Universitas Indonesia

Final Year Project Report

PERFORMANCE CHARACTERIZATION

OF MIMO IN POPULATED ENVIRONMENT

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Abstract

By comparing the performance of IEEE 802.11n and 802.11g standard, the project aimed to characterize the performance of MIMO (Multiple Input Multiple Output) that is represented by the 802.11n standard and SISO (Single Input Single Output) that is represented by the 802.11g standard in real world environment. By conducting the performance characterization in a populated environment MIMO's advantage to SISO became more apparent.

The connection speeds or data rates of each standard are the main consideration in the characterization. These are done by establish an ad hoc connection and simulating download and upload between 2 computer (PC) terminals, using the "Elephant and Mice" method of varying between 1 large file and several small files. These simulations were done in real world environment, where obstacle and the movement of people are the integral part of the design of the simulation to achieve the idea of performance characterization in populated environment.

Statement of Authorship

The work contained in this project report has not been previously submitted for a degree or diploma at any other tertiary educational institution. To the best of my knowledge and belief, the project report contains no material previously published or written by another person except where due reference is made.

Signed ....

Date ....

Table of Contents

Table of Contents

Table of Figures

Acknowledgements

As a human, we cannot live by ourselves. Therefore during the course of this project, I have been very thankful for many people that assisted and supported me. I would like to present a big thank you to Dr. Karla Ziri-Castro, my project supervisor for her guidance throughout the project. It has been a big help for me to complete the project according to the standard supervise by one of the expertise in the telecommunication field.

I would also like to thank my project partner, Muhammad Iqbal Dalel for his help, spirit, and hard work in making this project. It has been an outstanding experience working together with you. I would also like to thank my family, my best friends, and everyone else who assisted me on this project.

Thank you very much everyone.

Chapter 1 Introduction

Nowadays, wireless services have become an integral part of our daily activities. Wireless network offer more flexibility and efficient advantage than the wired network. The wireless services also have become standard in all mobile computers. Improvement for higher network capacity and performance is essential to overcome the limitation of the widely used wireless SISO (Single Input Single Output) system. To increase spectral efficiency, several options like higher bandwidth, optimized modulation or even code-multiplex systems offer practically limited potential.

MIMO (Multiple Input Multiple Output) Systems utilize space-multiplex by using antenna arrays to enhance the efficiency in the used bandwidth. The systems use multiple inputs and multiple outputs from the same channel. MIMO technology are includes in the new draft IEEE 802.11n with the corresponding OFDM technology. The draft IEEE 802.11n was made to improve the widely used IEEE 802.11g which is SISO standard.

In this report, student focus on the idea of MIMO advantage of SISO in achieving better performance characteristic in real world environment. Student believes that improvement of data rate performance is essential to identify the superiority of MIMO since it is one of the key aspects of wireless networking activities. This report will explained the simulation and observation of MIMO performance in real world environment done by the student to verify the improvement in data rate performance as the expected result.

Chapter 2 Background Theory

In wireless communication, MIMO technology is the current theme of international research. The use of multiple antennas at both of the transmitter and receiver to improve communication performance, offers significant increases in data throughput and coverage range without additional bandwidth or transmit power. Thus higher spectral efficiency (more bits per second per hertz of bandwidth) can be achieved.

One of the differences between MIMO and non MIMO system are MIMO channel has multiple links and performs on the same frequency. Moreover, the separation and the equalization of all the signal paths has become the main consideration.

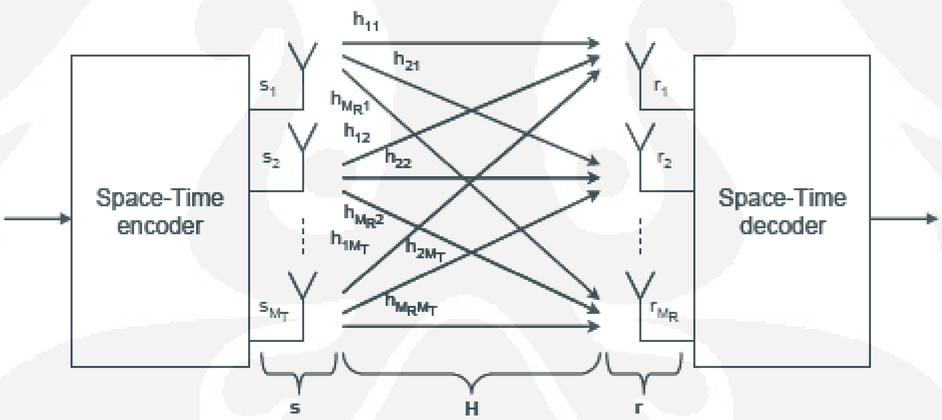


Figure 1 the physical MIMO channel

From the figure above, the channel includes the matrix H with the direct and indirect channel components. Understanding of matrix H is important for decoding purpose. Note that pre coding can be used if the receiver sends the channel approximation to the transmitter which will enhance MIMO performances. The direct components (e.g. h_{11}) correspond to channel flatness while the indirect components (e.g. h_{21}) represent the channel isolation. Sent and received signal are represented by s and r symbols, respectively.

Most channel capacity improvements are based on bandwidth extensions or other modulations while MIMO capacity increases linearly with the number of antennas. According to Claude Elwood Shannon theory of channel capacity for SISO systems,

$$C_{siso} = f_g \log_2\left(1 + \frac{S}{N}\right)$$

The equation includes the transmission bandwidth f_g and the signal to noise ratio. As comparison, the channel capacity equation for MIMO systems is,

$$C_{mimo} = M f_g \log_2\left(1 + \frac{S}{N}\right)$$

M is the minimum number of transmitting or receiving antennas and represents the number of spatial streams.

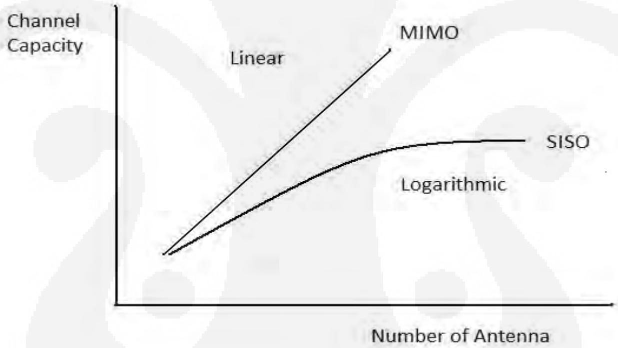


Figure 2 channel capacity improvement

Number of antenna can also determine the cost of the system. The cost of the system will grow considerably with the increase number of antenna. According to Atheros Communications white paper written by Winston Sun, Ph.D. in 2006, "Maximizing MIMO Effectiveness by Multiplying WLAN Radios x3", the best trade-off between performance and cost lies in 3x3 system configuration.

There are 3 important features of the MIMO systems, spatial multiplexing, spatial diversity, and multipath propagation.

2.1 Spatial Multiplexing

Spatial multiplexing is a transmission technique in MIMO wireless communication to transmit multiple data streams over more than one antenna. Space dimension is able to reuse or multiplex more than one time using this technique. Spatial multiplexing also offers an opportunity to increase throughput without the use of additional spectral bandwidth. There are two type of spatial multiplexing, V-BLAST and Space-Time Codes.

V-BLAST (Vertical Bell Laboratories Layered Space-Time) transmits spatial un-coded data streams without any consideration in equalizing the signal at the receiver. V-BLAST method cannot separate data streams. This could result multi-stream interference (MSI) to appear an makes the transmission unsteady. Unlike V-BLAST, space-time codes deliver orthogonal and by this means independent data streams. Space-time coded signal can be detected by using simple linear process and achieves reasonable results. Space-time code method is widely used for spatial multiplexing technique in MIMO systems than the V-BLAST method.

A linear capacity gain can be achieved with spatial multiplexing in relation to the number of transmit antennas. On the other hand, spatial multiplexing is struggled to achieve a good signal quality.

2.2 Spatial Diversity

Spatial diversity has a basic concept of transmitting the signal via several independent diversity branches to get independent signal replicas. In other words, spatial diversity relies on the transmission of structured redundancy. It can be achieved via the diversity of time, frequency, space, or polarization.

Spatial diversity can be narrowed down into two types, Tx-Diversity and Rx-Diversity. In Tx-Diversity, signal copy is transmitted from another antenna (e.g. 2x1). It is similar to mono and stereo signal, where human is able to sense a tone better in the form of a stereo signal. Tx-Diversity can be used by applying Alamouti Space-Time Code.

Figure 3 the Alamouti space-time block code for 2 Tx antennas

Using space-time codes enhance the performance and make spatial diversity reusable. The process involves delayed diversity using delayed transmission, where the copy of the signal is not only sent from another antenna but also at another time. The widely used space-time codes design and the easiest ways to achieve spatial diversity is Space-Time Block Code or STBC. Another design, Space-Time Trellis Code or STTC is more complex and expensive to use.

In Rx-Diversity, the received signal is multiple evaluated (e.g. 2x1). This type of diversity is comparable to two ears, which obviously more pleasing and better to hear than just one. Rx-Diversity can be applied by using more receiving antennas than transmitting antennas and a proper combining algorithm.

Using a combination of spatial multiplexing in the near field and spatial diversity in the far field, the optimal performance and coverage of a wireless communication system can be reached. Moreover, the trade off between spatial multiplexing and spatial diversity is essential for reliable and sturdy MIMO systems.

2.3 Multipath Propagation

The basic definition of multipath propagation is propagation of a signal in more than one path due to the presence of interferences or obstacles which result in constructive interference, destructive interference, or phase shifting of the signal.

Multipath fading environment is essential for MIMO systems in terms of spectral efficiency. In contrast with the SISO systems, MIMO split a single user's data stream into multiple substreams and then use an array of transmit antennas to simultaneously transmit the streams into the same frequency band. In SISO systems, the signal will interfere to each other due to the use of single antenna. On the other hand, in MIMO systems it is possible to use the scattering of those signals to enhance, rather than degrade, transmission accuracy. Separate parallel subchannels then created using spatial signatures from the scattered paths. Furthermore, an array of receiver antennas detects the multiple transmitted substreams. The rate of transmission is increased in proportion to the number of transmit antennas.

