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PERFORMANCE CHARACTERIZATION OF MIMO IN POPULATED ENVIRONMENT

SKRIPSI

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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.

Table of Contents

1. Introduction 1

2 Background Theory 2

2.1 Spatial Multiplexing 3

2.2 Spatial Diversity 4

2.3 Multipath Propagation 5

3. Test Procedures and Parameters 6

3.1 Test Equipments 7

3.2 Test Procedure 8

3.2.1 Test Using WirelessMon 9

3.2.2 Test Using JPerf 10

4. Test Results and Analysis 11

4.1 Control Environment 11

4.2 Populated Environment 16

4.2.1 WirelessMon Wireless Diagnostic Software 16

4.2.2 JPerf Network Measurement Graphical Tool 21

5. Conclusion 29

APPENDIX I Linksys WPC100 Data Sheet

APPENDIX II D-Link DWA643 Data Sheet

List of Figures

Figure 1 Array of antenna in MIMO 3

Figure 2 channel capacity improvement 3

Figure 3 Multi-Channel Wireless Telecommunication 3

Figure 4 Receiver Diversity 4

Figure 5 Myer Centre Food Court 6

Figure 6 Test Diagram 7

Figure 7 Linksys WPC300N and D-Link DWA-643 MiMo Notebook Adapter 8

Figure 8 WirelessMon Wireless Diagnostic Software Interface 10

Figure 9 Jperf Network Measurement Graphical Tool Interface 10

Figure 10 MIMO in control environment (large file) 11

Figure 11 MIMO in control environment (small files) 12

Figure 12 SISO in control environment (large file) 13

Figure 13 SISO in control environment (small files) 14

Figure 14 MIMO in populated environment (large file) 16

Figure 15 MIMO in populated environment (small files) 17

Figure 16 SISO in populated environment (large file) 18

Figure 17 SISO in populated environment (small files) 19

Figure 18 TCP protocol in populated environment 21

Figure 19 MIMO UDP protocol with 10 MB allocated bandwidth 22

Figure 20 MIMO UDP protocol with 4 MB allocated bandwidth 23

Figure 21 MIMO UDP protocol with 200 KB allocated bandwidth 24

Figure 22 SISO UDP protocol with 10 MB allocated bandwidth 25

Figure 23 SISO UDP protocol with 4 MB allocated bandwidth 26

Figure 24 SISO UDP protocol with 200 KB allocated bandwidth 27

List of Tables

Table 1 MIMO and SISO in Control Environment 15

Table 2 Populated Environment Test Using WirelessMon 20

Table 3 Populated Environment Test Using JPerf 28

1. Introduction

This project aimed to characterize the performance of MIMO (Multiple Input Multiple Output) technology in populated environment. MIMO introduce new possibilities in wireless networking by promising higher capacity and reliability compared to non MIMO or SISO (Single Input Single Output) technology.

1.1 Objective

The aim of this project is achieved by the process of comparing the performance MIMO and SISO in populated environment. Performance characterization of MIMO in populated environment was based on this process of comparison. This comparison was based on several test designed to observe the performance and working of each MIMO and SISO technology

MIMO technology was represented by the new draft IEEE 802.11n and SISO of course was represented by IEEE 802.11g standard. 2 IEEE 802.11g equipped laptops and widely available draft IEEE 802.11n network card were to become the primary hardware of the test. Appropriate network diagnostic and monitoring software were the utilized to record data rate of each test since data rate was the main measurements of the comparison.

1.2 Expected Result and Limitations

This project expected for MIMO to exhibit higher data rate than SISO in populated environment chosen for the test. This will prove that MIMO is superior and more reliable than SISO. Test at control/unpopulated environment should become the basis of comparison for the test.

Because of the random aspects of the interferences presents in the populated environment, unexpected results that are did not confirm with control environment as the basis of comparison were exhibited. Results from populated environment test are largely dependent on the condition of the test site. Random people movement while presenting a real world environment condition also pose a somewhat uncertainty in analysis and conclusion.

2. Background Theory

Multiple Inputs, Multiple Outputs (MIMO) technology is a wireless technology that uses multiple transmitters and receivers to transfer more data at the same time. MIMO technology uses the concept of multipath propagation where transmitted information bounces off walls, ceilings, people, and other objects, reaching the receiving antenna multiple times via different angles and at slightly different times. Older SISO technology consider multipath as a loss where it actually reduce the quality of the received signal itself.

Figure 1 Array of antenna in MIMO

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.

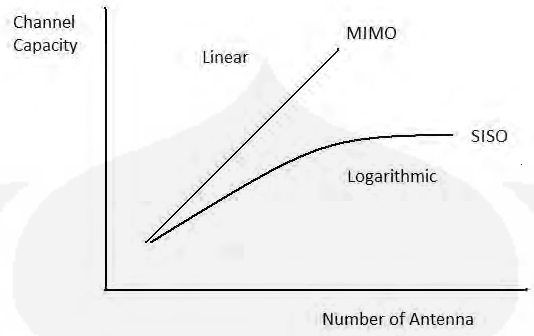


Figure 2 channel capacity improvement

Although higher number of antenna means higher capacity, the cost factor should also be factored. The cost of the system will increase exponentially with the number of the antenna. Atheros Communications white paper written by Winston Sun, Ph.D. in 2006, and "Maximizing MIMO Effectiveness by Multiplying WLAN Radios x3" described that the best trade of between cost and number of antenna comes from 3 by 3 as in 3 transmitters and 3 receiver configuration.

In general MIMO presented with 3 important features that gives MIMO its advantages. These features are spatial multiplexing, spatial diversity, and multipath propagation.

2.1 Spatial Multiplexing

Spatial multiplexing can be defined as the process of multiplexing (divide) where a data stream is transmitted several branches and several (independent) channels in space. In other word spatial multiplexing enables MIMO to transmit more than one data streams at more than one antenna.

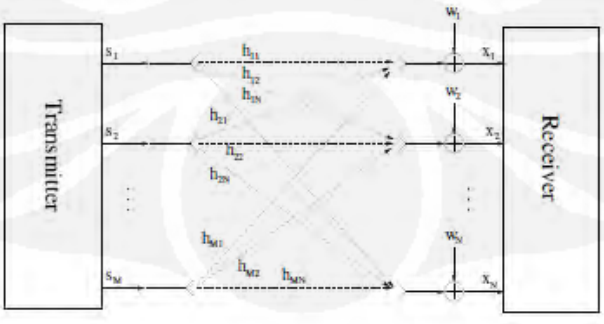


Figure 3 Multi-Channel Wireless Telecommunication

Spatial multiplexing uses Space Time Code to transmit each of the independent data streams over different channels. Higher capacity gain is achieved with spatial multiplexing, at the expense of 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 via space. Spatial diversity consists of receiver diversity and transmitter diversity.

At receiver diversity, several signal received will be combined at the receiver. The same signal is received by different antenna and are evaluated and combined at the receiver side. The advantage of receiver diversity is that quality of signal received will be improved by the combining process. There are several combining techniques for receiver diversity, selection combining (SC), equal gain combining (EGC), and maximum ratio combining (MRC).

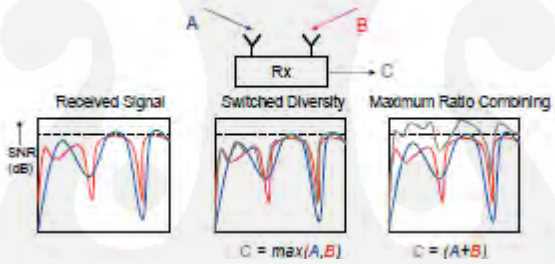


Figure 4 Receiver Diversity

Transmitter diversity means the signal is transmitted via multiple independent channels. This technique is hoped to improve the error performance of the signal since more signal are transmitted means the likelihood of an error or signal lost is decreased.

Spatial diversity unlike spatial multiplexing will not increase bandwidth, but will decrease error. An efficient balancing between the use of spatial multiplexing and spatial diversity will produce a robust and reliable Multi-Channel telecommunications. These 2 aspects are vital for the development of MIMO technology.

2.3 Multipath Propagation

Multipath propagation is the phenomenon when signal received by the antenna comes from multiple paths. This happens because of the presence of interferences or obstacles at the signal path. SISO regards multipath propagation as loss or some form of interference.

MIMO divide a data stream into multiple substreams and then use an array of transmitting antennas to simultaneously transmit the streams into the same channel, thus increasing the data capacity of a channel. Multiple data streams that will interfere with each other in SISO are actually used to enhance the quality and capacity of the signal in MIMO.

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.

3. Test Procedures and Parameters

Basically the test procedure involved 2 laptops in ad-hoc connection that made to send data to each other. Widely available Draft IEEE 802.11n Cards are used for MIMO test and the laptops built in network cards (IEEE 802.11g) are used for SISO. Appropriate network monitoring and diagnostic software then utilized to conduct the test.

Requirement for the test site is that it is a populated environment with substantial people movements. This will ensure the tests to be as close as possible to real world environment. With regards to this requirement Myer Centre Food Court at Brisbane CBD, Australia is chosen as the test site. Being a food court this site will present considerable populated environment at lunch hour, thus a perfect spot.

Figure 5 Myer Centre Food Court

Tests commenced at two site conditions, control and populated. With the test conducted at the same site but with empty/unpopulated condition, results from control test are hoped to be free from interference that are present at the populated environment; this result then used as a comparison for the analysis.

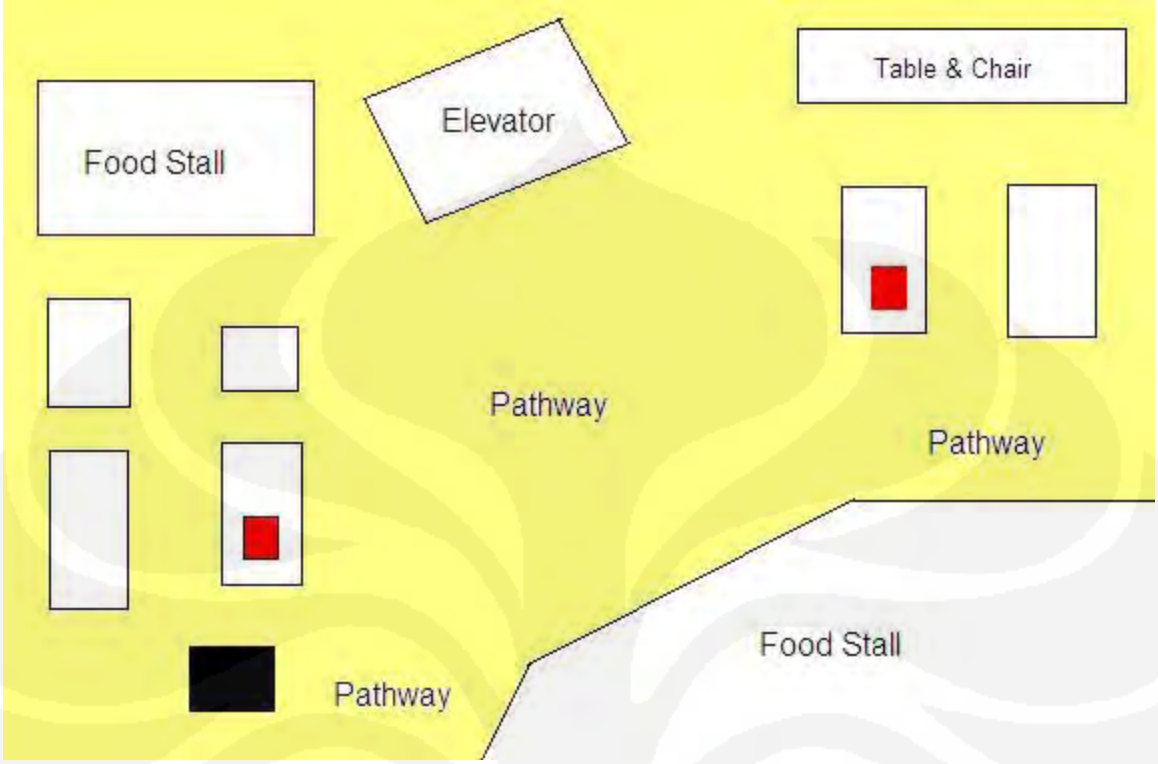


Figure 6 Test Diagram

Diagram above pictures the configuration for the test. The red rectangular shape is the positions of each laptop. People constantly passed by the pathway, thus contributing interferences between the 2 laptops. The reliability, resistance to interference, and overall functionality of each system at this environment are the aspects that hoped to be determined by this test.

