A Study of the Impact of People Movement on Wi-Fi Link Throughput using Propagation Measurements

by

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Abstract

There has been a tremendous growth in the deployment of Wi-Fi networks (i.e. IEEE 802.11 networks) in recent years. This growth is due to the flexibility, low cost, simplicity, and user mobility offered by the technology. While various key performance limiting factors of Wi-Fi networks such as wireless protocols, radio propagation environment and signal interference have been studied by many network researchers, the effect of people movement on Wi-Fi throughput performance has not fully been explored yet. This research aims to investigate the impact of people movement on Wi-Fi link throughput in indoor environments. Setting up experimental scenarios by using a pair of wireless laptops to file share where there is human movement between the two nodes, Wi-Fi link throughput is measured in an obstructed office block, laboratory, library, and suburban residential home environments. The collected data from experimental study showed that the performance difference between fixed and random human movement had an overall average of 2.21 ±0.07Mbps. Empirical results have shown that the impact of people movement (fixed and random people movements) on Wi-Fi link throughput is insignificant.

Acknowledgements

I would like to thank

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- Finally, I would like to thank my parents and family who have played a very important role in my life and encouraged me during difficult times.

Contents

List of Abbreviations and Acronyms

ACK	Acknowledgement
AODV	Ad hoc on-demand distance vector
AP	Access point
BS	Base station
BSS	Basic service set
CCK	Complimentary code keying
CDF	Cumulative distribution function
CDMA	Code division multiple access
CFP	Contention-free period
CSMA	Carrier-sense multiple access
CSMA/CA	Carrier-sense multiple access with collision avoidance
CSMA/CD	Carrier-sense multiple access with collision detection
dB	Decibel
dBm	dB-milliwatts
DCF	Distributed coordination function (IEEE 802.11)
DIFS	DCF inter-frame space
DS-CDMA	Direct sequence code division multiple access
DSDV	Destination sequence distance vector
DSSS	Direct sequence spread spectrum
802.11	IEEE 802.11
ESS	Extended service set
FDD	Frequency division duplexing
FDMA	Frequency division multiple access

FHSS	Frequency-hopping spread spectrum
FTP	File transfer protocol
MAC	Medium access control
MT	Mobile terminal (Mobile station)
PCF	Point coordination function
PDA	Personal digital assistant
PHY	Physical
RF	Radio frequency
RSS	Received signal strength
Rx	Receiver
TCP	Transmission control protocol
Tx	Transmitter
UDP	User datagram protocol
Wi-Fi	Wireless fidelity (IEEE 802.11)
WLAN	Wireless local area network

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Chapter 1

Introduction

Wi-Fi technology has grown rapidly due to high demand of information over the internet in recent years. Research papers have been written to identify the performance of Wi-Fi networks in different environments, but the impact of people (human) movement on Wi-Fi link throughput has not been explored thoroughly.

The growth of IEEE 802.11 ("802.11") wireless local area networks (WLANs) was mainly due to the simplicity of setup, cost and flexibility that is accessible by this technology. There are many potential areas that can make use of WLAN technologies such as a hospital, where it can provide quick accessibility to database information, sharing files over a wireless medium, and the constant office shifting where physical cables are not feasible [1, 2]. Schools can also benefit from this technology as it facilitates e-learning, increase revenue and scalability for multiple users in different locations, this increasing the area size of the wireless network for more users to access data [3]. There's no requirement where you need to use school computers to do homework as users can roam around in various locations using mobile devices to access information through a wireless network.

As Wi-Fi is one of the most popular technologies for information gathering through the World Wide Web (WWW), the amount of technological resources has become more demanding due to high end applications (i.e. video and voice) where capacity of WLANs has become an issue. Institute of Electrical and Electronics Engineers (IEEE) committee have standardised the 802.11 technology for different users requiring different performances over a network. Standards provided by IEEE are 802.11a (released in 1999), 802.11b (released in 1999), 802.11g (released in 2003) and the newly implemented 802.11n (released in 2009). These standardised 802.11 protocols are used depending on the environment the WLAN will be deployed. A basic example can be justified as if you are in a large organisation with heavy users accessing the Wi-Fi network and the area of the building is very large, then using 802.11n may be feasible due to it consisting of high data stream rates and has large signal coverage. Currently 802.11b/g is currently the common protocol deployed in residential homes and small offices.