In MIMO, multipath propagation is highly related to OFDM (Orthogonal Frequency Division Multiplex). OFDM divides the signal into several orthogonal subcarriers so they will not interfere with each other. The STBC can be inserted to the subcarriers to provide spectral efficiency. In result, OFDM offers a robust multi-path system suitable for MIMO.

Chapter 3 Test Design

According to the background theory of the MIMO systems, MIMO data rate performance is more superior to SISO systems. Student tries to support the theory by simulating and observing the performance of MIMO in real world environment. Verifying the improvement in data rate is the expected result of the project.

The test is conducted at Myer Centre food court in Brisbane CBD, Queensland Australia. Student believes that the environment of a food court is suitable as the obstacle and movement of people were adequate to simulate a populated environment. As a comparison, the test is done in two different times, busy lunch time for the populated environment and late afternoon for the controlled environment. Two different wireless network measurement softwares were used to record the data rate.

3.1 Test Equipment

MIMO wireless notebook adapters are used to simulate MIMO systems. While for the SISO systems, student use the on board notebook wireless adapters. Below is the list of equipment use for the simulation,

Hardware

- Sony VAIO VGN-SZ483N Notebook
- HP mini 2140 Notebook
- Linksys WPC300N MiMo Notebook Adapter
- D-Link DWA-643 MiMo Notebook Adapter
- Sony-Ericsson W800i Camera Phone

Software

- FileZilla FTP Client and Server
- WirelessMon Wireless Diagnostic Software
- Jperf Network Measurement Graphical Tool

The Camera phone is used to record the environment when the test is conducted. FTP client and server software is used to simulate upload and download connection between two notebooks. The student use two different wireless network measurements software, WirelessMon for monitoring and record data rate which works with FTP client and server software. Another software is Jperf, used for simulate and record data rate in TCP and UDP protocols and able to work without the use of FTP client and server software.

Data sheet for notebook specification and MIMO notebook adapters are listed in the appendix.

3.2 Test Procedure

Test procedure for this project was divided into two according to the software used.

3.2.1 Test Procedure Using WirelessMon

Two laptops were set up as p2p (peer-to-peer) connection with approximate distance of 6 meters. One of them is assigned as server, and the other is acted as a client. Files then exchange between two laptop using FTP software to simulate upload and download, each with the same time period. There are 2 type of file was used, a single large file and multiple small files. The large file size is 700 MB, and the small files size 3 MB each. WirelessMon Wireless Diagnostic software installed in one of the computer was used to record the total data rate during the process. This test is done in both of the populated and controlled environment for MIMO and SISO systems, with a total of 16 tests.

3.2.2 Test Procedure Using Jperf

Two laptops were set up as p2p (peer-to-peer) connection with approximate distance of 6 meters. Jperf can perform the upload and download simulation without the use of FTP client and server software but both of the notebooks must have the Jperf software installed. Jperf measure the network in 2 different protocols, UDP and TCP. Data rate and jitter are measured in UDP tests. Only Data rate is measured in TCP tests. TCP configuration is set to default while for UDP there are 3 tests in that differ in bandwidth, which are 10 MB, 4 MB, and 200 KB. These bandwidths were chosen to observe the effect of bandwidth landslide and minimum bandwidth condition. Jperf is used only in populated environment as a comparison for the Wireless Mon test result. A total of 14 tests were done for this software.

3.3 Test Diagram

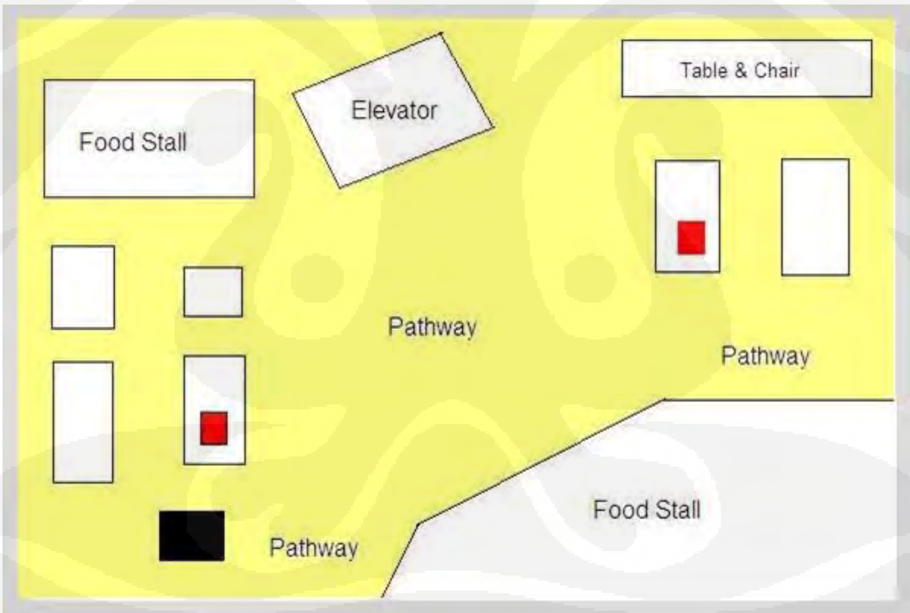


Figure 4 test diagram

The red square in the diagram represent the notebook position. Distance between the notebooks is approximately 6 metre. The black square represent column and the white square represent furniture (table and chairs) unless stated otherwise.

3.4 Expected Result

The test was conducted primarily to record data rates for MIMO and SISO each. WirelessMon will produce 4 results for each system which consist of large file and small files download and upload, each for control and populated environment. JPerf will only be used in populated environment. By comparing the results from the control and populated environment, the performance characterization of each system can be concluded. In populated environment MIMO should exhibit higher data rate.

Chapter 4 Test Result and Analysis

Results from the test were then plotted into graphs using Microsoft Excel. In this chapter, all the graphs and analysis are organized according to the software used in the tests.

4.1 WirelessMon

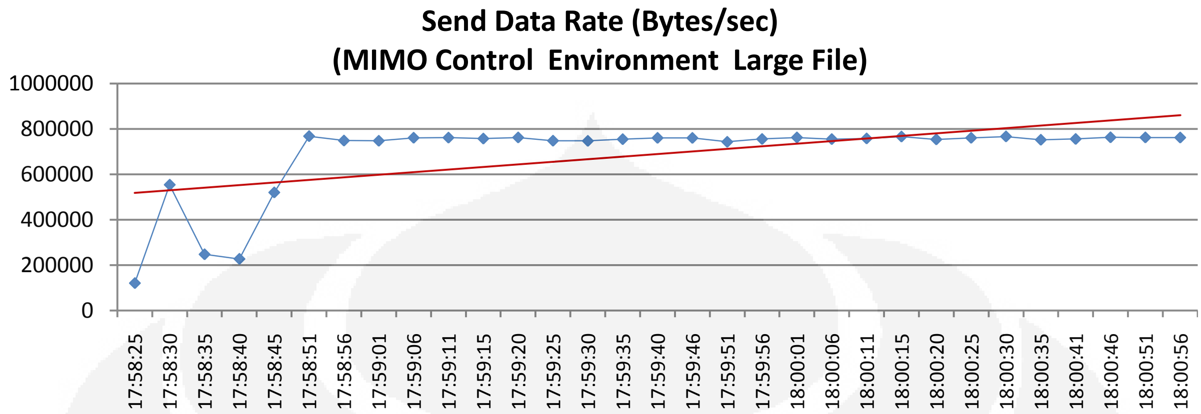
WirelessMon wireless diagnostic software is a tool to monitor the status of wireless adapters and gather information about nearby wireless access points in real time, log the information collected into files, and provides comprehensive graphing of signal level and real time IP and WiFi statistics.

The test results using WirelessMon then organized according the environment. The purpose is to give another comparison of systems performance characteristic in terms of different environment.

4.1.1 Control Environment

The student define control environment as a condition where there are not much people movement in the surrounding. A maximum constant data rate is expected as the result, where the minimum movement of people and unobstructed line of sight between two notebooks are attained.

4.1.1.1 MIMO system in Control Environment Using WirelessMon



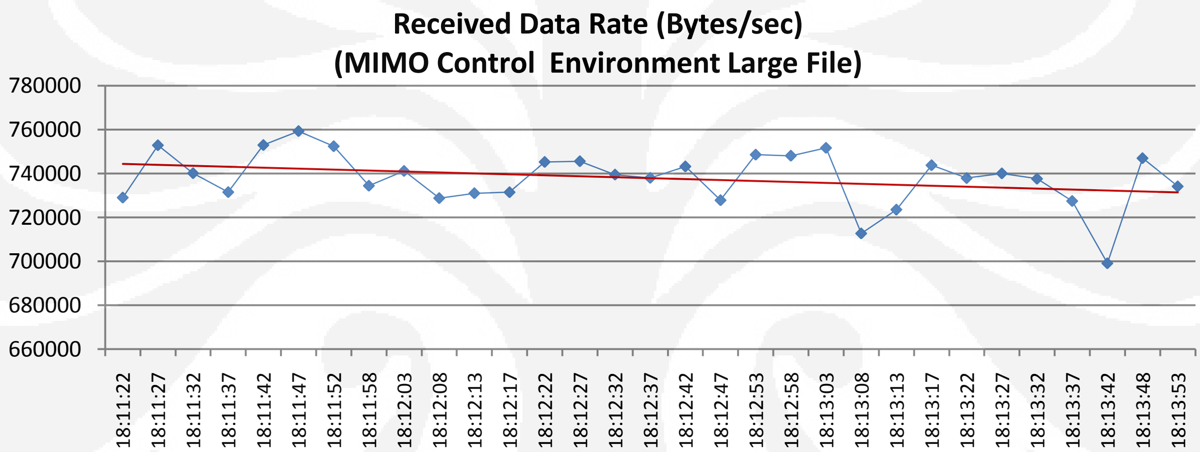
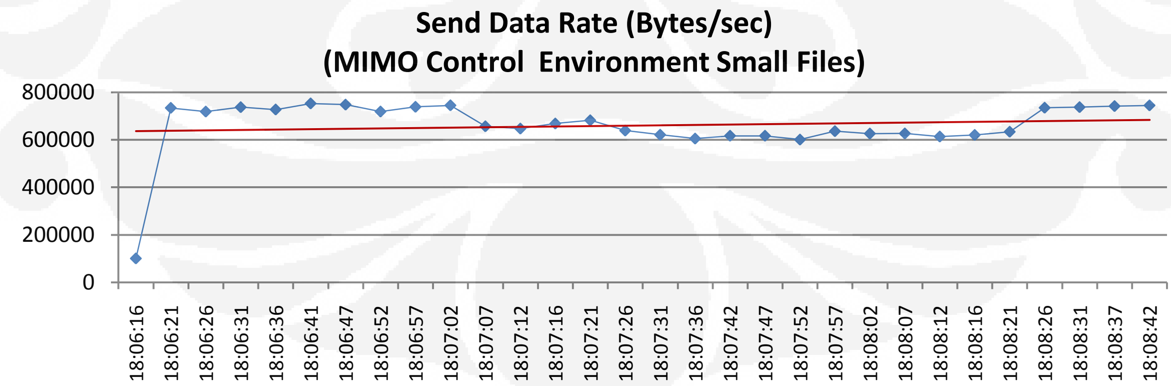