3.1 Test Equipments

3.1.1 Hardware

Laptops that are used in this test are Sony VAIO VGN-SZ483N Notebook and HP mini 2140 Notebook and both laptops have IEEE 802.11g standard built in network card installed. These laptops should represent consumer laptops that are commonly available in the market today.

Linksys WPC300N and D-Link DWA-643 MiMo Notebook Adapter are the network cards used in MIMO test. The need for 2 different brands is due to the

difference in the PCI slot at each laptop. Sony VAIO still equipped with the old standard Card Bus slot while the newer HP mini is equipped with the Express Card Slot.

Figure 7 Linksys WPC300N and D-Link DWA-643 MiMo Notebook Adapter

Other equipments used in the test are Sony-Ericsson camera phone and Nikon digital camera for documentary purpose.

3.1.2 Software

Softwares used in the test are FileZilla FTP Client and Server, WirelessMon Wireless Diagnostic Software, and Jperf Network Measurement Graphical Tool. File/data exchange between the two laptops is set by FileZilla while test monitoring and diagnosing are handled by WirelessMon and JPerf.

Both monitoring softwares are configured to measure data rate and total data exchanged for each test. Jitter in millisecond at UDP protocol test can be recorded with JPerf. Raw data then compiled and made into graph using Excel.

3.2 Test Procedure

Basic outline of the test is divided by 2, using WirelessMon and JPerf. FileZilla can only exchanged data, because of that WirelessMon is needed as the monitoring software. JPerf on the other hand is capable of both tasks. Each test procedures outlined below was enacted identically for both MIMO and SISO. Both monitoring software were set to record at their maximum sampling rate, 10 samples at a second for WirelessMon and 1 sample at a second for JPerf.

3.2.1Test Using WirelessMon

Two laptops were set up as ad-hoc connection with approximate distance of 6 meters. Files then exchanged using FileZilla software between two laptops to simulate upload and download. WirelessMon actively monitored and recorded the data from the test. There are 2 types of data exchanged using FileZilla, 1 large file and several small files.

One of the laptop assigned as a server, and the other laptop were the client. First the client will download data from server as the send data test. Next client will upload data to server or received data test. Both tests are done with 2 types of file, a large file with 700MB size and several small files at 3MB each. Each test was set to last for 5 minutes or 300 seconds. WirelessMon Software functioned to monitor and record total data rate and total data exchanged at the tests.

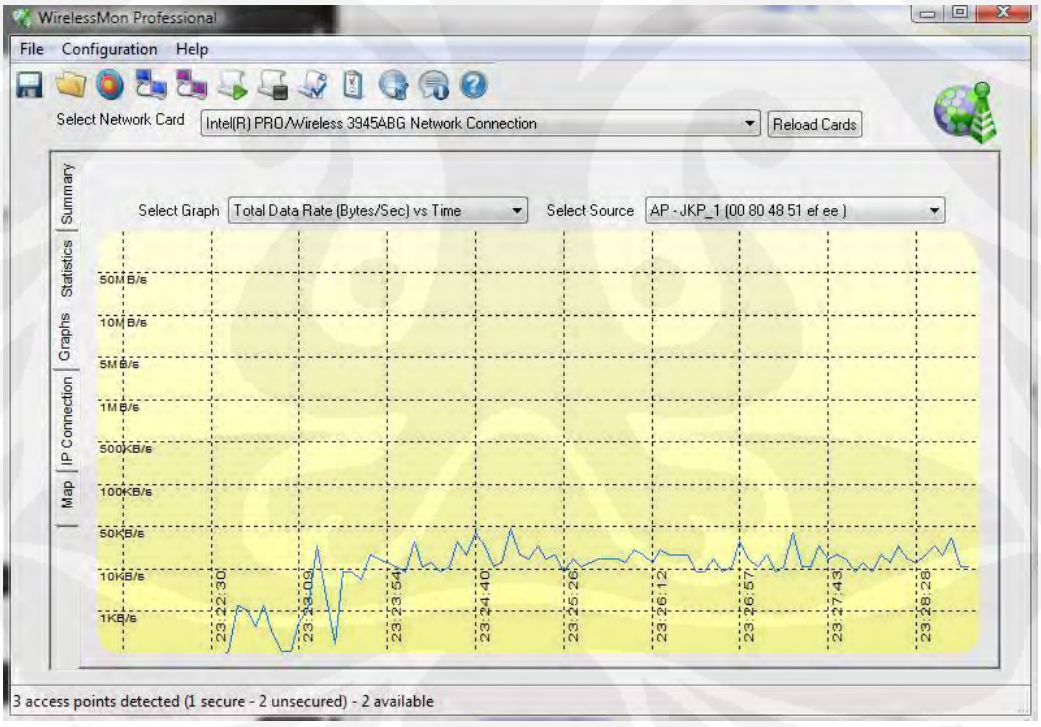


Figure 8 WirelessMon Wireless Diagnostic Software Interface

There were a total of 16 tests with WirelessMon, each for MIMO and SISO at control and populated environment with large file and small files while sending and receiving data.

3.2.2Test Using JPerf

As with the test using WirelessMon, Two laptops were set up as ad-hoc connection with approximate distance of 6 meters. JPerf handled the data exchange and monitoring and recording by itself unlike previous where it needs 2 separate softwares. With JPerf there were 2 protocols that are tested, TCP and UDP. This software also permits user to allocate specific bandwidth for UDP protocol test.

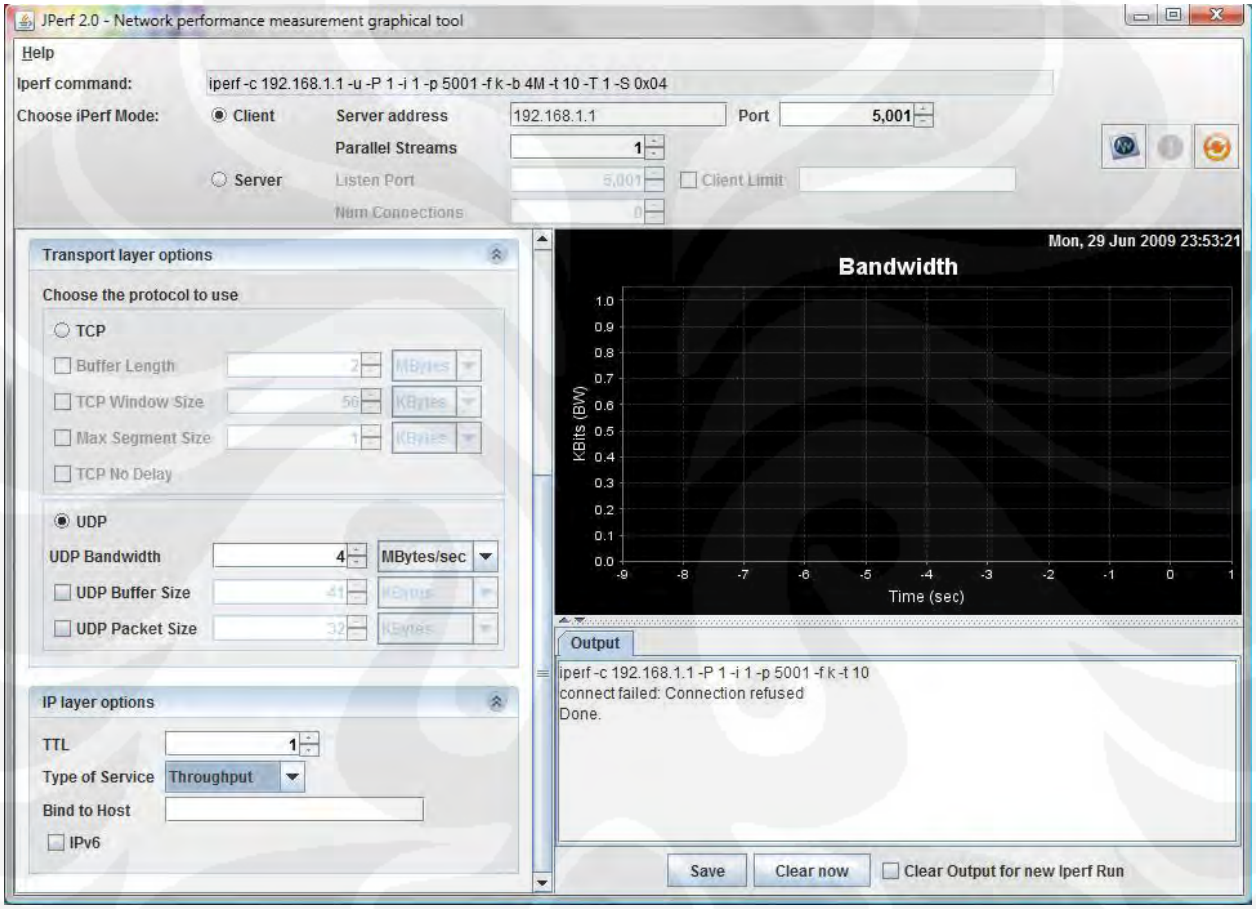


Figure 9 Jperf Network Measurement Graphical Tool Interface

One laptop acted as server and the other one as client, both need to be installed with JPerf. For TCP protocol test JPerf was set to run at its default configuration, test duration was 300 seconds. JPerf then recorded the total data rate and total data exchanged for each test.

UDP protocol tests required 3 different allocated bandwidths, 10MB, 4MB and 200KB with duration also at 300 seconds. Only populated environment is evaluated at this test with JPerf. There are a total of 14 tests at this test section

4. Test Results and Analysis

The results of the test are compiled into specific graphs. There are a total of 8 graphs for test control environment and 22 graphs for populated environment. Graphs from control environment are divided in pairs based on the size of file parameter, large and small with results from MIMO displayed first. Below is the graph from MIMO in control environment test results using WirelessMon.