Even though wireless networks have great advantages (i.e. eliminating of cables), it still lacks in performances when data is being transmitted through propagation environment. Signal strength and transmission speed can substantially decrease as radio waves can refract of various objects in a propagated environment. Interference of radio waves occurring in a dense environment can produce problems where packets drop and delay can occur over a wireless network which causes problematic performance issues.

In order to overcome wireless network performance issues and ensure the network is getting its best throughput, several techniques have been developed to overcome roadblocks before deploying the technology. These techniques which are currently being used are (1) computer simulation (i.e. OPNET or ns-2), (2) radio propagation measurements and (3) analytical modelling. Computer simulation is an easy and economical way of designing mock-up versions of a network without the need of expensive hardware. But it can be very difficult to justify conclusions when looking at real life scenarios, for example human interferences where accurate throughput cannot be recorded in a network simulator due to the randomness of people movement and propagation interferences. Using propagation measurements provides a great way on finding the relationship between signal strength and Wi-Fi throughput as there are many factors that influence performances in various environments.

Wireless networks in a dense environment can slow down throughput rates and decrease signal strength. Therefore careful consideration of access points must be addressed in order to optimize network performance. Testing the 802.11 technologies in different areas in a heavily obstructed environment can provide better understanding on where AP's are best placed for better performances. If there is no testing done before final deployment of Wi-Fi technology, then time and cost spent would result to being wasted

The objective of this dissertation is discussed next.

1.1 Objective of this dissertation

The aim of this dissertation is to study the effect of people (human) movement on Wi-Fi link throughput using propagation measurements in a variety of environments, such as a suburban residential house, laboratory, library, lunch room and office room.

Using real hardware and software in different scenarios (no human, fixed human and random human movement) in an environment will provide a comparative analysis to identify if there is any significant difference in Wi-Fi throughput performance.

The structure of this dissertation is discussed next.

1.2 Dissertation Structure

The remainder of the dissertation is structured as follows. Chapter 2 describes related work on 802.11 physical and MAC layer protocols, also talks about common IEEE 802.11 standards used currently in every day environments. It also discusses the two operation modes of 802.11 and various propagation measurements. Chapter 3 however talks about research methodology in the area of wireless networks and how different techniques can be used for experimental work. Chapter 4 we report on the design and implementation of the experiments. Also we talk about the basic hardware and software used in order to operate the experiments. Chapter 5 presents analysis for all scenarios in each experiment to identify if there is significant impact in throughput between no human, fixed human and random human movement. Chapter 6 concludes the dissertation by summarising each chapter and present an overall findings made by the study. It also highlights possible research directions.

Chapter 2

Background and Related Work

2.1 Overview of the IEEE 802.11 Standard

For a number of years wireless computing has grown rapidly without the requirements of wired networks. A group was formed in 1884 *"when electricity was becoming a major force in society"* called Institute of Electrical and Electronic Engineers (known as IEEE). Over decades the committee has been a major source for current researchers in the area of engineering and information technology, this providing a *"global institute"* for innovation from practitioners to represent factorial information to users around the world [4].

IEEE 802.11 standard was first published in 1997 where it consisted of low data rates of 1Mbps and 2Mbps using the frequency band of 2.4GHz ISM. The frequency utilizes frequency hopping spread spectrum (FHSS) or direct-sequence spread spectrum (DSSS). The range of transmission was approximately 20 meters indoor radius and 100 meters over an outdoor radius. The standard 802.11 covered both medium access control layer (MAC) and physical layer (PHY) [5]. Protocol 802.11a and 802.11b were both released in 1999. 802.11a operated at 5GHz frequency where it supported data rates up to 54Mbps. Using the 5GHz unlicensed band had the ability to freely transmit data, but the downside in using this protocol is due to the high frequency it uses, the frequency is absorbed a lot more and consist a smaller signal range compared to other standardised 802.11 protocols.