Figure 5 MIMO in control environment data rate graph (large file)



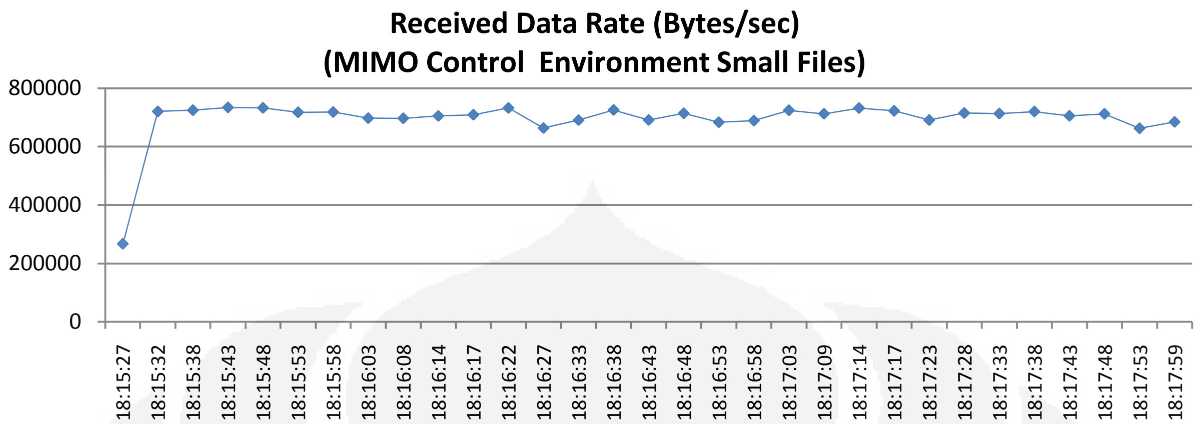
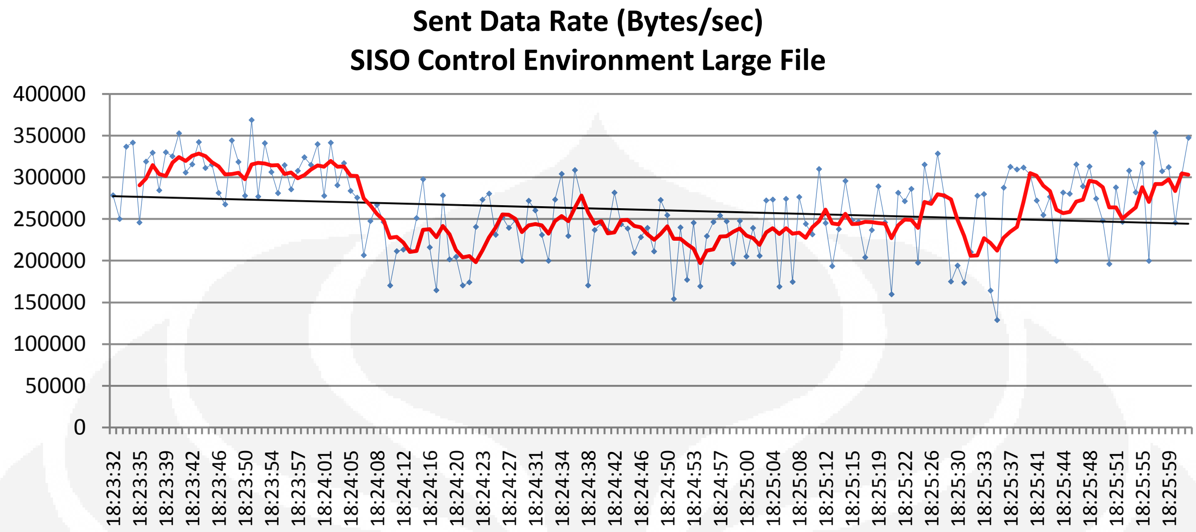


Figure 6 MIMO in control environment data rate graph (small files)

Both of the figures above show a same data rate pattern, where a rising time is evident in the entire graph. A rising time occur when the connection between two notebooks is established and then reach the potential value. The slight fluctuations of data rate during the connection are caused by unexpected interference at the test site. The received data rate graph for the large file shows more erratic data rate than the other. This incident is existed due to more interference, when suddenly there were several people obstructing the line of sight at the time of the test.

MIMO systems have shown that in a control environment, it capable to reach an average data rate up to 700 KB/sec. It also exhibits a similar data rate for both of the large file and the small files.

4.1.1.2 SISO system in Control Environment using WirelessMon



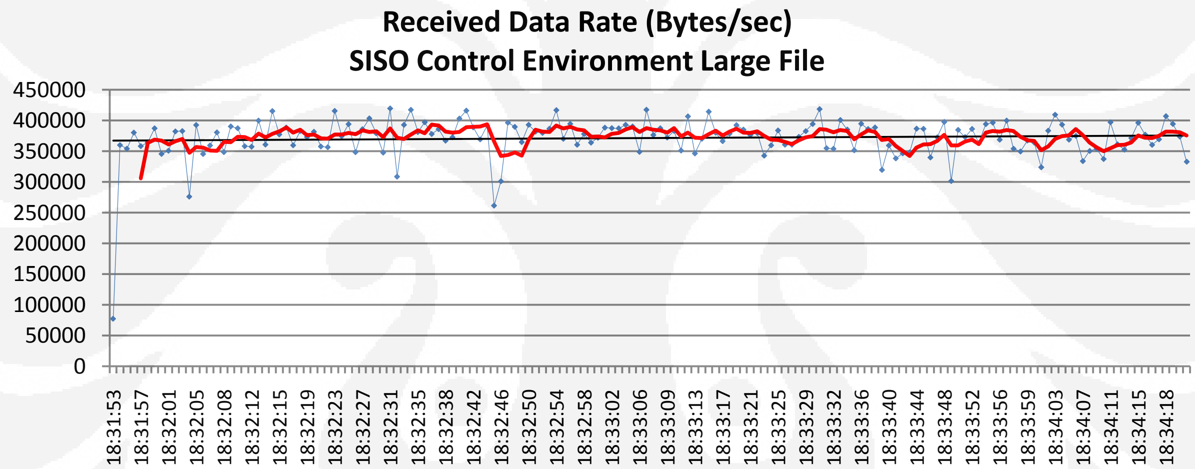
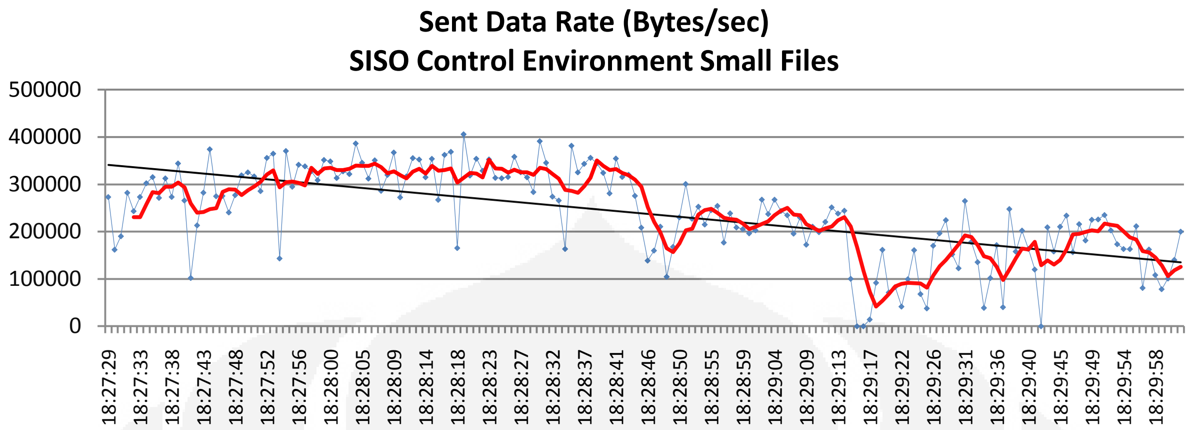


Figure 7 SISO in control environment data rate graph (large file)



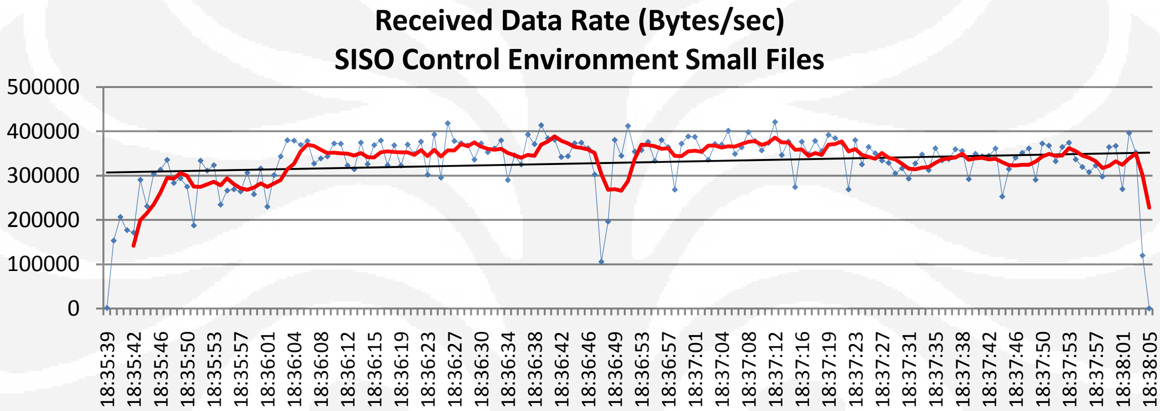


Figure 8 SISO in control environment data rate graph (small files)

SISO systems produced more samples per second than MIMO because of the difference of computation power. For instance, MIMO use more complicated algorithm to process the signal than MIMO which result in more time needed. An averaging trend line (marked as red line in the figure) is used to simplify the comparison with the MIMO graph.