4.1 Control Environment

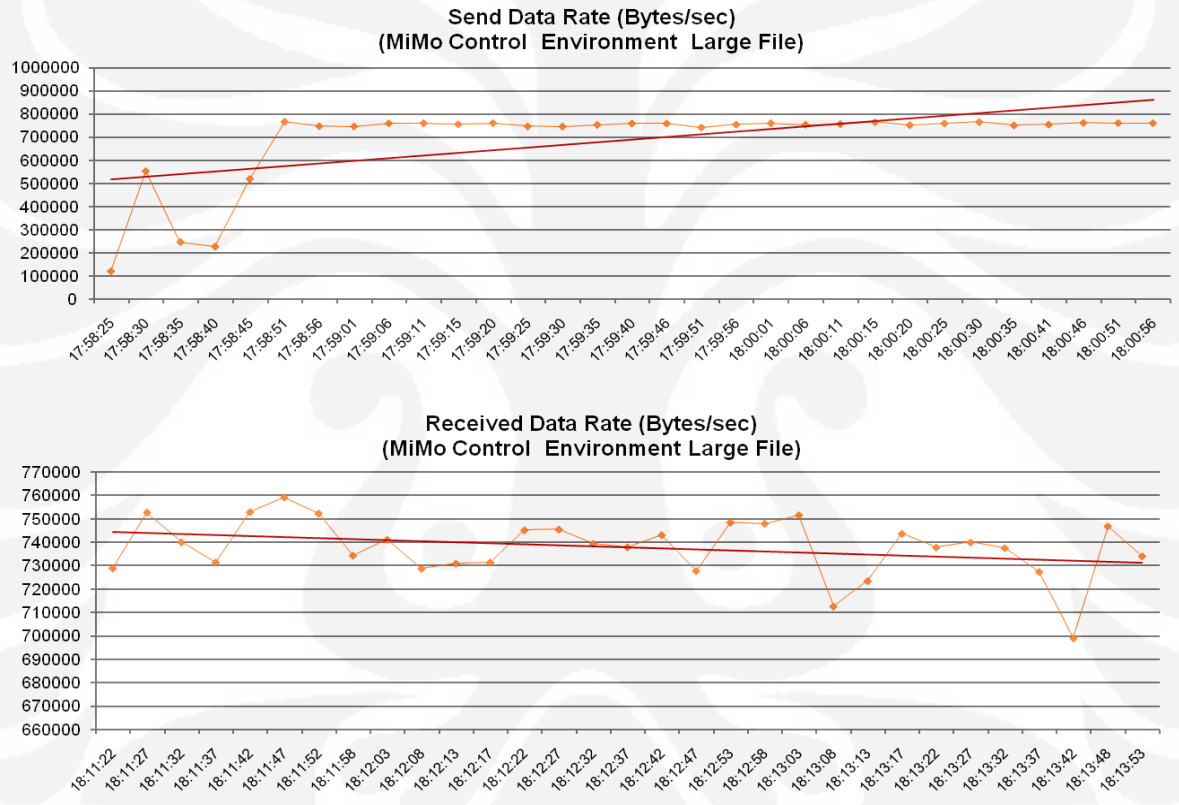


Figure 10 MIMO in control environment (large file)

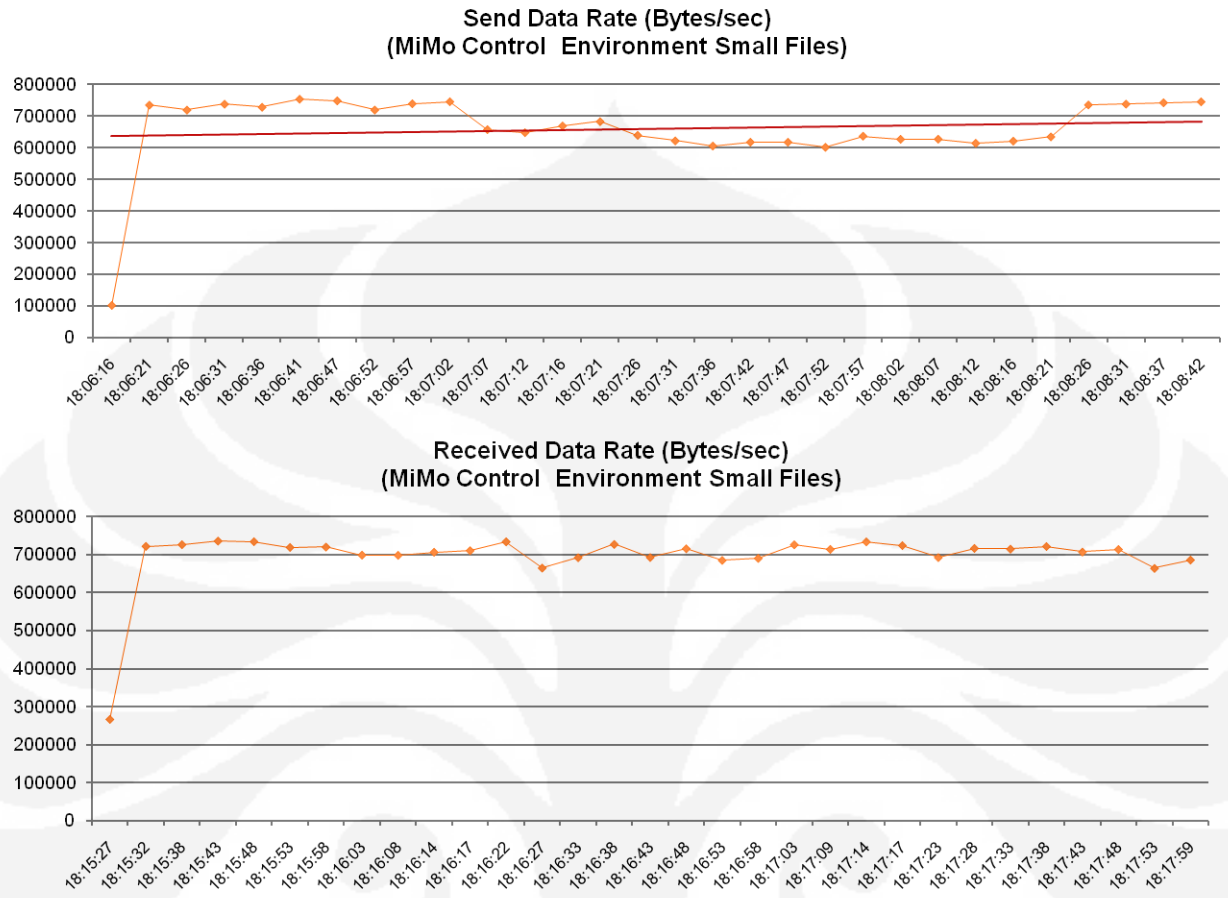


Figure 11 MIMO in control environment (small files)

All the graphs followed an expected pattern of rising at beginning to reach potential value and stay stable with little fluctuation until the connection broke off. An anomaly at the graph for received data rate where more fluctuation existed is due to unexpected interference at control environment test site.

Overall MIMO at control environment exhibited an average of 700KBps data rates both for 1 large file and several small files that are used for the test. For small files test, more fluctuations were originally expected because the system needed to start over in sending the data for each file that are present. The cycle of rise then settle should repeat for each files sent unlike large file test where the data rates rise at the beginning then settled at potential value for the rest of the test.

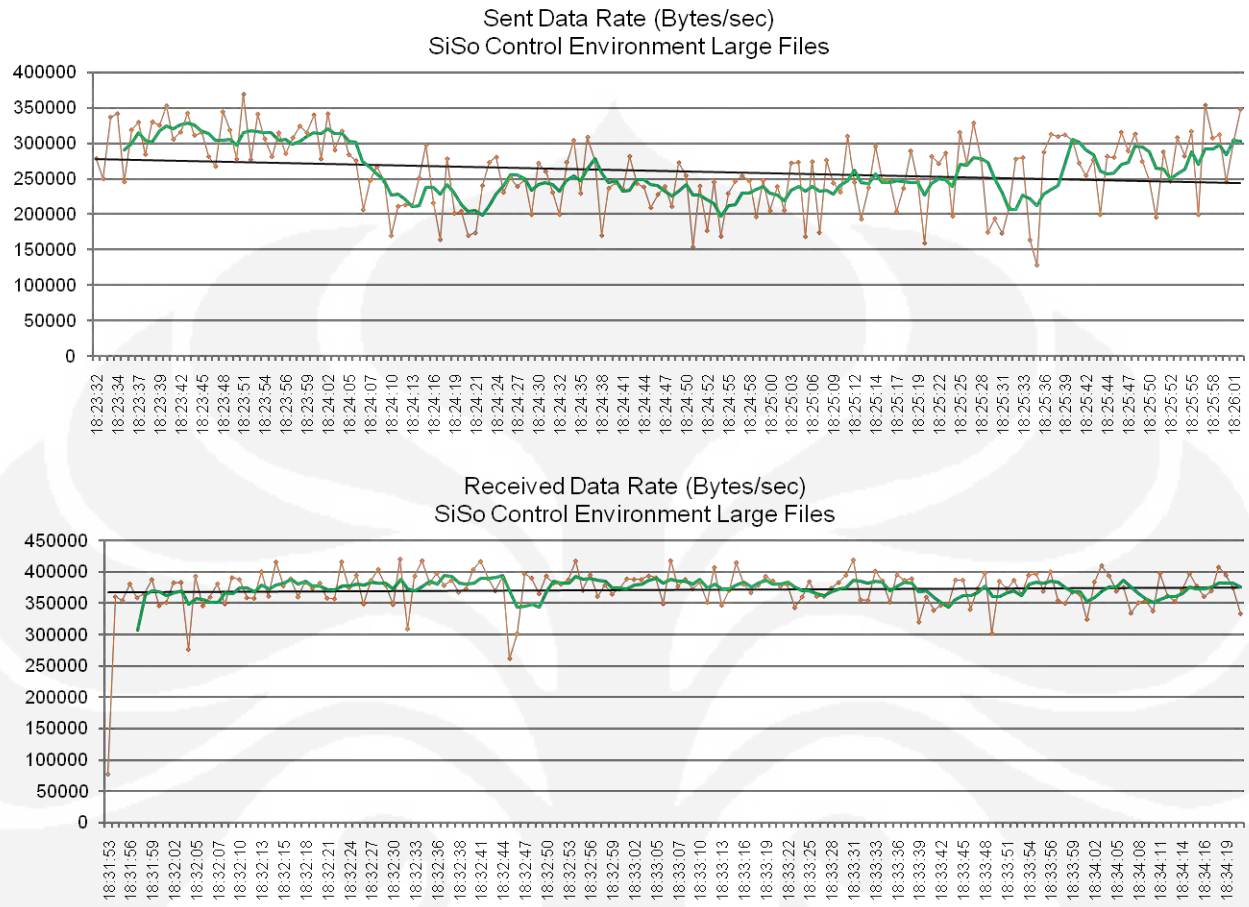


Figure 12 SISO in control environment (large file)

Results from SISO at control environment are similar to MIMO. Because SISO produced more samples per second then MIMO due to the limitation in computation power, averaging trend line were present to simplify the comparison between them. This trend line should equate the two results together and further analysis will be based on this trend line.

Result from received data rate was the most similar from the results form MIMO. Rise at the beginning the settled at the system potential value. Some fluctuation present although overall it is quite stable.

Send data rate presented more fluctuation. Average data rate for this test showed consistent result at around 260KBps so this anomaly could be caused by unexpected interference at the test environment.