In comparison, 802.11b was quickly accepted as a standard wireless local area network technology in 1999. The protocol had dramatically increased throughput along with price which led to its popularity. As 802.11b operated using a different frequency band of 2.4GHz, the hardware can lose slight performance due to interferences where it shares the same frequency from various electronic radio devices (i.e. micro ovens, baby monitors or Bluetooth devices). This protocol compared to 802.11a produces larger radio coverage (approximately 35 meters indoor and 140 meters outdoor) and data rates of 5Mbps and 11Mbps. Due to high data rates the technology adopted complementary key coding (CCK) and direct sequence spread spectrum (DSSS) techniques are used to handle stability of wireless LANs [6-8].

With the rapid increase in popularity and high end multimedia applications (i.e. video) of wireless technology, larger amount of data rates is required. IEEE next introduced a standard of 802.11g during 2003 which was to provide higher throughput rates of up to 54Mbps using the same frequency band of 2.4GHz. Due to large number of users in everyday environment using different wireless technologies, the 802.11g became an improved protocol where it has enabled backward compatibility with 802.11b. But a major downfall to this protocol is that it experiences the same interference problems as 802.11b where devices operating in this range include cordless telephones and Bluetooth devices. Overall the standard 802.11b and 802.11g is currently the most common standard used in an everyday wireless environment [9-10].

As large organisations are consistently growing the increase in wireless data capacity and signal strength is very important for large enterprises. Therefore IEEE amended the current protocol of 802.11n in 2009. This protocol introduced the standard by adding a multi-input multi-output antenna (MIMO) where it operates in an already busy 2.4GHz and 5GHz frequency band. One of the main advancement of this stand is the maximum data rate where it handles over twice the maximum data rate of 802.11g at 600Mbps. Not only does this protocol consist the ability to have high throughput rate, this technology also has a substantial increase of signal range (indoor approximately 70 meters and out range 250 meters) [11-12].

Table 2.1: Common 802.11 standards [13]

802.11 Protocol	Frequency	Maximum Data Rate	Approximate Range	Ad-hoc ability
802.11a (OFDM)	5GHz	54Mbps	120m	Yes
802.11b (DSSS)	2.4GHz	11Mbps	140m	Yes
802.11g (CCK, OFDM)	2.4GHz	54Mbps	140m	Yes
802.11n (OFDM)	2.4/5GHz	600Mbps	250m	Yes

IEEE 802.11 wireless network operates in two modes: (1) Infrastructure; and (2) Ad hoc mode. In the infrastructure mode (figure 2.1), the network consist of an access point (AP) which acts as a

coordinator between different mobile terminals (MT). On the other hand, an ad hoc mode (figure 2.2) has the ability to communicate to each mobile terminal via "*a peer-to-peer level*".

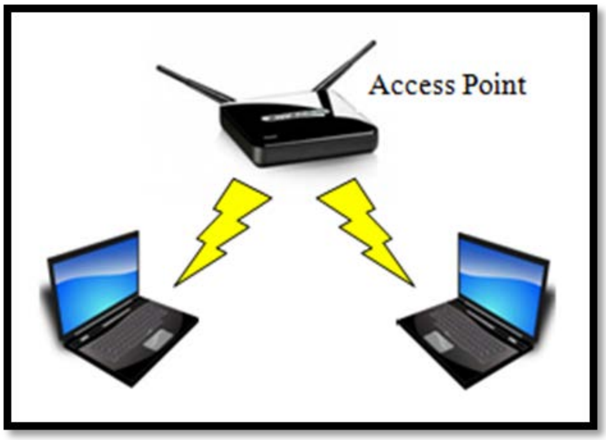

Figure 2.1: Infrastructure Mode

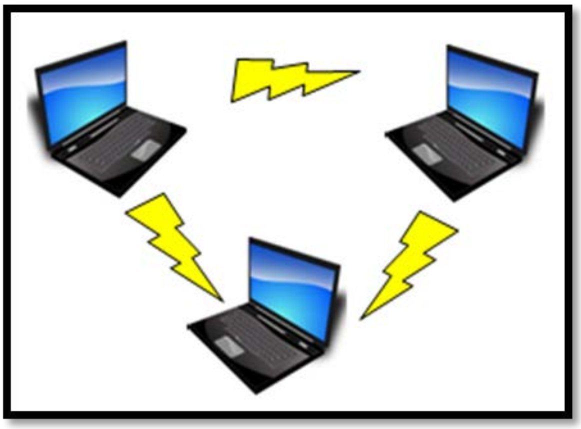

Figure 2.2: Ad hoc Mode

There consist of three different network architectures that have been defined by IEEE for 802.11: (1) basic service set (BSS); (2) extended service set (ESS); and (3) independent basic service set (IBSS).