The SISO test result show more fluctuation than the MIMO systems in the control environment but the overall trend lines for all the SISO graphs show a stable result. On the other hand, the SISO small files send data rate graph show more variation than the other because of another unexpected interference caused by the movement of people between the two notebooks. Furthermore, the rise and fall is more often showed in the overall SISO small files figure because the system needed to start over in sending the data for each file queued. This incident can be seen in the graph, where at one point the data rate drop to almost 100 KB/sec.

4.1.1.3 Data Rate Comparison in Control Environment Using WirelessMon

The average value of data rate in both MIMO and SISO system are summarized in the figure 9 below. It is clearly shown that received data rate for the entire test in control environment is slightly higher than the send data rate average value. In MIMO system, this is happened because one of the MIMO wireless network adapter is using the newer and faster express card connection.

SISO produces samples five times higher than MIMO. As previously explained, MIMO requires more calculation and complex algorithm to process the signal. The use of trend line in the SISO graphs is to give an accurate comparison to the MIMO graphs. From the average data rates, the advantage of MIMO systems is justified in the control environment and both of the systems behave as expected.

Transfer Type/ Result	Send Large File	Received Large File	Send Small Files	Received Small Files
Avg. Data Rates (Bytes/s)	689,139.16	737,960.9	660,064.7	693,898.8
Total Data (Bytes)	103,370,874	110,694,135	99,009,705	104,084,820
Number of Data	30	30	30	30

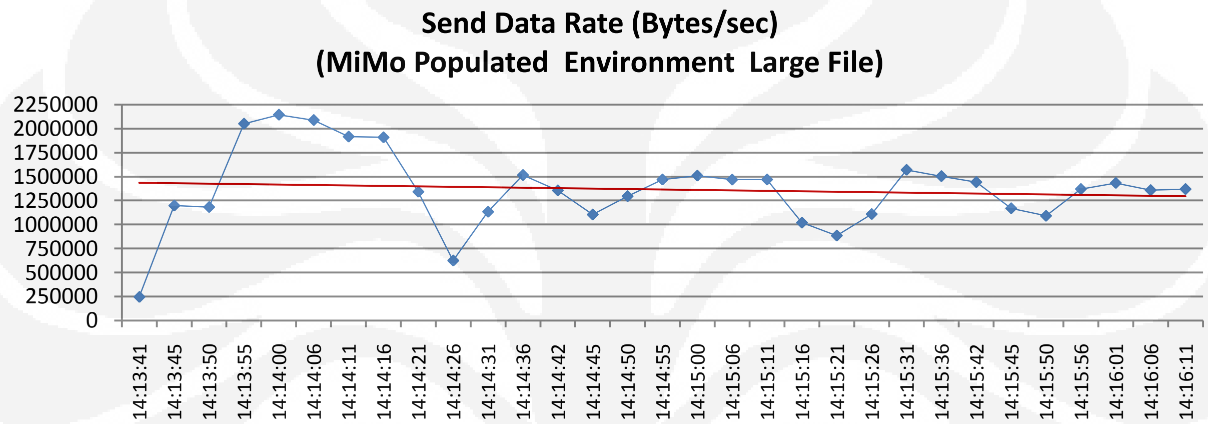
Transfer Type/ Result	Send Large File	Received Large File	Send Small Files	Received Small Files
Avg. Data Rates (Bytes/s)	260,984.6	371,545.9	238,114.5	333,703.90
Total Data (Bytes)	39,147,690	55,731,885	35,717,175	50,055,585
Number of Data	163	155	169	154

Figure 9 MIMO vs SISO data rate comparison table in control environment

4.1.2 Populated Environment

Populated environment is the suitable condition to simulate MIMO systems capabilities in real world environment. In contrast to control environment, student expects a lot of people movement to observe and justify the performance characteristic of MIMO systems then compare it to SISO systems.

4.1.2.1 MIMO system in Populated Environment Using WirelessMon



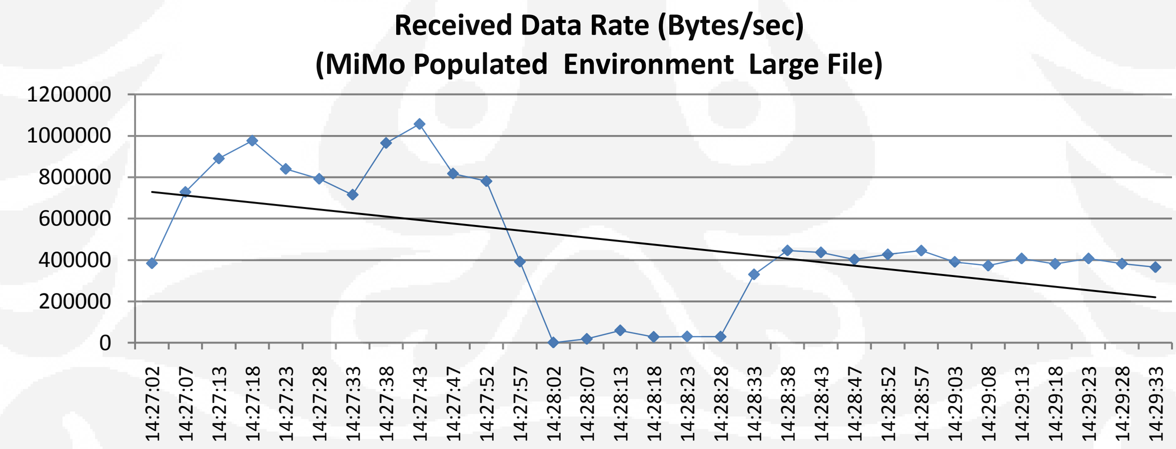
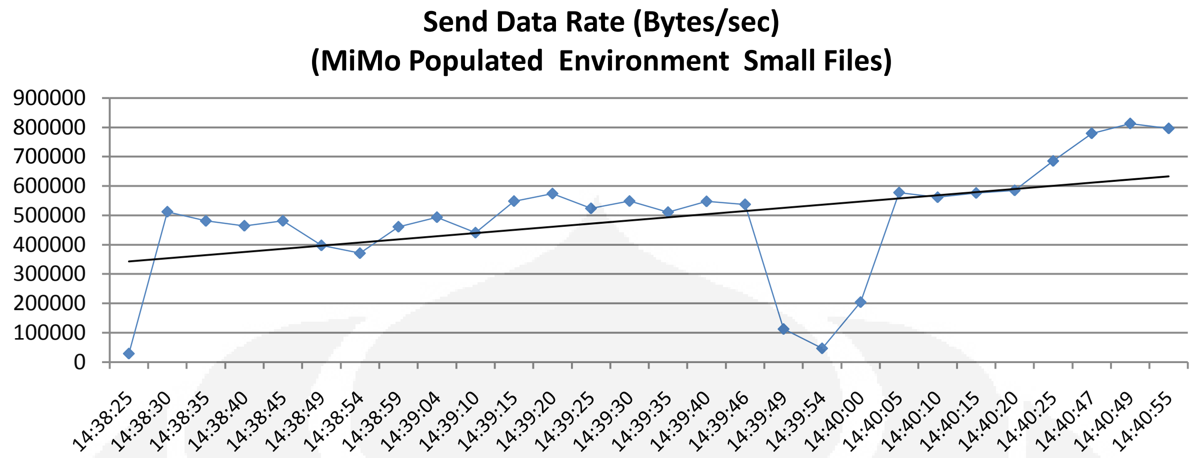


Figure 10 MIMO in populated environment data rate graph (large file)



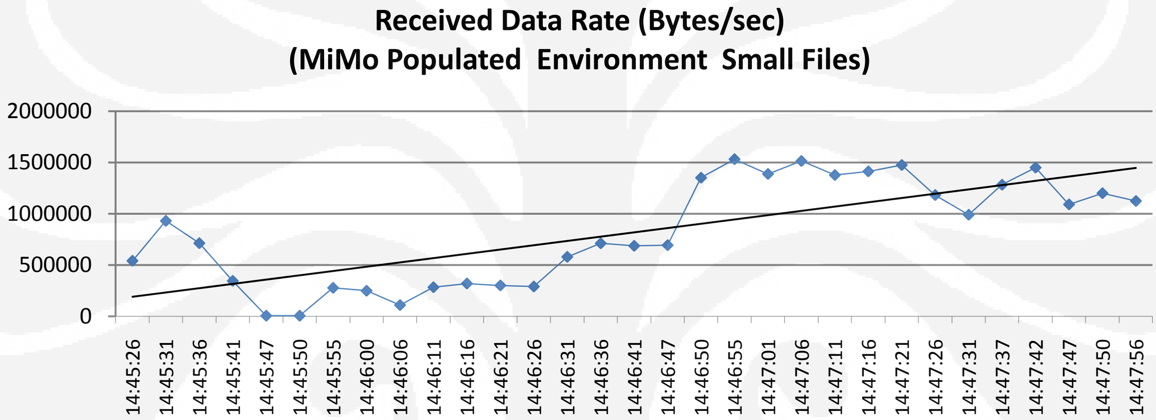


Figure 11 MIMO in populated environment data rate graph (small files)

A same pattern with the control environment is shown in the above figures. The data rate rise to potential value at the start of the connection. In the sent data rate large file graph, the data rate was sharply increased to more than 2 MB/sec then decrease to around 700 KB/sec. This incident is happened due to the effect of spatial multiplexing which increases the throughput which then fluctuates because of the interference by the surrounding activities.