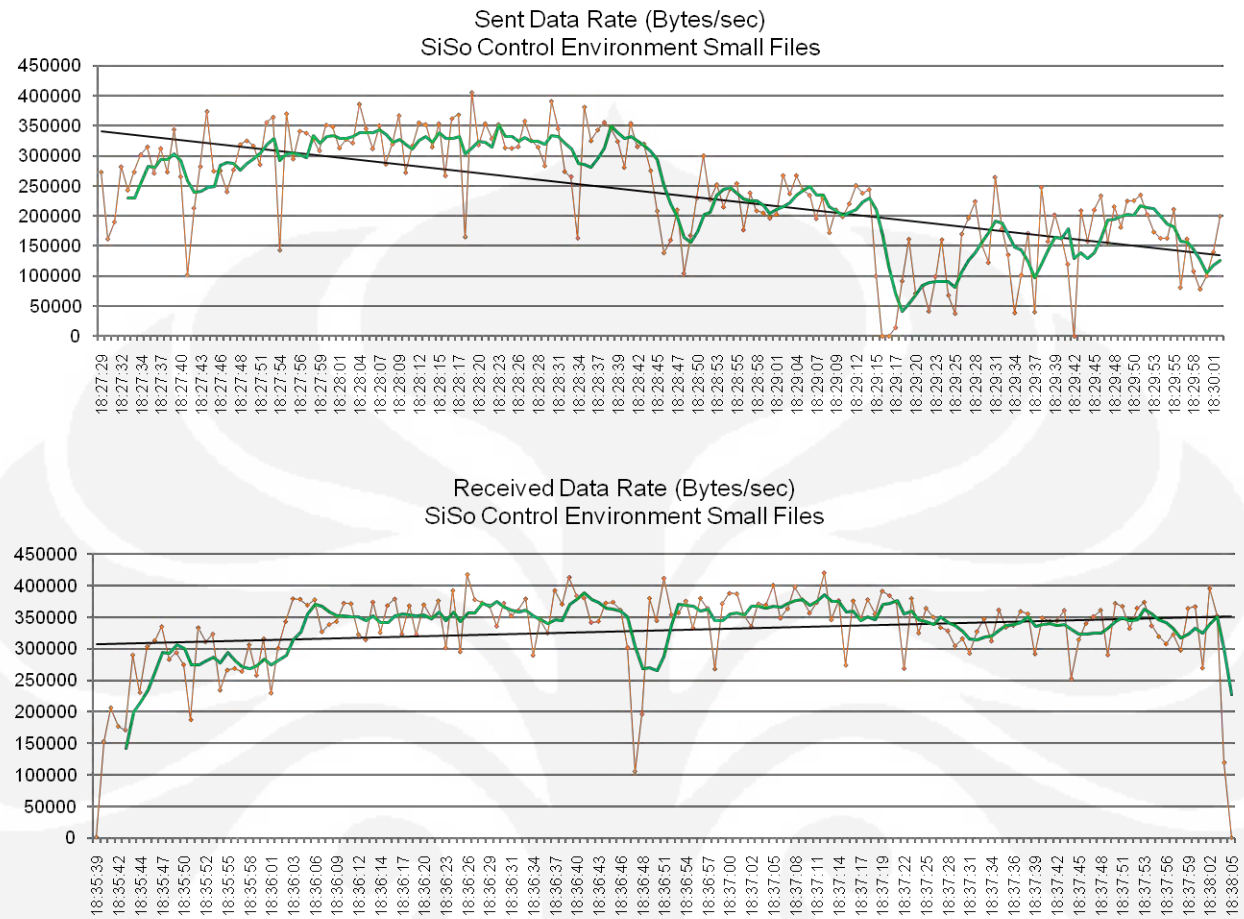


Figure 13 SISO in control environment (small files)

As mentioned before, more fluctuations in data rate were expected for small files test due to the behavior of the system to repeat rise and settle cycle for every files. Send data rate once again showed more fluctuation and lower average data rate then received data rate. At one point data rate even drop to 100KB/s although the average is still around 240KBps.

Received data rate exhibited again very similar to result from MIMO. Rising data rate before settled at potential value. Data rate was mostly stable with average of 330KBps.

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

Table 1 MIMO and SISO in Control Environment

Result from all test showed that the average values from received data rate are higher although not significant compared to send data rate average value. For MIMO, this could be from the higher performance of the MIMO network card used for that section of the test. The card utilizes newer and theoretically faster express card connection.

SISO produced 5 times more samples than MIMO. This is true for the rest of the test due to more computation power was needed to solve the more complex algorithm from MIMO. By utilizing an averaging trend line for the graph, more accurate comparison between SISO and MIMO despite the different number of samples produced was expected.

4.2 Populated Environment

4.2.1 WirelessMon Wireless Diagnostic Software

4.2.1.1 MIMO

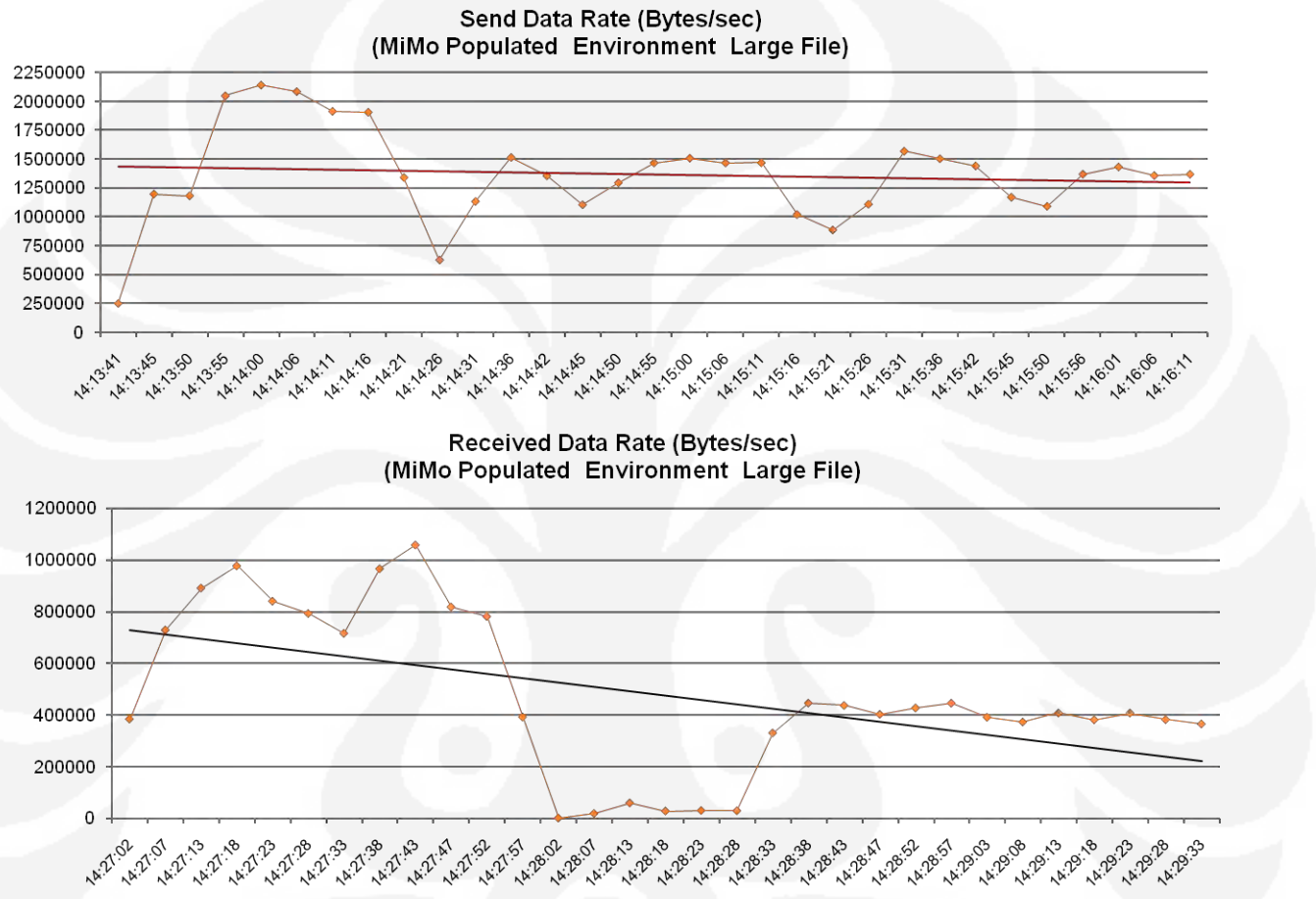


Figure 14 MIMO in populated environment (large file)

As with the control environment test, data rate rise at the beginning to the potential value. Send data rate even zoomed up to more than 2 Mbps before dived down, and then rise again before finally settling down.

Received data rate followed similar pattern, although at the middle data rates dropped significantly to almost zero for around 7 seconds it rise again before finally settling down at a stable rate. Data showed around 473Kbps of average data rates.

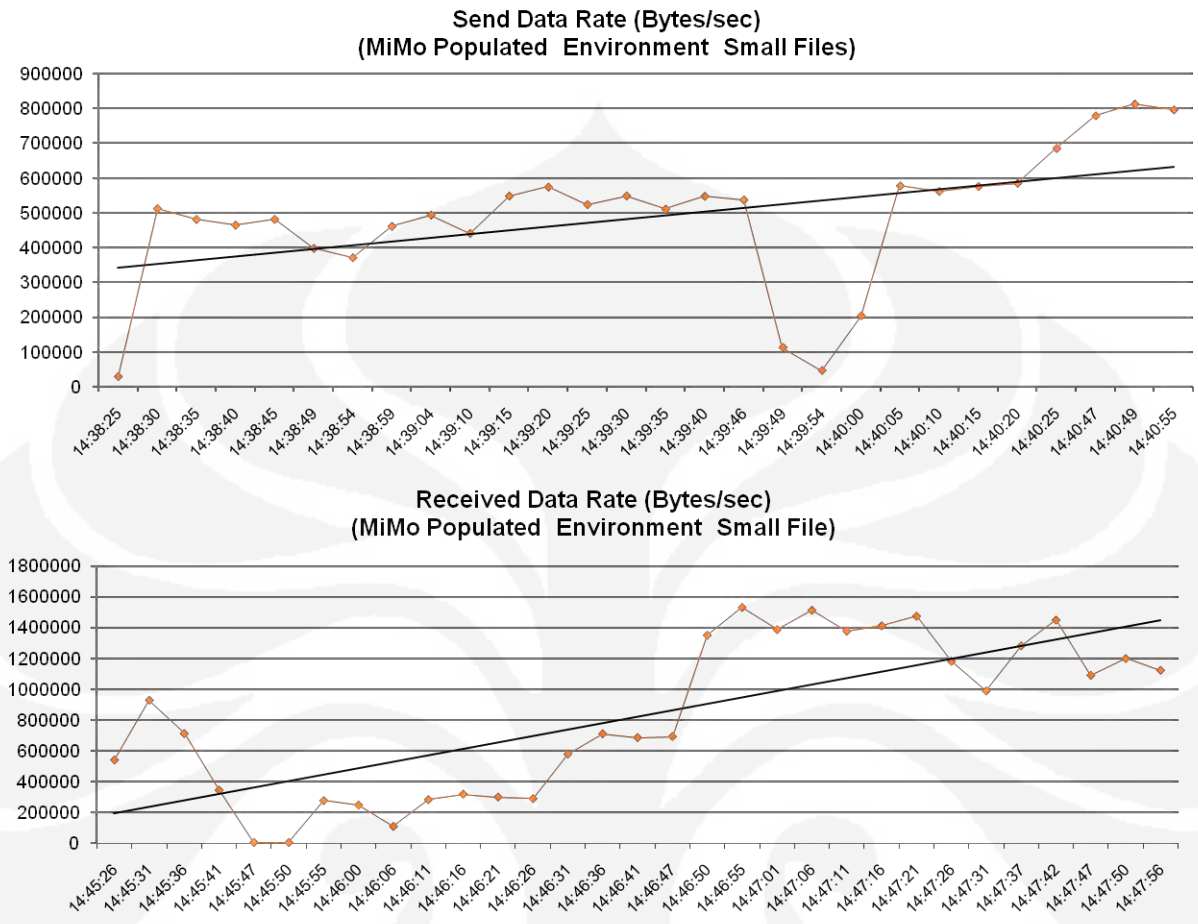


Figure 15 MIMO in populated environment (small files)

Send data rate follow similar pattern of rise then settled. Data rates dropped down quite significantly before rising and settling down again. There is no anomaly or specific concern regarding send data rate graph. Average data rates was calculated at around 487 Kbps

Received data rate starts at somewhat low values, but finally able to rise and settled. Both trend lines for both graphs showed an incline. Average data rates was calculated at around 817 Kbps.