IBSS (figure 2.3) is the most basic WLAN topology which consist groups of mobile terminals (MT) where all nodes have the ability to recognise one another, and is also transfer data through a wireless media in a peer-to-peer manner. All nodes must be in signal range of each other for communication to occur, else if one node is out of signal range then data cannot be sent, hence this topology is referred to independent basic service set or also known as ad hoc [14-15].

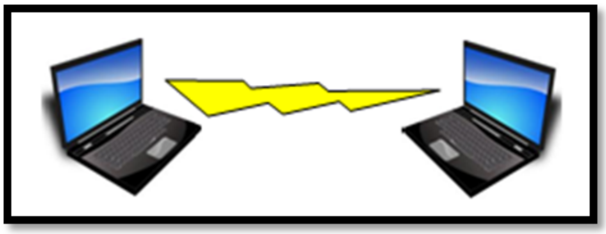

Figure 2.3: Independent Service Set (ISS)

BSS (figure 2.4) contains more than two wireless nodes. The nodes act as an access point or a wireless workstation. All stations in a BSS no longer communicate directly and therefore the AP acts as a master to control the station. An extended service set (ESS) is a set of more than one basic service set which can extend the range of the mobility and coverage for a wireless node (figure 2.5).

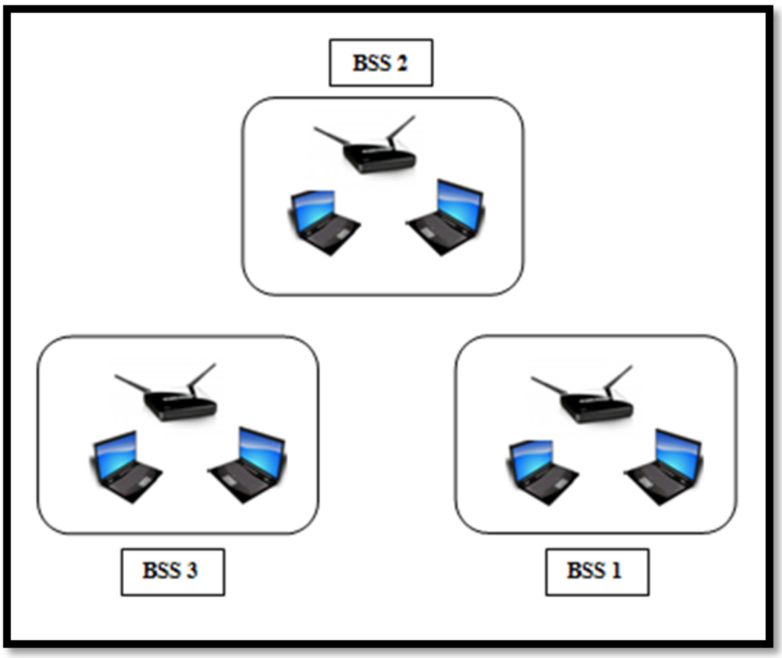

Figure 2.4: Basic Service Set

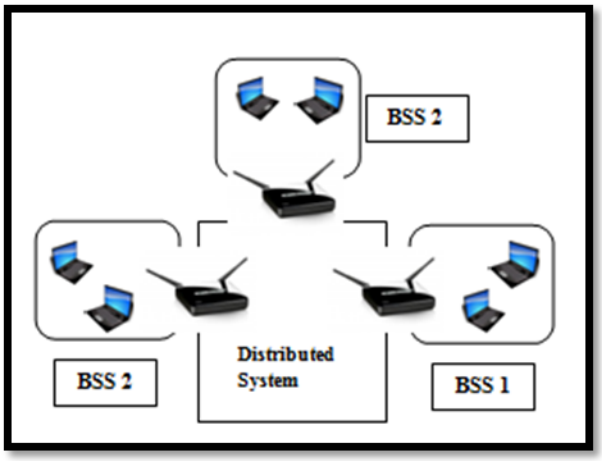

Figure 2.5: Extended Service Set

2.2 The IEEE 802.11 Protocols (Wi-Fi)

IEEE 802.11 standard consist of two important layers which is (1) MAC layer and; (2) Physical layer. Even though 802.11 take up different physical layer technologies, they still use the logical link control (LLC), media access control (MAC) and link layer address space (48bit).