The different fluctuation pattern in all the MIMO systems graphs is highly related to the unpredictable interference of the environment or in this case, movement of people. Another example shown in received data rate graphs for large file, in the middle of the connection the data rates dropped significantly to almost zero for around 7 seconds before it rise again and reach a stable rate. For small files, the trend line for both graphs shows an incline due to less presence of people than the other two tests.

4.1.2.2 SISO system in Populated Environment using WirelessMon

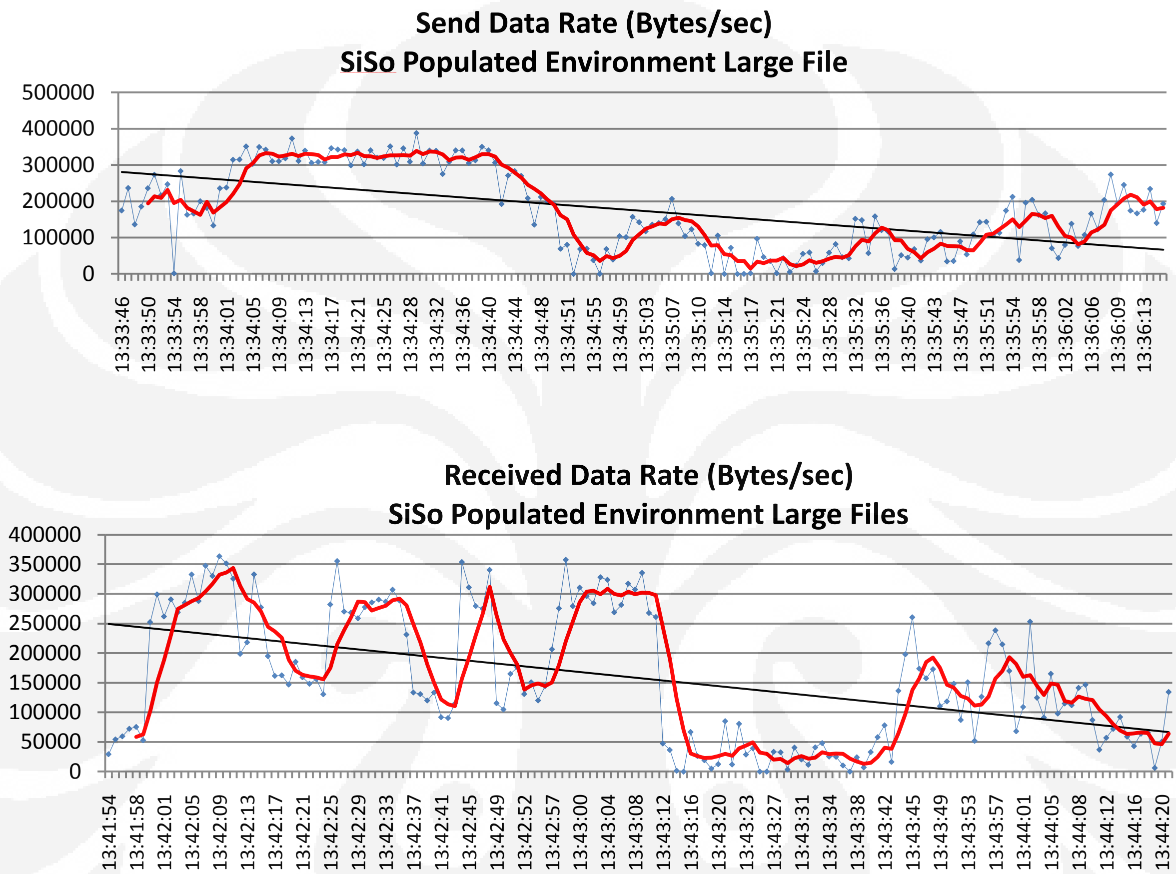
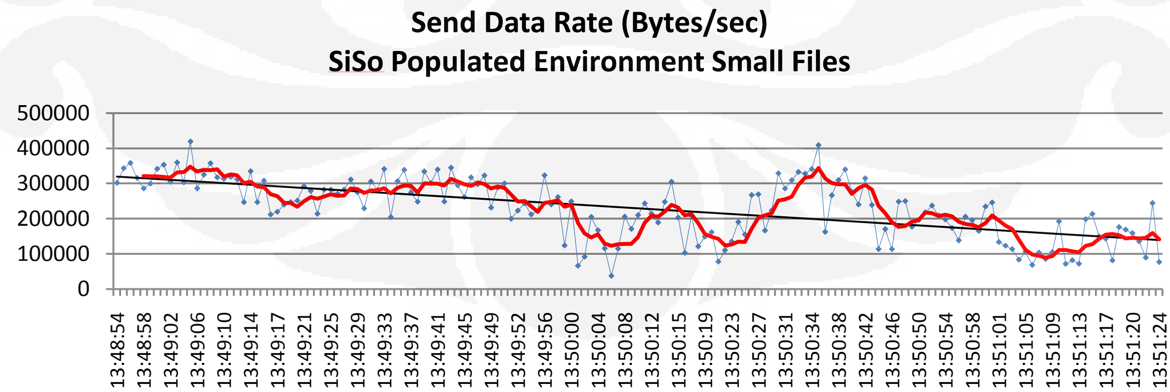


Figure 12 SISO in populated environment data rate graph (large file)



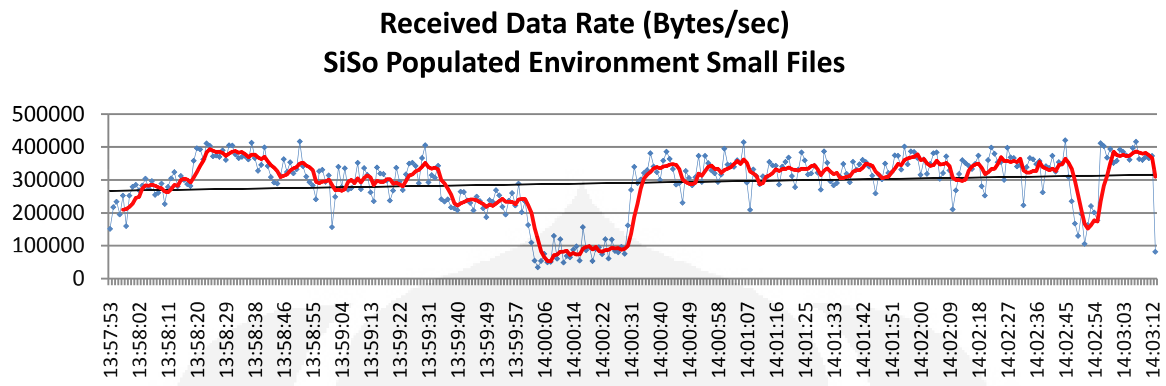


Figure 13 SISO in populated environment data rate graph (small files)

The sent data rate graph for the large file has a similar pattern with the MIMO. Although for SISO, it only reaches a peak data rate value at around 350 KB/sec. For the received data rate or upload simulation, the fluctuation is very large. It varies from 350 KB/sec down to less than 50 KB/sec, and never reaches a steady value of data rate.

For SISO small multiple files test, the result shows much small variation than the large file test. The cycle of rise and settle for each file sent is contributed to small up and down pattern. Again note that the red line is the average trend line for comparison with the MIMO system graphs due to difference number of data.

4.1.2.3 Data Rate Comparison in Populated Environment Using WirelessMon

In populated environment, MIMO system capable to reach an average of 1.3 MB/sec with a peak data rate of 2 MB/sec. The different pattern of average data rates in populated environment with the control environment is because the faster express card connection only useful when sending small files in populated environment or in other words that large files transmission is affected by the presence of people.

The results also showed that in the same given time, MIMO exhibit higher data rates than SISO. SISO also showed significantly lower data rates than control environment test. On the other hand, MIMO showed an extensive increase in data rates and also small decrease compared with the result in control environment.

Transfer Type/ Result	Send Large File	Received Large File	Send Small Files	Received Small Files
Avg. Data Rates (Bytes/s)	1,365,379	473,974.10	487,862.40	819,429.60
Total Data Sent (Bytes)	204,806,850	71,096,115	73,179,360	122,914,440
Number of Data	30	30	27	30

Transfer Type/ Result	Send Large File	Received Large File	Send Small Files	Received Small Files
Avg. Data Rates (Bytes/s)	173,433.10	159,500	224,254.50	262,218.40
Total Data Sent (Bytes)	26,014,965	23,925,000	33,638,175	39,332,760
Number of Data	159	157	162	154

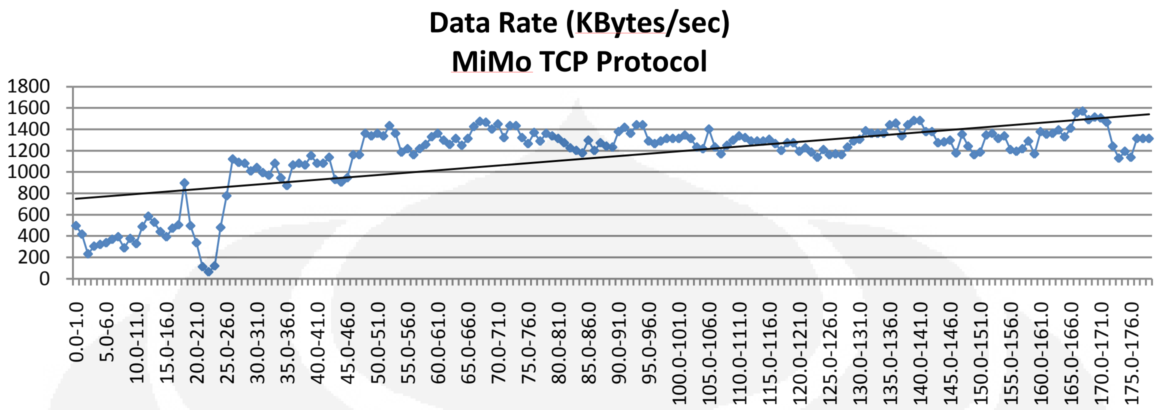
Figure 14 MIMO vs SISO data rate comparison table in populated environment

4.2 Jperf Network Measurement Tool

Jperf network measurement tool is software to measure the bandwidth and the quality of a network link using UDP and TCP test. Jperf need to be installed in both of notebooks, because one notebook must act as a client and the other act as a server. Test using Jperf only conducted in the populated environment. The result then use as comparison with the WirelessMon software.