4.2.1.2 SISO

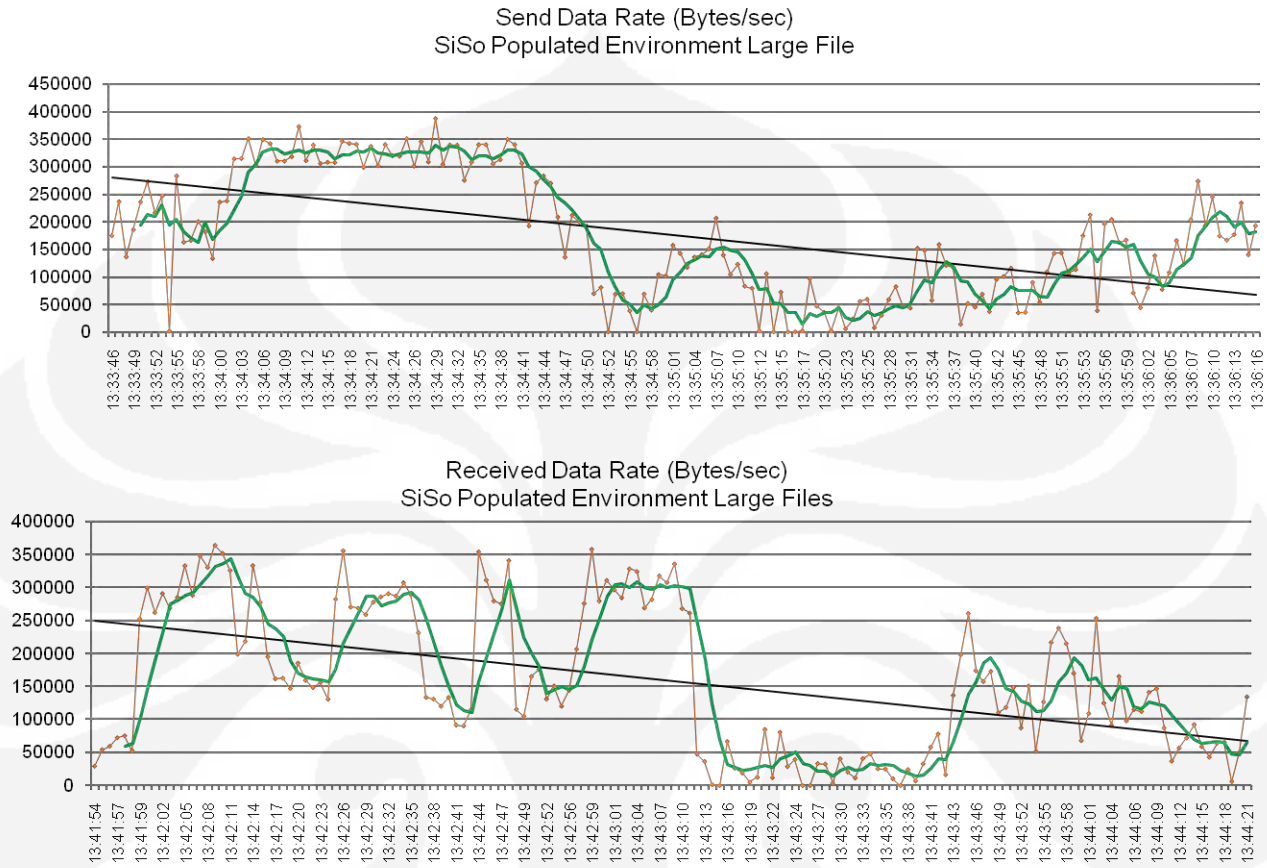


Figure 16 SISO in populated environment (large file)

As with control environment test, averaging trend lines are presented to simplify the comparison for SISO. Peak data rate value for SISO in populated environment was only at around 350 Kbps, compared to MIMO that managed to reach more than 2 Mbps if only for no more than 10 seconds.

Send data rates showed stable values but then dropped at the middle of session and did not manage to rise to its maximum value again. Received data rates exhibited large fluctuations. Values dropped to less than 50 Kbps before rising again although again did not manage to rise to its maximum value.

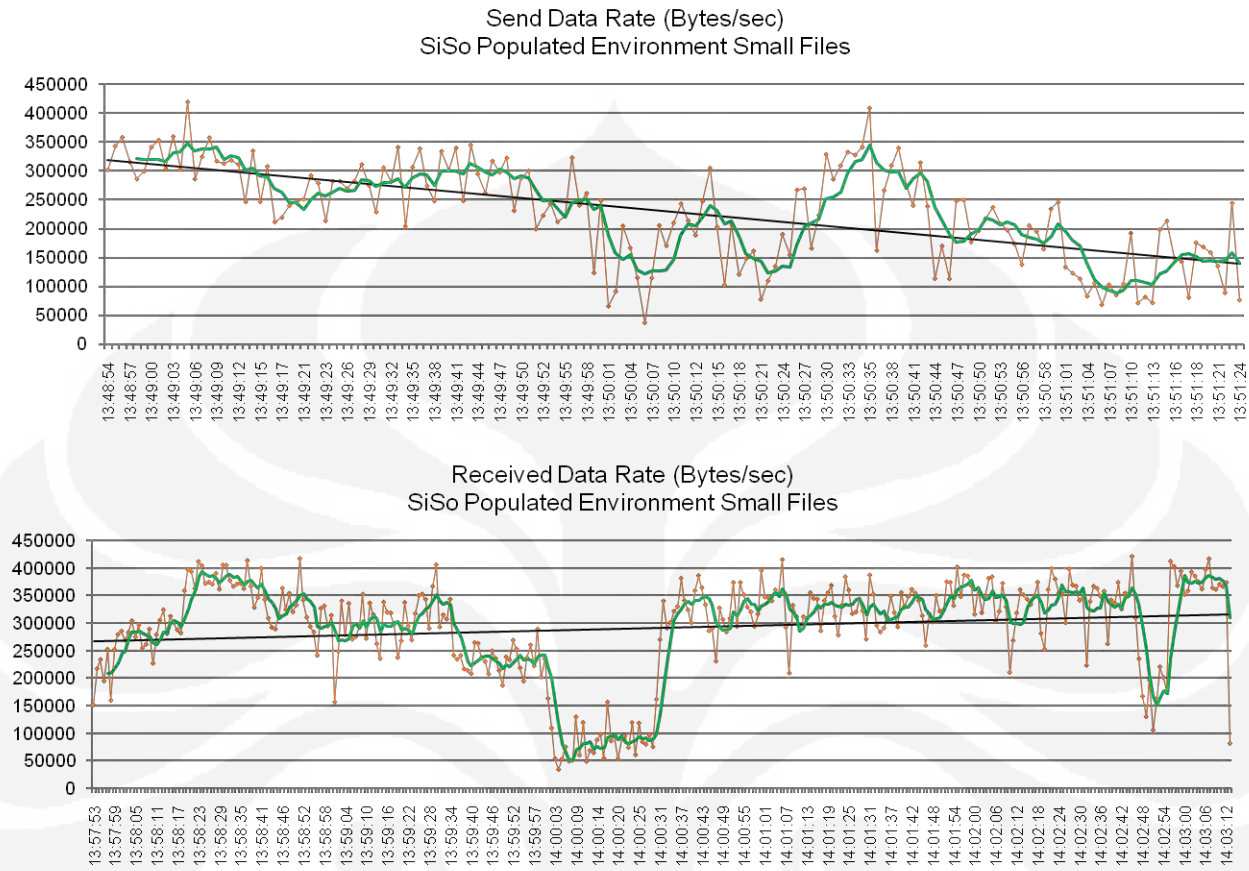


Figure 17 SISO in populated environment (small files)

The expected behavior for small files test is that result will showed more small fluctuation as the cycle of rise and settle repeated for each file sent. This is true for SISO as the graph showed. The orange line as the actual data sampled even showed this fact more distinctly.

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

Table 2 Populated Environment Test Using WirelessMon

Data from control environment showed trend that received data rate exhibited higher average than send data rate. MIMO at populated environment exhibited higher average for send large file and received small file, however SISO showed higher average at small files test. This might mean that the faster express card connection is only useful when sending small files in populated environments or in other words that large files transmission is affected by the presence of people.

We can also conclude from those facts that populated environment tests were largely dependent on the condition of the test site.

SISO also showed significantly lower data rates than control environment test while MIMO exhibited small decrease and even notable increase in data rate compared with its result at control environment.

4.2.2 JPerf Network Measurement Graphical Tool

4.2.2.1 MIMO

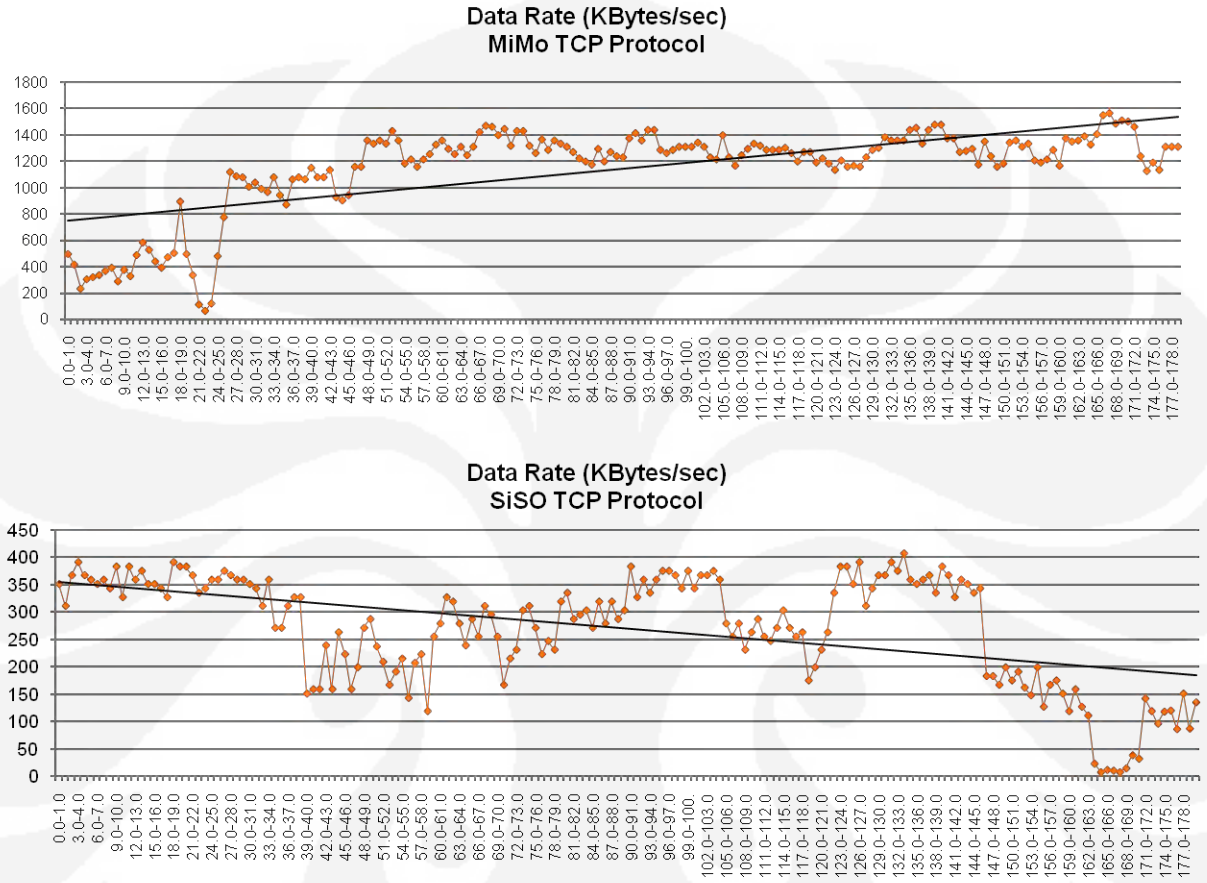


Figure 18 TCP protocol in populated environment

JPerf produced more neat results because both MIMO and SISO tests generated equal number of sample at 1 sample per second. Primary difference between MIMO and SISO at this test is their respective data rates. Peak value for MIMO can reach more than 1.5 Mbps while SISO only reached 400 Kbps.