Data Link Layer (MAC)	802.2		
	802.11		
Physical Layer (PHY)	DSSS	FHSS	Infrared

Figure 2.6: 802.11 structures

The first defined layer in an OSI model is the Physical layer (PHY), this layer is designed to carry raw bits of data rather than logical data packets over a physical link on connecting nodes. The second layer in the OSI model is the Data Link layer where it provided transfer of data between network entities.

2.2.1 Physical Layer

The physical layer is the interface between wireless media and medium access control (MAC) where this layer both transmits and receives data frames. The physical layer is compromised of two sub layers which is physical layer convergence procedure (PLCP) sublayer and physical medium dependent (PMD) [16].

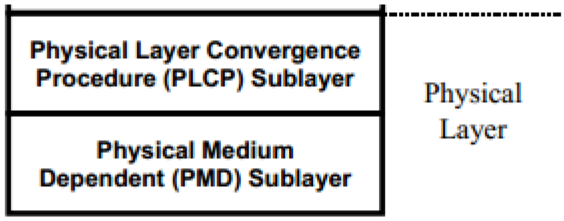

Figure 2.7: Basic Physical Layer Model

The physical layer convergence procedure (PLCP) sublayer is designed to specify a method used to map the MAC sublayer protocol data unit into framing formats to suite the physical medium dependant (figure 2.7) [17].The PLCP adds a specific PHY header and a forwarded field to the MPDU that contains the required data needed for physical layer receivers and transmitters [18].

Physical Medium Dependent (PMD) has the ability to define the information of transmitting and receiving of individual bits on a physical medium. PMD's main responsibility is to encompass signal coding, bit timing, interacting with a physical medium which can be used for fast Ethernet to Gigabit Ethernet.

2.2.2 Medium Access Control

IEEE 802.11 defines two forms of medium access which is distributed coordination function (DCF) and point coordination function (PCF). DCF is a must requirement and is based on the carrier sense multiple access with collision avoidance (CSMA/CA) protocol. However PCF is optional and is integrated with the DCF.

As mentioned above, DCF is a protocol which uses four way handshakes with carrier sensing to maximize the throughput while avoiding packet collision. A packet collision is referred to when a node is receiving more than one packet at a time, this resulting in both packets not correctly being received. Furthermore DCF has the ability to support both ad hoc and infrastructure wireless modes.

Due to PCF being an optional feature, PCF works *"in conjunction with DCF, PCF was included specifically to accommodate time bounded connection oriented services"*, this meaning that the PCF can provide contention free service [19]. An AP operating in PCF mode issues a beacon at regular intervals, the beacon establishes a window of transmitted opportunity. Each window consist of contention free period (CFP) and contention period (CP), however PCF wasn't widely supported in the industry due to several limitations [20].

2.3 Radio Propagation Characteristics

It is essential to understand the characteristics of radio propagation in a WLAN as it can influence the performances of data transmission and signal strength, there can be heavy loss in throughput, loss in packet transmission or delay in packets being received if bad AP or wireless devises is placed in a cluttered space. There are various factors that can cause radio propagation to happen such as radio frequency, geographical location of WLAN, wireless devices, reflection, and absorption of radio waves, transmission power and distance. Therefore it can be difficult to analyse in a real life situation when using software simulation to provide an accurate radio propagation network performance output. Radio propagation and signal strength are effected by numerous factors such as attenuation, path lost, interference and multi-path propagation [21-22]. These common characteristic is described as follows:

Attenuation

Attenuation refers to when data being transmitted between multiple nodes the signal power becomes slightly weaker [23]. Therefore material surroundings in a suburban residential home environment such as plasterboard or glass windows can cause an impact on signal attenuation this cause loss in performance and devices not consisting of sufficient signal strength [24].