The expected result of the test is a verification of MIMO systems performance characteristic superiority to SISO systems.

4.2.1 MIMO in Populated Environment using Jperf



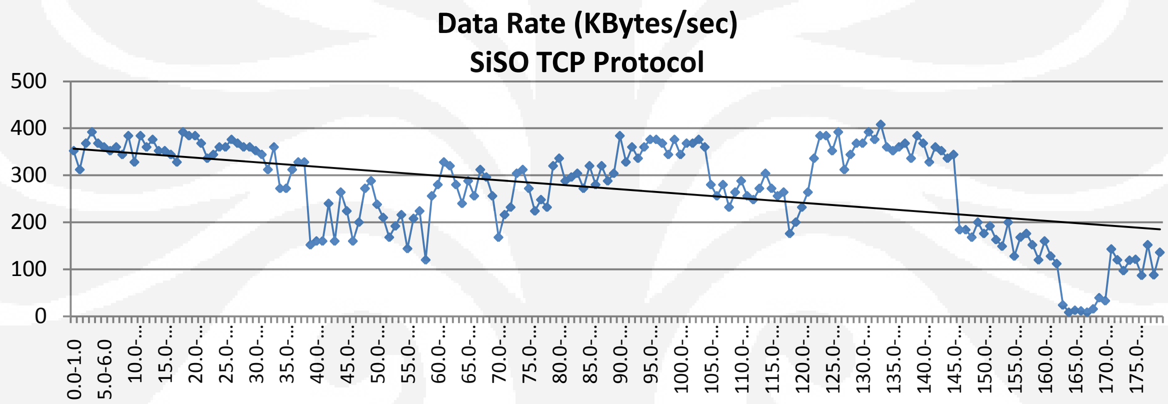


Figure 15 MIMO TCP graphs in populated environment

Differ with the result using WirelessMon, Jperf generated equal number of sample at 1 sample per second. The effect can be seen from the graph, there is no need to use an average trend line as the comparison. In addition, MIMO can reach more than 1.5 MB/sec data rate while SISO only reached 400KB/sec.

A different trend also shown from the graphs, MIMO produces more stable result than the SISO. SISO exhibit more variation in data rate down to almost zero near the end of connection.

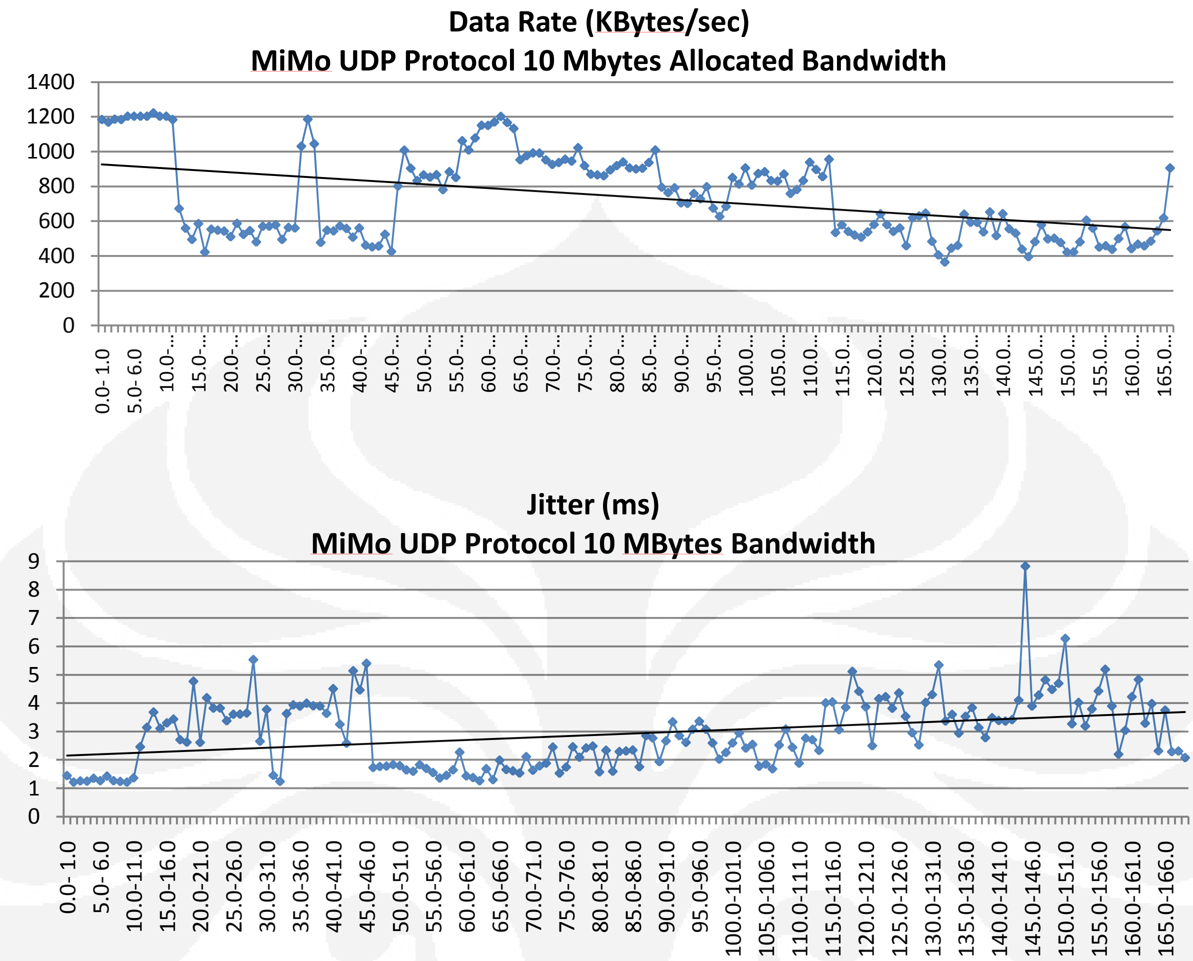
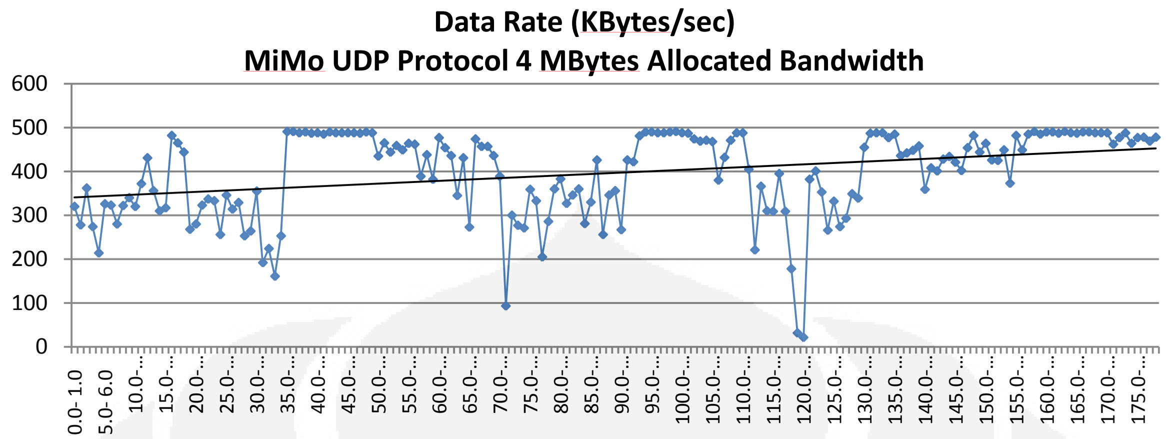


Figure 16 MIMO UDP graph with an allocate bandwidth of 10 MB

The Idea using 10 MB as the bandwidth reference was student intention to know the maximum data rate that can be achieved for both MIMO and SISO systems. The maximum data rate is around 1.2 MB/sec, while then dropped drastically to around 500 KB/sec due to the interference.

The jitter value is inversely related to the data rates. This is shown from the graph, when there is a drop in the data rate then there is increase in the jitter value. An average value of 3.9 ms jitter rate is a good value.