MIMO also exhibited smaller and tighter fluctuation also a more stable trend. SISO's data rates even dropped to almost zero at a point at the test.

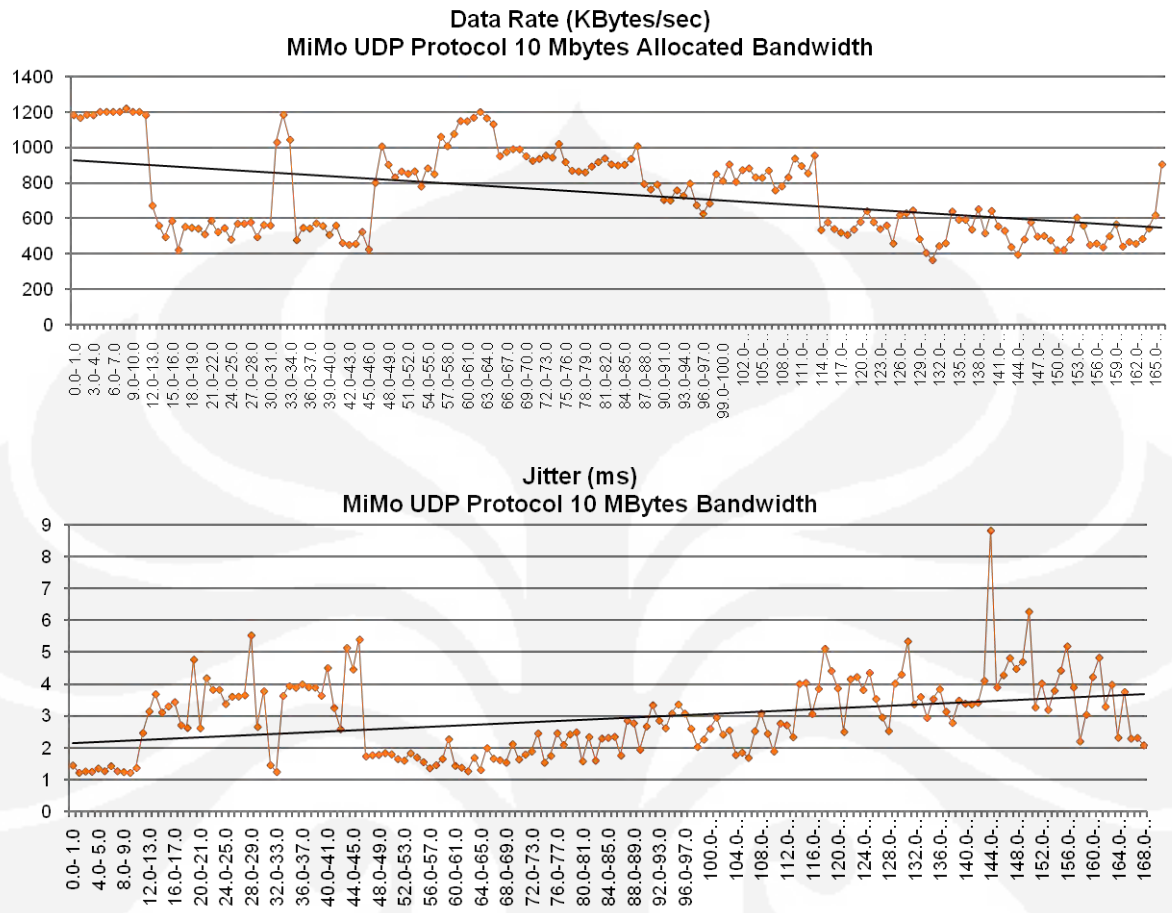


Figure 19 MIMO UDP protocol with 10 MB allocated bandwidth

At the first of the set of 3 test procedures for UDP protocol 10 Mbytes of bandwidth is allocated with the intention of reaching the highest possible data rate for both MIMO and SISO.

From the result the highest possible data rate value for MIMO with allocated bandwidth of 10 Mbytes is around 1.2 Mbps. Result below 5ms is considered an excellent value for jitter rate. With average value of 3.9 ms jitter rate for MIMO in populated environment is highly acceptable. The value of jitter is proportionately inverted with data rates. Rise in jitter corresponded to drop in data rates.

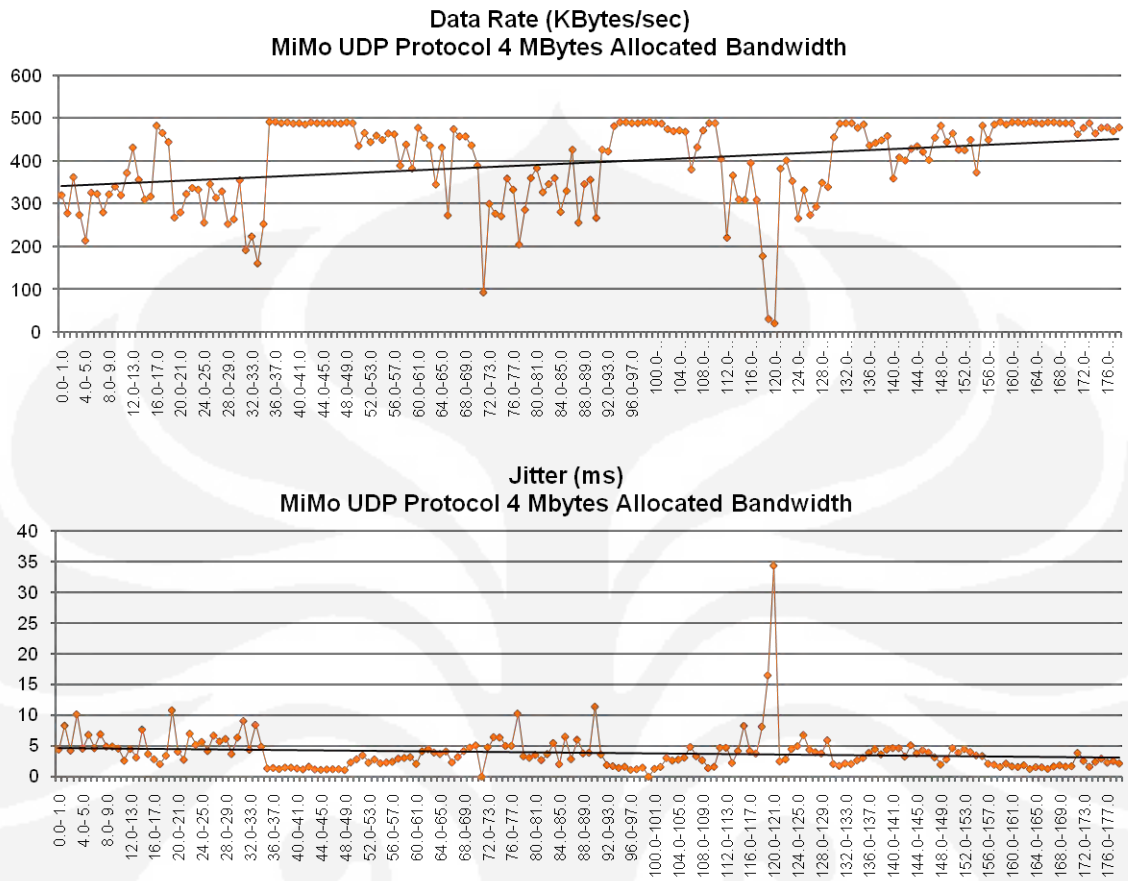


Figure 20 MIMO UDP protocol with 4 MB allocated bandwidth

Maximum data rate value for UDP protocol test with 4 Mbytes allocated bandwidth is around 500 Kbps with average value of around 400 Kbps. Jitter rate are also inside acceptable value although at one point the value rise significantly to 35 ms that is corresponded with data rates dropped to almost zero.

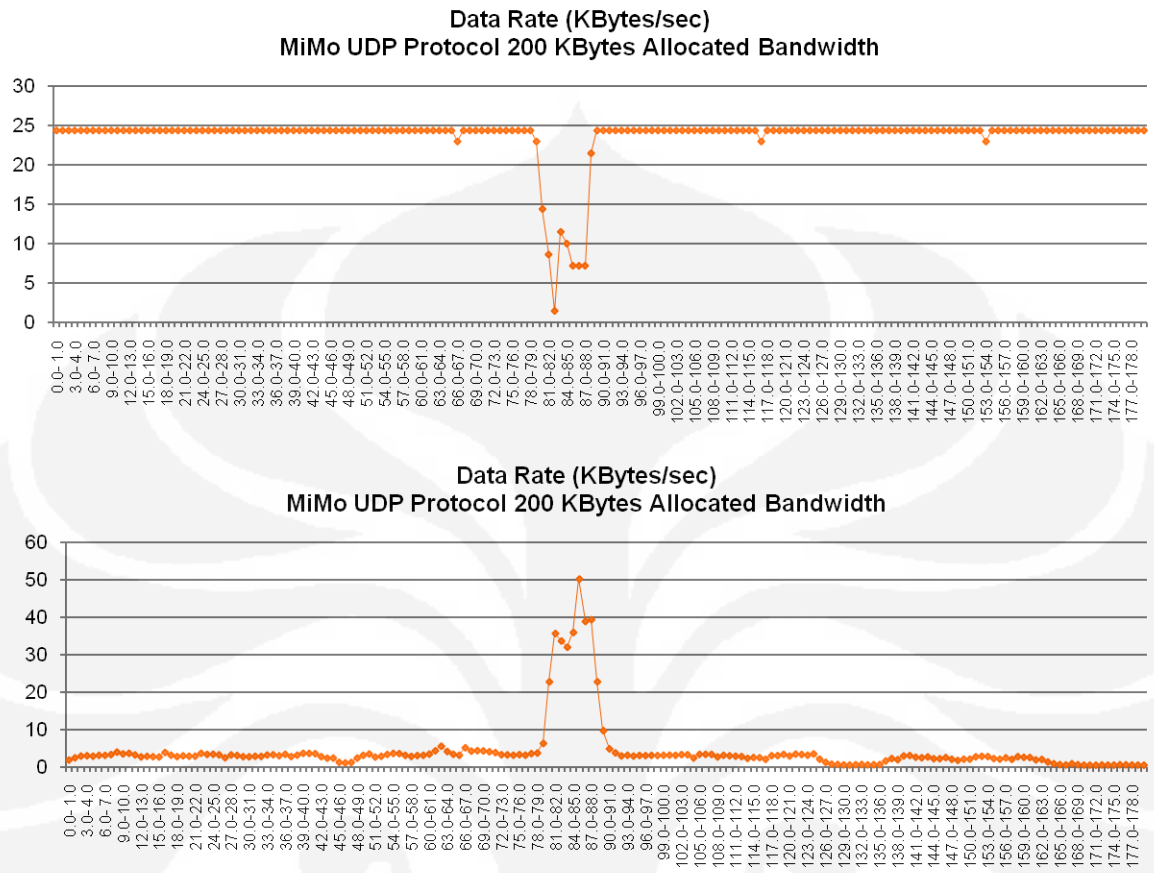


Figure 21 MIMO UDP protocol with 200 KB allocated bandwidth

Above graph clearly showed that MIMO for UDP protocol at 200Kbytes allocated bandwidth could only reached a maximum data rate of 25 Kbps. With relatively low allocated bandwidth, data rates are forced to maximum most of the time. The test hoped to let through a constant amount of data regardless the condition of the environment and/or interference presented to observe the performance of the system while in that condition.