Interference

Interference consist a cluster of noises isolating the frequency range of 2.4GHz or 5GHz ISM band (in wireless networking terms). This noise is resulted in man-made equipment’s such as microwave ovens or Bluetooth devices where they share the same frequency range as 802.11b, 802.11g and 802.11n. If there are too many ISM devices operating with the same frequency of 2.4GHz in a small area, then the result in wireless performance can substantially have an impact where degradation of throughput will occur.

Multi-path propagation

Absorption, reflection and diffraction of radio waves can directly cause multi-path propagation where this is very common in an indoor environment due to various obstructions. During data transmission the radio waves would travel depending on the antenna either bi-directional or omni-directional direction. Bi-directional is when radio waves transmit signals in one direction, whereas omni-directional antennas send out radio waves in all directions. When radio signal transmits, the signals would reflect, absorb and diffract from objects that is placed in the area of transmitted signal. When multi-path propagation occurs, there can be a loss in radio coverage where the receiver may not get enough signal power to receive data, or the reflected signals causes a delay when data is transmitted [25].

Table 2.2: Key researchers and their main contributions in Wi-Fi performance study

Researcher	***Main contribution***	***Year***	***Key concepts/description***
N. Golmie, et al. [26]	Mutual Interference Analysis	2003	Investigated the effect of Mutual Interference on the performance of Bluetooth and IEEE 802.11b Systems
M. Heusse, et al. [27]	Analysis using DCF method	2003	Investigated Performance Anomaly using 802.11b DCF Method
K. Jain, et al. [28]	Interference Analysis on Wi-Fi networks	2005	Measured the Impact of Interference on Multi-hop Wi-Fi Networks
A.Doefexi,etal. [29]	Comparative Analysis between 802.11a and 802.11 Performance	2003	Performed an evaluation on 802.11a and 802.11g WLANS in a Corporate Office Environment
A. Jhonsson,et al. [30]	Analysis of Dispersion Methods	2004	Measured Dispersion-based Methods in a Ad Hoc Network
E. Perahia [31]	Discussed IEEE 802.11n Technology	2008	Discussed Development, History, Process and Technology of IEEE 802.11n
Y. Xiao [32]	Analysis of increasing IEEE 802.11n performance	2005	Enhanced higher Throughput in WLANs (802.11n)
E. Lo [33]	Discussed and Analysed Throughput Performance and Signal Strength in a Office Block	2007	Investigated the impact of Signal Strength on Wi-Fi performance
N. Sarkar, et al.	Measured throughput	2006	Wi-Fi Performance Measurements in

[34]	performance in a office block		the Crowded Office Environment
Jhon Stein [35]	Analysed various propagation interferences in Wi-Fi network	1997	Indoor Radio WLAN Performance in a Dense Office Environment

Table 2.2 provides citation made by previous case studies that have investigated propagation measurements, simulations studies and overview of IEEE 802.11 standards. Through the readings by past researchers has provided a way to develop and implement techniques for experimental investigation using people movement.

2.4 Summary

Chapter 2 talks about different standards of IEEE 802.11 used in every day environments, we also discussed different operation modes of 802.11, radio propagation and research contributors for this study. Chapter 3 discusses research methodology that will be adopted for the experimental design.

Chapter 3
Research Methodology

A literature review in areas of 802.11 standards (Wi-Fi), MAC layer, physical layer and propagation characteristics have been represented in chapter 2. This chapter provides a discussion on research methodologies in the area of wireless networks.

The primary objective of this dissertation is to study people movement on Wi-Fi link throughput and identify if there's any significant changes influencing the performance of WLANs. To achieve this objective, radio propagation measurements (using hardware, software and people movement) approach is used to carry out the research. However software simulators will not be used due to the research being solely based on experimental trials. Network packages such as OPNET and ns-2 have limiting factors which does not poses the ability to place real world characteristics in each scenario. As mentioned by Johnson [36] that simulation models does not possess sufficient capturing of sensor and radio irregularity in complex, real-world environment, especially indoors, and talked about by [37] where *"NS-2does not implement the physical layer of the network stack nor does it implement the characteristics of the physical medium"*. It also poses difficulty when analysing real life scenarios where there consists series of objects and radio interferences which can alter Wi-Fi throughput performance. Therefore software simulated methods are inadequate for my research as it lacks in-depth study on WLANs in various aspects.

