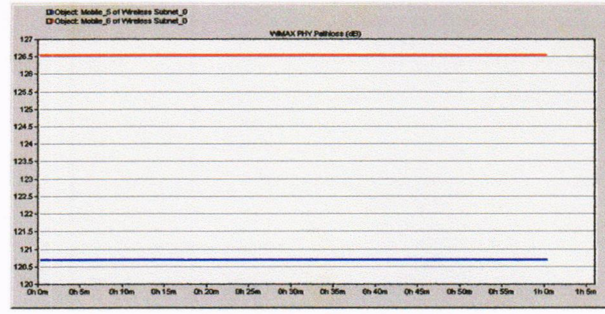

Figure 16. MIMO and SISO BS

Figure 15 and 16 show the pathloss condition. Although the MS is applied with the same pathloss environment which is vehicular, the best connection is received by Mobile_5.

Downlink SNR

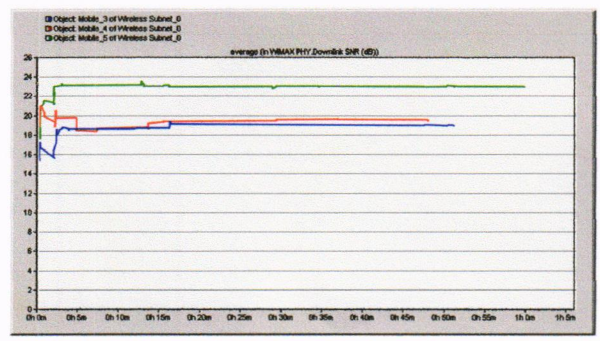

Figure 17

SNR relates to the packet dropped rate by the PHY layer. The MS_3 is far from BS with MCS of QPSK ½ , which means, the packet dropped is higher as compared to MS_4 and MS_5. It will affect the SNR as shown in Figure 17. Due to low SNR, MS_3 has higher drop rate.

Spectral Efficiency

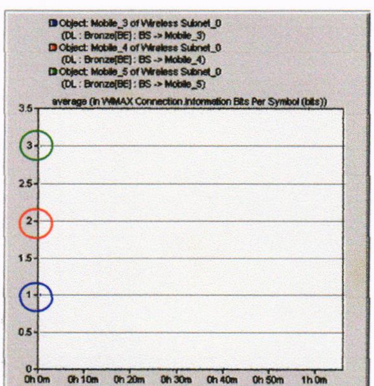

Figure 18

Figure 18 shows the spectral efficiency which is calculated theoretically is the same with the simulation results. It is proved by employing the formula below and data from Table 1:-

$$Spectral\ Efficiency,\ N = \frac{\log M}{\log 2} x\ code\ rate$$

Where; M = Modulation value

Example: Modulation 16 QAM ½

$$Spectral\ Efficiency,\ N = \frac{\log 16}{\log 2} x\ code\ rate$$

$$=4 \times \frac{1}{2}$$

$$= 2\ \text{bit/s/Hz}$$

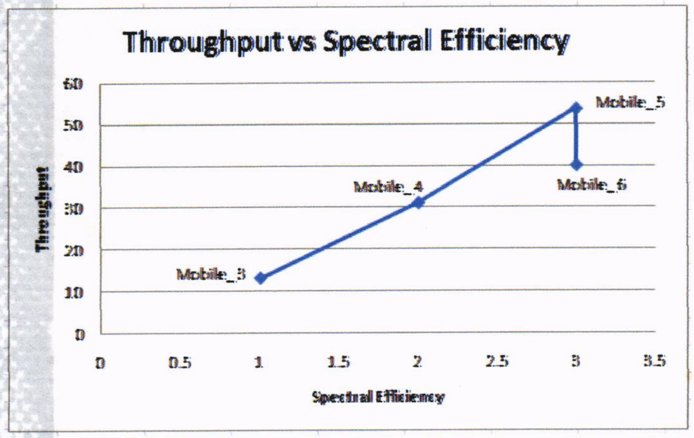

Figure 19

Figure 19 shows that, Mobile_5 has the best performance with highest spectral efficiency and throughput compared the other MS.

IV.CONCLUSION

The conclusion from the objective of this project is achieved. The throughput, packet dropped, downlink pages, SNR and spectral efficiency performance is studied. Combination of MCS and MIMO technique improved the throughput with less packet dropped, faster response when downloading the pages and enhance the spectral efficiency.

The recommendation of future work is that to conduct real measurement on site and compare the results with simulation. Another recommendation is redesign the parameters and find the impact on the system performance through different scenarios. Change several parameters to analyze the performances including station transmit power, station antenna gain, pathloss model and MAC scheduling type.

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