4.2.2.2 SISO

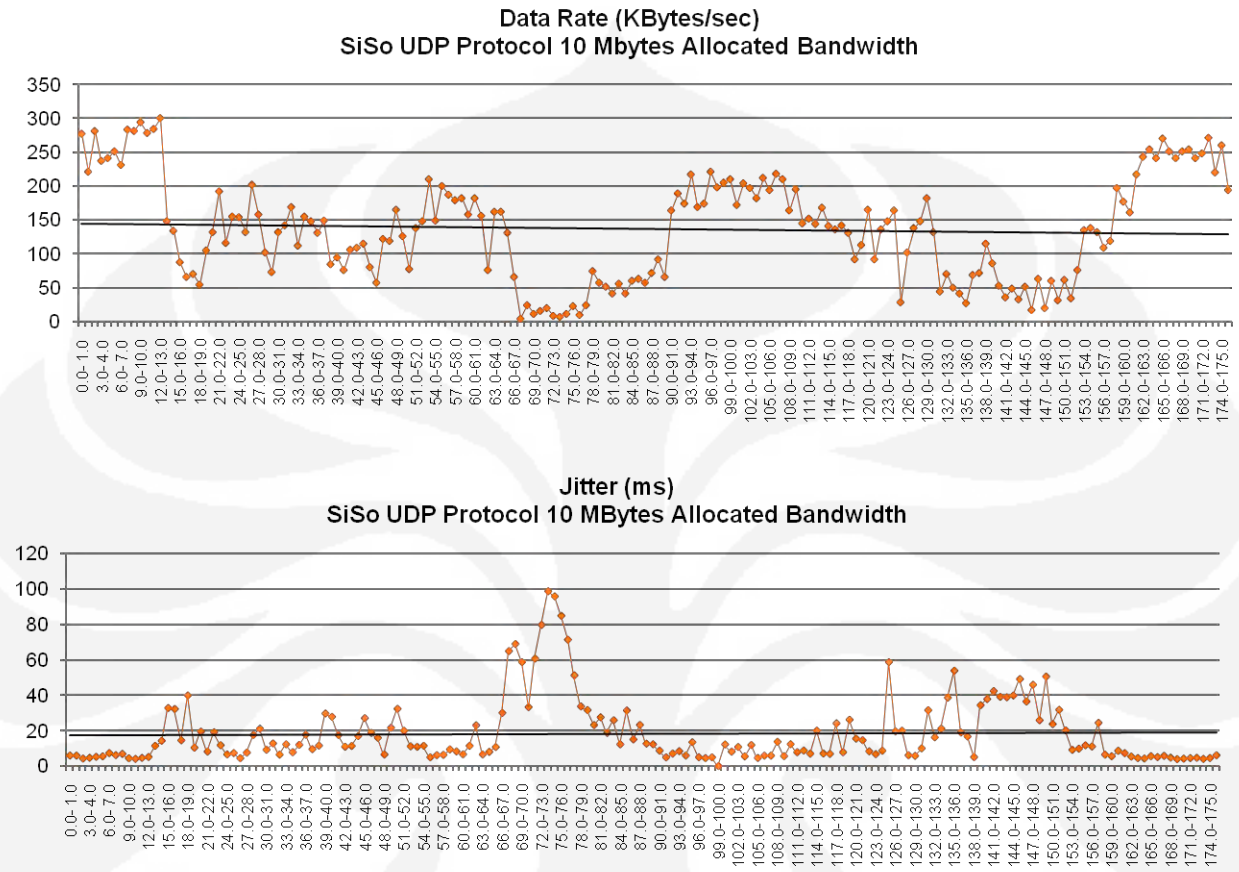


Figure 22 SISO UDP protocol with 10 MB allocated bandwidth

With allocated bandwidth of 10 Mbytes, SISO for UDP protocol can only reach a maximum data rate of 300 Kbps, 4 times lower than MIMO at the same allocated bandwidth. Jitter rate also significantly worse at average value of 18 ms almost 4 times of MIMO. Jitter value even reached up to 100 ms at one time.

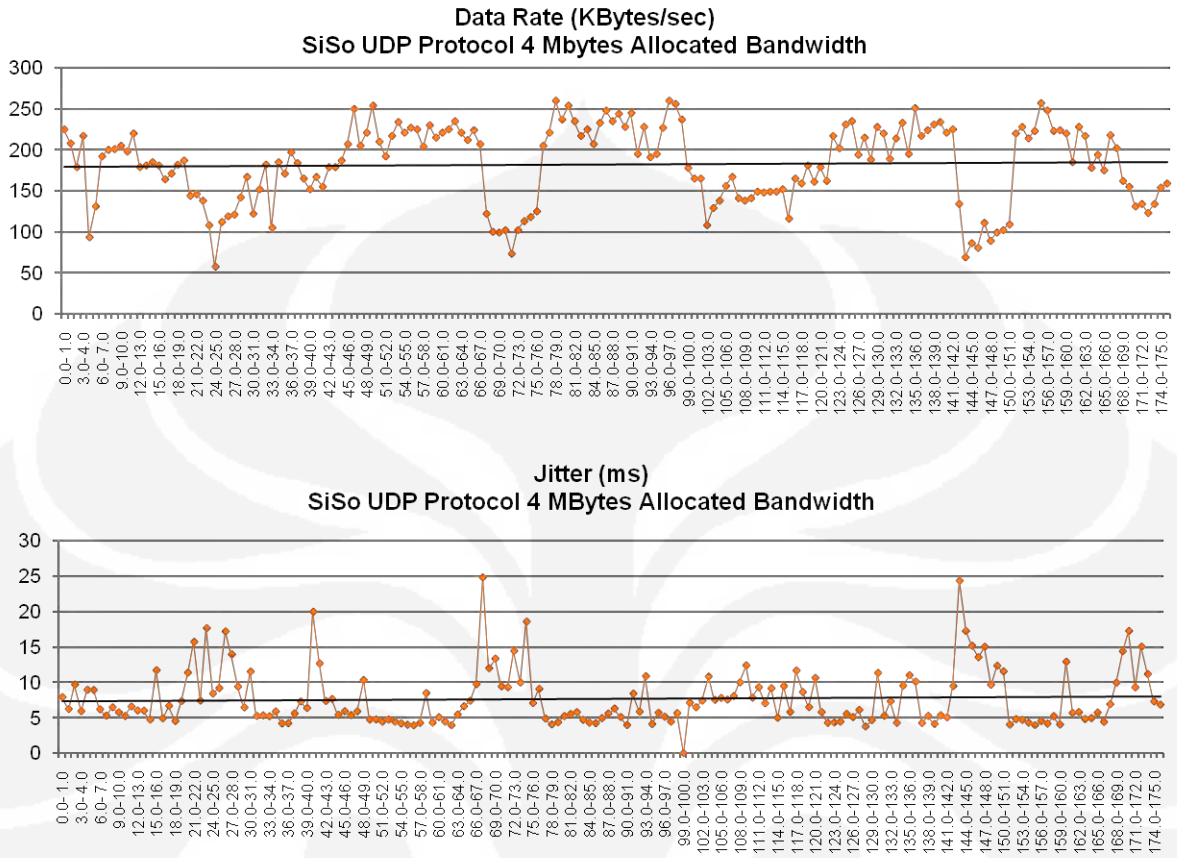


Figure 23 SISO UDP protocol with 4 MB allocated bandwidth

With allocated bandwidth of 4 Mbytes, SISO for UDP protocol reached a maximum data rate of 250 Kbps, compared to 500 Kbps of MIMO at the same allocated bandwidth. Jitter rate is actually better than previous test at average value of 7.7 ms.

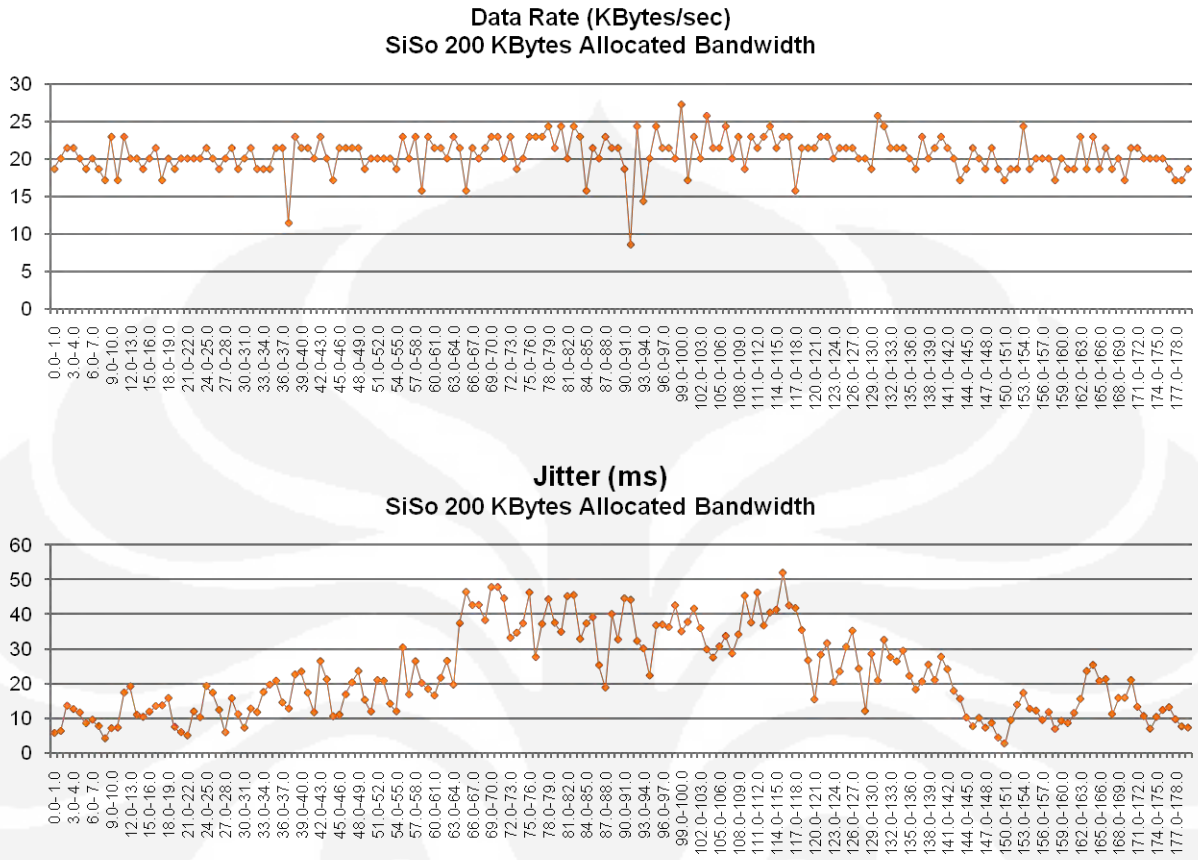


Figure 24 SISO UDP protocol with 200 KB allocated bandwidth

Unlike MIMO, SISO failed to produce relatively constant data rates with allocated bandwidth of 200 Kbytes. Data rate reached a maximum of a little above 25 Kbps. Jitter rate is the worst compared to all previous test with average value of 22 ms.

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

Table 3 Populated Environment Test Using JPerf

MIMO clearly showed superior performance compared with SISO for TCP test with 4 times the average data rates of SISO. UDP test also confirmed that MIMO exhibited relatively higher data rates than SISO at populated environment; MIMO also superior in terms of jitter rate with relatively large margin.

At 10 Mbytes allocated bandwidth, average data rate for SISO is lower than at 4 Mbytes allocated bandwidth. This fact proved that SISO is more susceptible to interferences than MIMO, as average jitter for 10 Mbytes bandwidth is much higher.

5. Conclusion

This project's objective was to characterize the performance of MIMO system in populated environment. Method to achieve it is to compare MIMO with SISO at the similar environment and identical test procedures. Expected result from the test is for MIMO to exhibit better performance compared to SISO in populated environment.

Data rate becomes the primary measurements at comparing the performance of MIMO and SISO. UDP protocol tests also introduced jitter rate as another measurements.