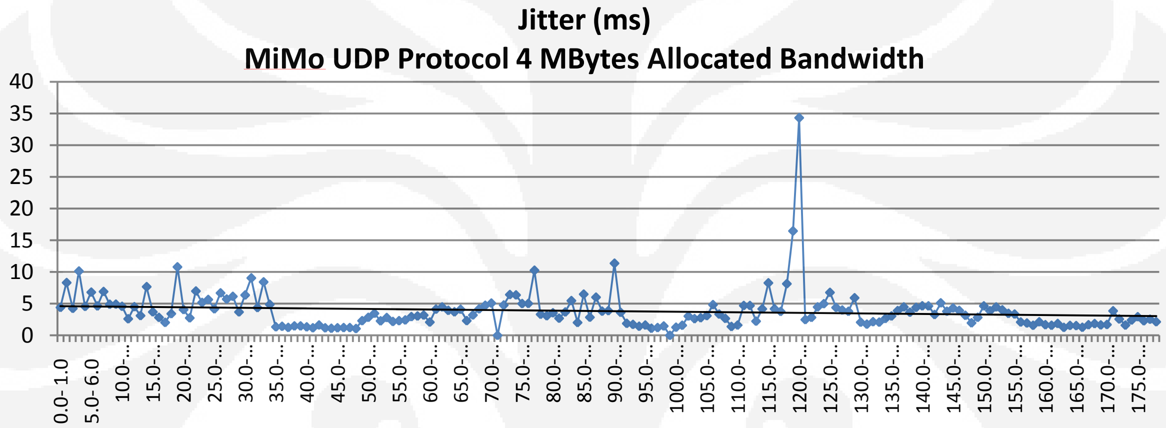
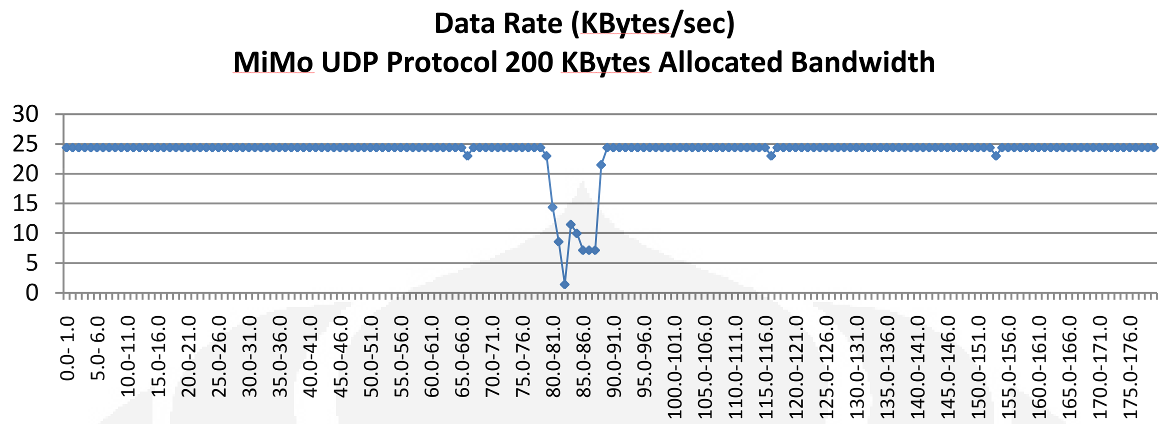


Figure 17 MIMO UDP graph with an allocation bandwidth of 4 MB

The UDP 4 MB allocated bandwidth graph shows a high number of variations. Again this is caused by the movement of people during the time of test. The highest data rate for UDP test with 4 MB allocated bandwidth is around 500 KB/sec.

The jitter value shows similar trend, drastically increase to around 35 ms when the data rate sharply decreased to almost 0 KB/sec



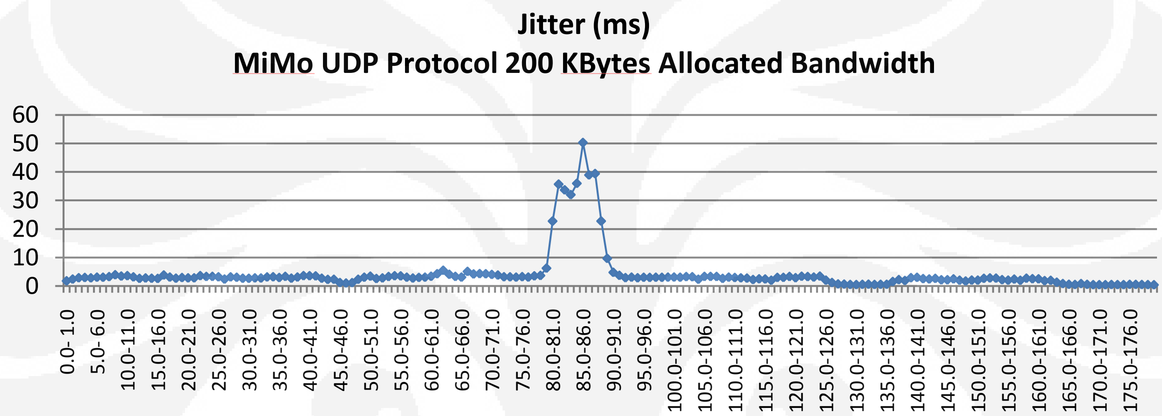
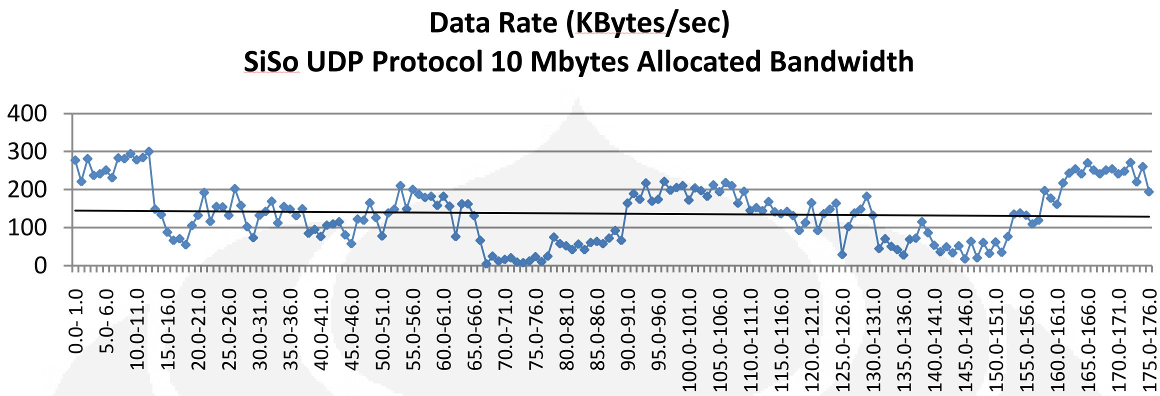


Figure 18 MIMO UDP graph with an allocated bandwidth of 200 KB

The purpose of this test is to limit the bandwidth allocated to 200 KB and check if there is any packet loss and a constant amount of data rate is achieved. The graphs shows that the maximum data rate is just at 25 KB/sec and the data rate is forced at the maximum because of the small bandwidth.

Jitter for this test showed another inversely proportional graph.

4.2.2 SISO in Populated Environment Using Jperf



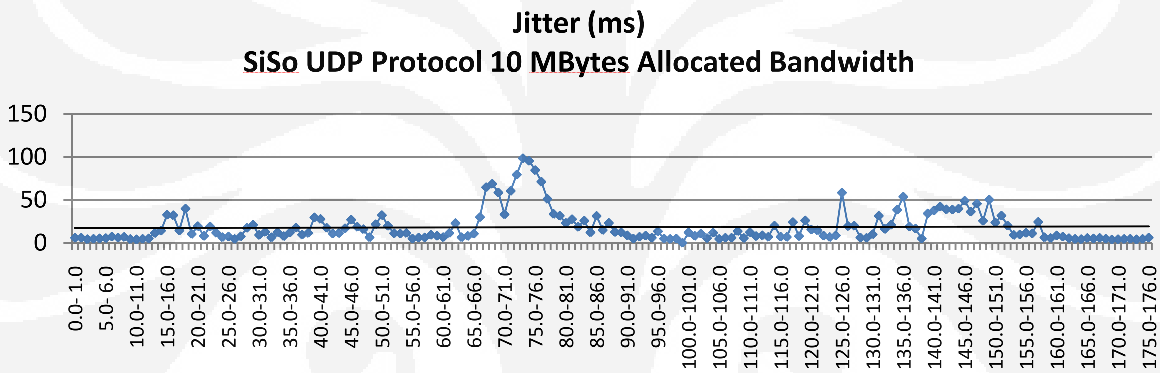
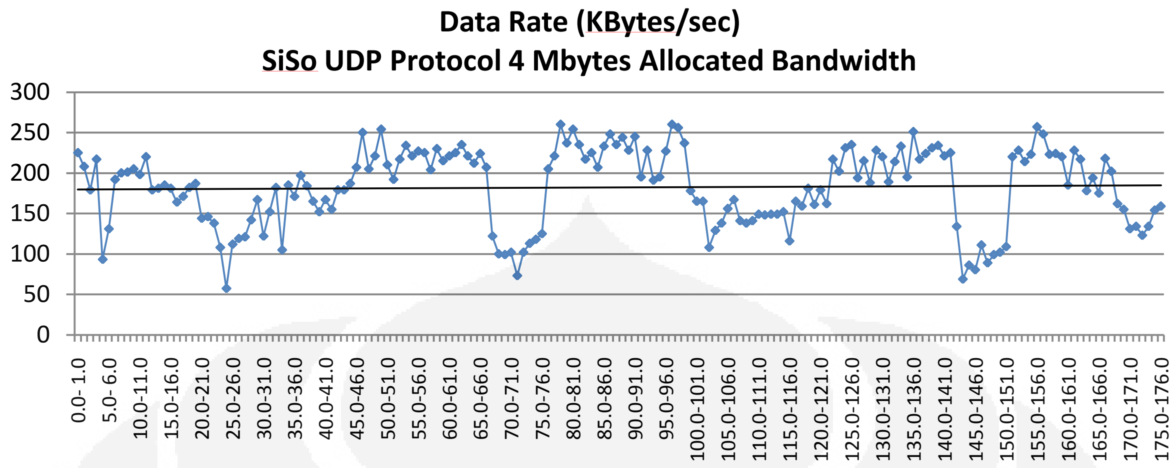


Figure 19 SISO UDP graph with an allocated bandwidth of 10 MB

From the graph it is clearly shown that the maximum data rate for 10 MB allocated bandwidth is 300 KB/sec. A decrease of fluctuation means during the connection there were not much people movement in the test area.

At the same allocated bandwidth, SISO systems exhibit 4 times lower data rate than MIMO system. Jitter value again is in inversely related to the data rate, but it consist of large value which is not very good.