It can be very difficult to understand the characteristics when generalising the WLAN performance as it can vary due to propagation environments (e.g. interference from dense material like concrete, or wall partitions) [38-40]. This can cause a drop or increase in the overall data transmission over a Wi-Fi network, therefore experiments carried out in the research will provide better understanding of human movement effects on Wi-Fi throughput between a pair of nodes.

Due to cost efficiency of wireless technology, researches can investigate further using real equipment and scenarios to provide accurate results. Due to the ability of using real hardware and viewing past case studies, we have adopted experimental methods and propagation measurements rather than simulation study or analytical modelling to gather precise information. Lo E. [41] investigated the impact of signal strength on Wi-Fi link throughput through propagation measurements using experimental methods in an office block, whereas [42] conducted a study on radio interference for WLAN throughput by using experimental measurements, Sowerby K and Sarkar N. [43] measured Wi-Fi performance measurements in a crowded office. These key researchers have used experimental techniques in order to produce accurate Wi-Fi throughput performances and data collection.

A limiting factor when conducting real life experiments is trying to maximise throughput performance due to a mixture of external interferences, such as signal reflection, absorption and diffraction from radio devices sharing the same frequency and moving objects in between a WLAN [44]. It can be difficult to make practical conclusions from a particular experiment, therefore accuracy and validation must be performed in order to produce efficient results for data collection.

Also in this dissertation we have used propagation measurements to identify if there is any significant Wi-Fi throughput performance difference in various environments (library, office block, laboratory, lunch room and a suburban residential home). Measurements of each scenarios and laptop placement will also be recorded to ensure that all experiments remain as constant as possible.

In order to collect data from test trials we conduct a series of experiments using a pair of portable wireless access points/omni-directional antennas and pair of laptops where we share a data file (129MB) over a pair of laptop.

Figure 3.1 illustrates the methodology used in order to define findings for the dissertation. The design is based on a science based model where the start process is defining propagation measurements for each scenario. This is based on recordings and ensuring during experiments all objects except for human stay constant. The next process consists of primary trials in order to identify if the room can be experimented in. If the room consist of too much interference, then another room will have to be considered. When the preliminary trials are completed we then begin the step of experimentation for different scenarios such as random, fixed and no human movement. For each scenario there will be a set of three trials to measure the accuracy of Wi-Fi throughput between a pair of nodes. Data collection and validation is compiled and performed next, this is to get a general understating if there is significant impact of people movement when there is human interferences. Finally a comparative analysis and conclusion is discussed to provide findings of research, however detailed design is discussed in chapter 4.