MIMO exhibited higher data rate performance at populated environment compared to SISO. All the test results showed that MIMO is superior to SISO in terms of data rates and jitter performance, in both TCP and UDP protocols.

When compared with control environment result, SISO showed significantly lower data rate. Unlike SISO, MIMO even exhibit higher data rate in populated environment compared to control environment.

Both monitoring software used at the test were set to record at their maximum sampling rate, 10 samples at a second for WirelessMon and 1 sample at a second for JPerf. WirelessMon failed to produce result at the desired sampling rate. SISO's result sampling rate was 1 sample per second and MIMO produced even smaller 5 samples per second. This was due to the limited processing power of laptops used for the test. Also that MIMO with its array of antenna and more complex algorithm than SISO further reduced the number of samples per second.

Reference

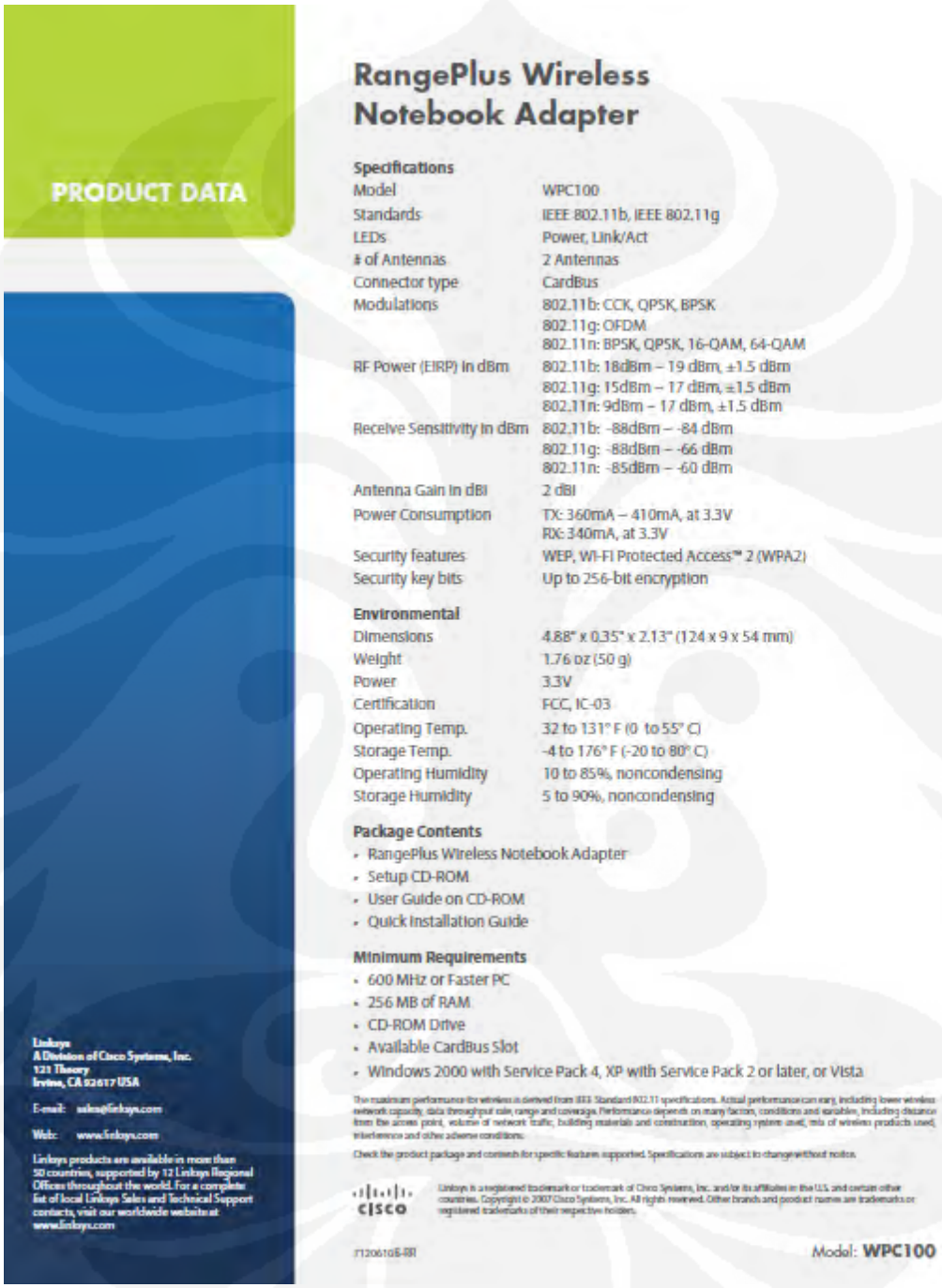
Schindler,S.,2006. Introduction to MIMO System. (Application Note 1MA102).Rohde & Scwarz

Jing,Y.,2004. Space-Time Code Design and It's Application in Wireless Network. California Institute of Technology

Juntti,M. Tutorial – MIMO Communications with Applications to (B)3G and 4G Systems. University of Oulu, Dept. Electrical and Inform. Eng.

Sun,W.,2006.Maximizing MIMO effectiveness by Multiplying WLAN Radios x3.Atheros Communications

APPENDICES



PRODUCT DATA

RangePlus Wireless Notebook Adapter

Specifications

Model	WPC100
Standards	IEEE 802.11b, IEEE 802.11g
LEDs	Power, Link/Act
# of Antennas	2 Antennas
Connector type	CardBus
Modulations	802.11b: CCK, QPSK, BPSK 802.11g: OFDM 802.11n: BPSK, QPSK, 16-QAM, 64-QAM
RF Power (EIRP) in dBm	802.11b: 18dBm – 19 dBm, ±1.5 dBm 802.11g: 15dBm – 17 dBm, ±1.5 dBm 802.11n: 9dBm – 17 dBm, ±1.5 dBm
Receive Sensitivity in dBm	802.11b: -88dBm – -84 dBm 802.11g: -88dBm – -66 dBm 802.11n: -85dBm – -60 dBm
Antenna Gain in dBi	2 dBi
Power Consumption	TX: 360mA – 410mA, at 3.3V RX: 340mA, at 3.3V
Security features	WEP, Wi-Fi Protected Access™ 2 (WPA2)
Security key bits	Up to 256-bit encryption

Environmental

Dimensions	4.88" x 0.35" x 2.13" (124 x 9 x 54 mm)
Weight	1.76 oz (50 g)
Power	3.3V
Certification	FCC, IC-03
Operating Temp.	32 to 131° F (0 to 55° C)
Storage Temp.	-4 to 176° F (-20 to 80° C)
Operating Humidity	10 to 85%, noncondensing
Storage Humidity	5 to 90%, noncondensing

Package Contents

- RangePlus Wireless Notebook Adapter
- Setup CD-ROM
- User Guide on CD-ROM
- Quick Installation Guide

Minimum Requirements

- 600 MHz or Faster PC
- 256 MB of RAM
- CD-ROM Drive
- Available CardBus Slot
- Windows 2000 with Service Pack 4, XP with Service Pack 2 or later, or Vista

The maximum performance for wireless is derived from IEEE Standard 802.11 specifications. Actual performance can vary, including lower wireless network capacity, data throughput rate, range and coverage. Performance depends on many factors, conditions and variables, including distance from the access point, volume of network traffic, building materials and construction, operating system used, mix of wireless products used, interference and other adverse conditions.

Check the product package and contents for specific features supported. Specifications are subject to change without notice.

Linksys
A Division of Cisco Systems, Inc.
121 Theory
Irvine, CA 92617 USA

E-mail: sales@linksys.com

Web: www.linksys.com

Linksys products are available in more than 50 countries, supported by 12 Linksys Regional Offices throughout the world. For a complete list of local Linksys Sales and Technical Support contacts, visit our worldwide website at www.linksys.com

RT206108-RR

Model: **WPC100**

D-Link

DWA-643

WHAT THIS PRODUCT DOES

Connect your notebook computer with an available ExpressCard™ slot to a wireless network and access a high-speed Internet connection, transfer files, and stream media from greater distances around your home or office.

XTREME N™ ADAPTER BENEFITS

- Delivers up to 14x faster speeds[1] and 6x farther range[1] than 802.11g
- Xtreme N technology enables HD video streaming, file sharing, enhanced Internet phone calling (VoIP), and surfing the Web
- Access secure wireless networks using advanced WPA™ or WPA2™ encryption
- Easy to install and use with D-Link's new Quick Adapter Setup Wizard
- Backward compatible with existing 802.11g networks

EXPRESSCARD BENEFITS

- Up to 236% faster than legacy CardBus[2]
- Approximately half the size and weight of a standard CardBus adapter
- Provides superior performance, better reliability, and expansion flexibility over CardBus[2]

YOUR NETWORK SETUP

TECHNICAL SPECIFICATIONS

STANDARDS
- IEEE 802.11n (draft 2.0)
- IEEE 802.11g

INTERFACE
ExpressCard/54

FREQUENCY RANGE
2.4GHz to 2.485GHz

SECURITY
- Wi-Fi Protected Access (WPA & WPA2)

LED
Activity

CERTIFICATIONS
FCC Class B, CE

OPERATING TEMPERATURE
32°F to 131°F (0°C to 55°C)

OPERATING HUMIDITY
90% Maximum (Non-condensing)

DIMENSIONS
- Item (WxDxH): 2.4" x 4.7" x 0.2"
- Packaging (WxDxH): 5.3" x 6.6" x 1.4"

WEIGHT
- Item: 0.20 lbs
- Packaging: 0.61 lbs

WARRANTY
1-Yr or Limited[3]

wireless family comparison

	Wireless G	Xtreme N
features		
wireless performance	●	●
advanced wireless network security	●	●
greater wireless coverage for homes & offices		●
easy network security setup		●
sustained wireless performance from farther distances		●
recommended applications		
high-speed Internet access & file sharing	●	●
enable lag-free gaming		●
enable jitter-free Internet phone calls (VoIP)		●
steady audio streaming		●
high-definition video streaming		●

[1] Maximum wireless signal rate derived from IEEE Standard 802.11g and draft 802.11n specifications. Actual data throughput will vary. Network conditions and environmental factors, including volume of network traffic, building materials and construction, and network overhead, lower actual data throughput rate. Environmental factors will adversely affect wireless signal range. Wireless range and speed rates are D-Link RELATIVE performance measurements based on the wireless range and speed rates of a standard Wireless G product from D-Link. Maximum throughput based on D-Link draft 802.11n devices.

[2] Maximum throughput derived from CardBus and ExpressCard™ specifications.

[3] 1-Year Limited Warranty available only in the USA and Canada.

[4] Computer must adhere to Microsoft's recommended System Requirements.

[5] Latest software and documentation are available at http://support.dlink.com

This product is based on IEEE draft 802.11n specifications and is not guaranteed to be forward compatible with future versions of IEEE 802.11n specifications. Compatibility with draft 802.11n devices from other manufacturers is not guaranteed. All references to speed and range, including the performance chart, are for comparison purposes only. Product specifications, size, and shape are subject to change without notice, and actual product appearance may differ from that depicted herein.

Wi-Fi PROTECTED SETUP

WIRELESS N

RECOMMENDED SYSTEM REQUIREMENTS
For Optimal Wireless Performance
- Xtreme N Wireless Router (D-Link DIR-655)

MINIMUM SYSTEM REQUIREMENTS
- Computer with:
  - Windows Vista™ (32-bit/64-bit), Windows® XP (SP2 or Windows 2000 (SP4
  - CD-ROM Drive
  - 300MHz Pentium® Processor
  - 64MB Memory
- For Internet Access:
  - Cable or DSL Modem
  - Wireless Router
  - Subscription with Internet Service Provider (ISP)

PACKAGE CONTENTS
- Xtreme N Notebook ExpressCard
- Quick Installation Guide
- CD-ROM with
  - Installation Wizard
  - Drivers
  - Product Documentation