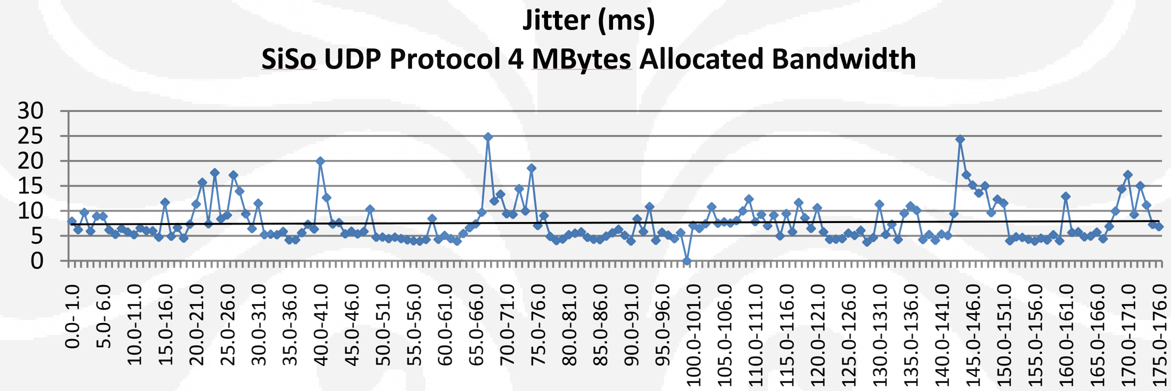
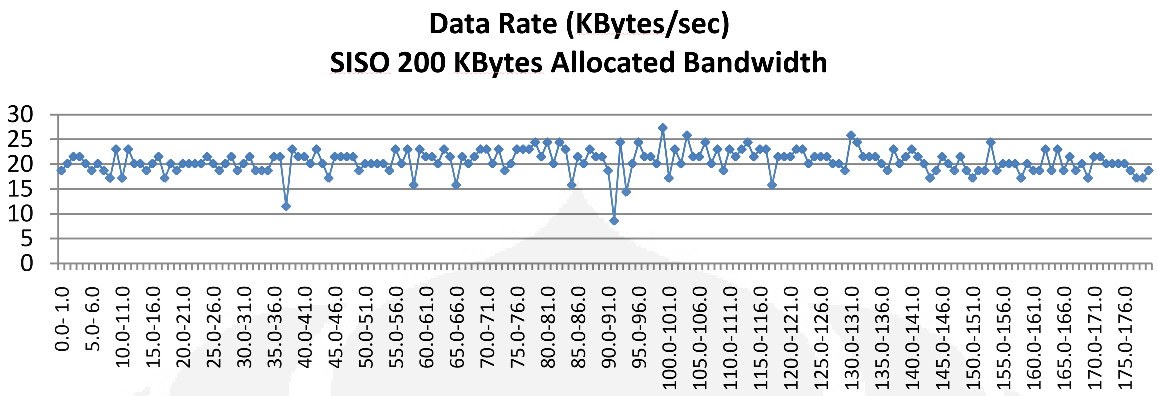


Figure 20 SISO UDP graph with an allocated bandwidth of 4 MB

The data rate graph for 4 MB UDP allocated bandwidth showed more fluctuation than the 10 MB. During the connection, the signal variability is increased because of movement of people in the test area is also increased. The maximum data rate achieved were 250 KB/sec, half of the MIMO result in the same allocated bandwidth.

Jitter showed a better result compared to the previous test at average value of 7.7 ms.



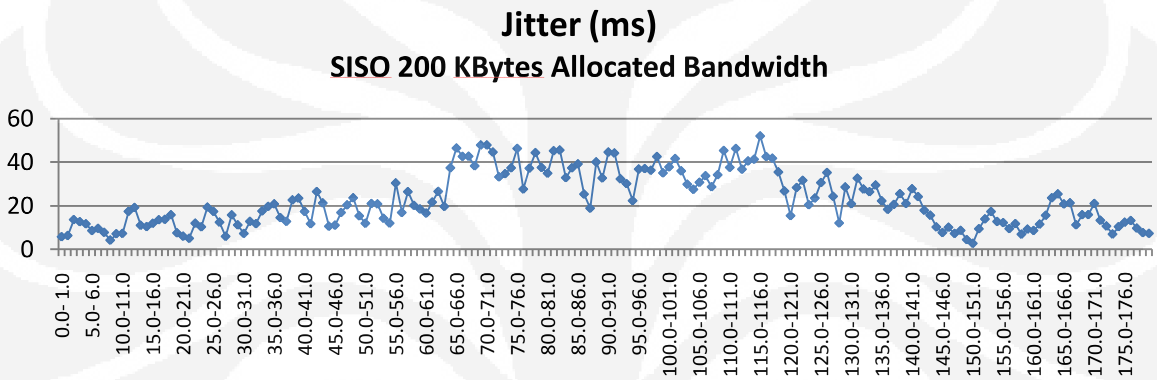


Figure 21 SISO UDP graph with an allocated bandwidth of 200 KB

Even for the 200 KB allocated bandwidth, SISO failed to generate constant maximum rate unlike MIMO. Peak data rate is recorded at 25 KB/sec and the graph shows a straight line with many rise and fall down to around 8 ms during the connection.

Jitter value for this test shows the highest number in all SISO test, with an average value of 22 ms, which considered as the worst value in the entire SISO test.

Protocol/ Result	Avg. Data Rates (Kbytes/s)	Total Data Sent (Kbytes)	Jitter (ms)
TCP	1,146	206,336	N/A
UDP 10 Mbytes	743.4	124,372	3.9
UDP 4 Mbytes	397	71,519	2.9
UDP 200 Kbytes	23.7	4,259	4.2

Protocol/ Result	Avg. Data Rates (Kbytes/s)	Total Data Sent (Kbytes)	Jitter (ms)
TCP	271	48,752	N/A
UDP 10 Mbytes	137	24,060	18.3
UDP 4 Mbytes	182	32,133	7.7
UDP 200 Kbytes	20.6	3,705	22.6

Figure 22 MIMO vs SISO average data rate comparison

The superiority of MIMO performance is clearly shown from the table above. In TCP test, MIMO outperform SISO 4 times the average data rate. All the jitter value for the MIMO systems is less than 5 ms, which is considered as a good value. Jitter value also determines the quality of the system. Number of jitter value is proportional to number of packet loss.

For the UDP SISO test, at 10 MB allocated bandwidth, the average data rate is lower than the 4 MB allocated bandwidth. This means that SISO is more vulnerable to interference than MIMO.

Chapter 5 Conclusion

MIMO (Multiple Input Multiple Output) systems technology was designed to overcome the limitation of the widely used SISO (Single Input Single Output) systems. The idea is to achieve better performance characteristic in real world environment. Improvement of data rate performance is essential to identify the superiority of MIMO since it is one of the key aspects of wireless networking activities. This project aimed to support that idea by simulating and observing the performance of MIMO in real world environment.

The result of the simulation and test is clearly shown that MIMO systems outperform SISO systems in terms of data rate and jitter, in both TCP and UDP protocols. Student use two network measurement software as a comparison to support the verification and both of them showed the expected results. One of the key aspects to consider is the limited computing or processing power used in MIMO systems due to the complex algorithm. This result in different number of sample taken at the given time compared to SISO systems.

Student believes that for any populated environment with different obstacles or different movement of people, MIMO will perform satisfactory than the SISO. The improvement of wireless network services is never going to stop. In the future MIMO will play an important role to many kind of wireless network application.

References

http://www.ieee.li/pdf/viewgraphs/wireless_mimo.pdf

http://www.cwc.oulu.fi/nrs04/slides/mimo_diversity.pdf

http://www.commsdesign.com/design_corner/showArticle.jhtml?articleID=16506164

http://en.wikipedia.org/wiki/Multipath_fading

http://en.wikipedia.org/wiki/MIMO

http://en.wikipedia.org/wiki/Spatial_multiplexing

Schindler, S, *Introduction to MIMO Systems*, Rohde and Schwarz. June 2006

Winston Sun, Ph.D, *MIMO Architecture The Power of 3*, Atheros Communication. May 2006

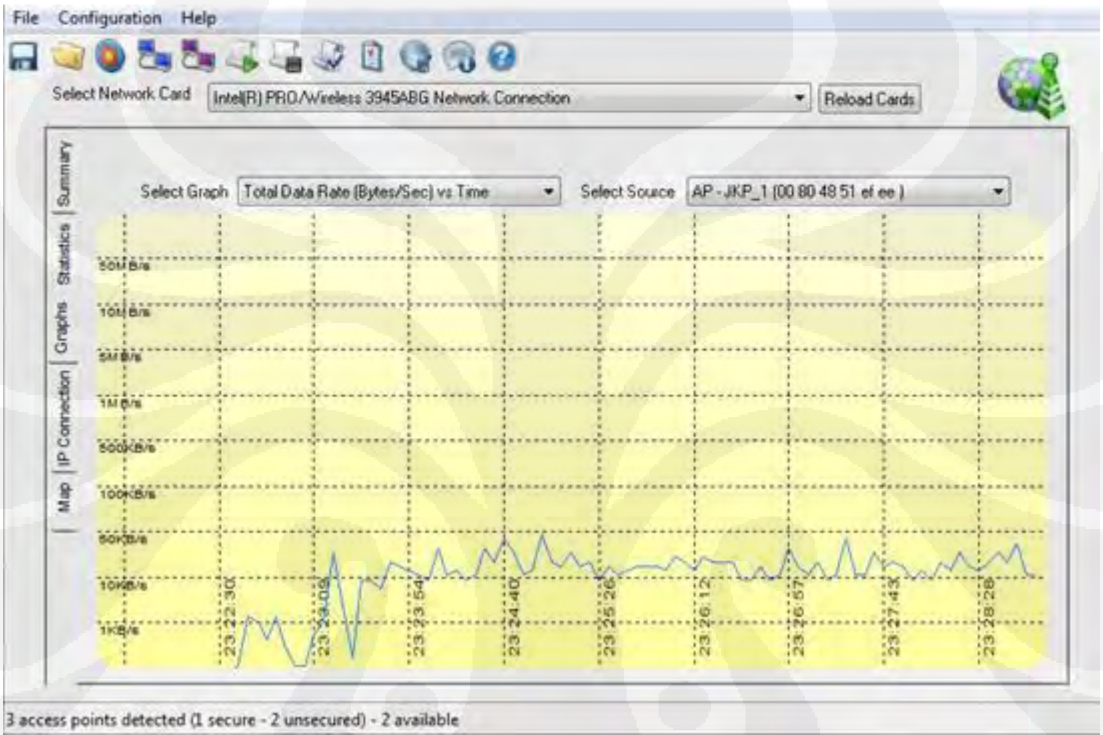
Winston Sun, Ph.D, *Maximizing MIMO Effectiveness by Multiplying WLAN Radios x3*, Atheros Communication. May 2006

Appendix I

Picture of Test Site, Myer Centre Food Court

Appendix II

WirelessMon Interface



Jperf Interface