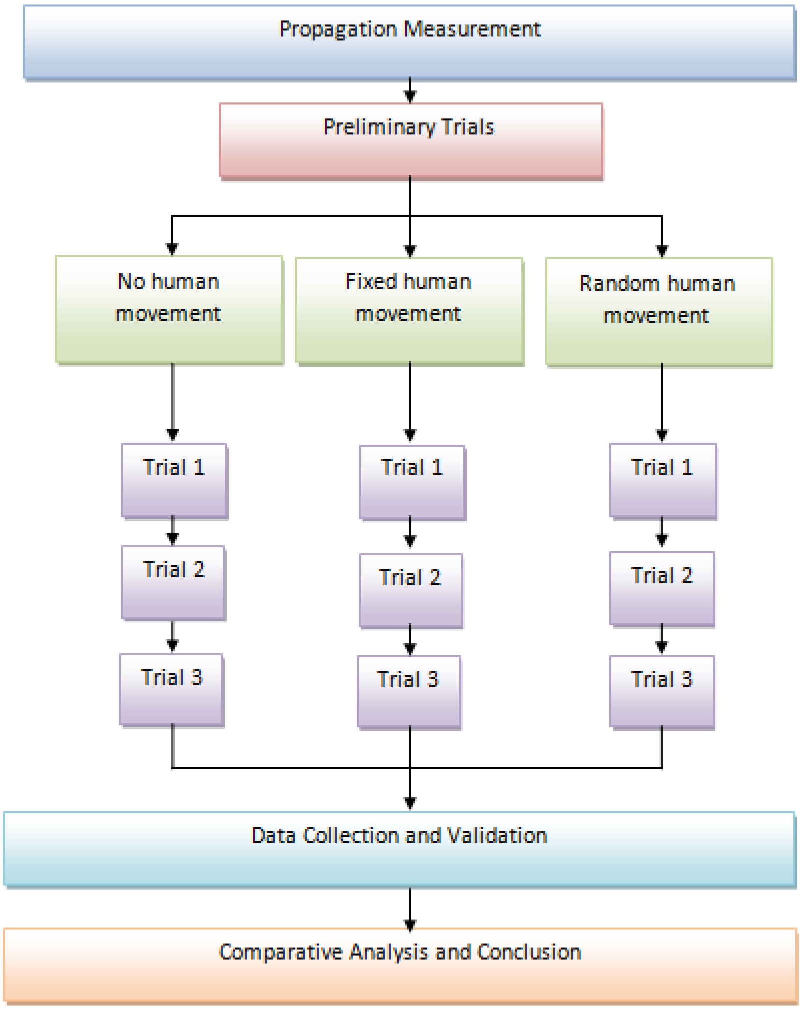

Figure 3.1: Methodological approach for research

Chapter 3 discusses methodology used from past researchers and for the experiments conducted to find if there is significant performance difference in Wi-Fi throughput, when there is human obstruction between a pair of nodes. An illustrated model is also displayed and discussed to show the structure of the dissertation and how experiments will be implemented. The next chapter discusses further in detail about the experimental design, hardware and software used, as well as measurement validation for running each experiment.

Chapter 4

Experimental Design

In chapter 3 research methodology used in the dissertation has been discussed. Chapter 4 however talks about the design, development and implementation phases for the experiments. Hardware and software is also discussed to give us best laptop placement in each environment. Details of each room are discussed to provide better understanding of each propagated environment.

The performance metrics used in the experiment are described in Section 4.1. The software and hardware configurations are presented in Section 4.2. Section 4.3 describes the propagation measurement environments. Section 4.4 provides scenario setup for no human, fixed human and random human movement for each experiment and section 4.5 discusses performance validation and accuracy prior to conducting the experiments.

4.1 Performance Metric

Due to experimental methods being adopted from previous case studies with slight alteration, a stop watch will be used to measure the file transmission time when data is sent across from sender (TX) to receiver (TX).

To calculate Wi-Fi throughput, a formula has been generalised where it is calculated by dividing the file size over transmission time. Throughput formula can be represented as follows:

Throughput (Mbps) *= Data Size (MB) / Transmission Time (Seconds)*

To identify if the pair of laptops are receiving good coverage, signal strength is measured in decibel-milliwatt (dBm) by using a software called inSSIDer, it is referenced to electrical power unit in decibel (dB), the typical range of wireless signal power in 802.11 generally operate between -70 to -90dBm.

Software and hardware used in the experiment is discussed next.

4.2 Software & Hardware Requirements

4.2.1 Software

The software's used in order to setup an ad hoc environment is described as follows:

- **Windows OS 7 Professional**
  Windows OS is required to have the ability to install various software's and also implement Windows file sharing between a pair of nodes.

- **inSSIDer**
  inSSIDer is used to measure the signal strength and detect access points in the surroundings of laptop placement. The software has the capability to identify hardware vendor of AP's, channels used, name of the network, security protocol used and frequency the AP's are using.

- **NETGEAR WINDA3100 smart wizard**
  The smart wizard is used to create an ad hoc environment between a pair of laptops in order to share files. This software can show performance changes when data is being transferred over a network.

4.2.2 Hardware

Hardware used in the experiments consisted of two wireless laptops, a pair of wireless adapters, basic tools for recording and measuring the area and distance of the pair of laptops (i.e. measuring tape, pen paper and table chart) were used in this propagation measurements. Brief hardware specifications states as follows:

- **Laptop 1**
  - Brand: Hewlett Packard
  - Model: HP Mini 311

- **Laptop 2**
  - Brand: Dell
  - Model: Dell XPS 15

- **IEEE 802.11a/b/g/n USB Wireless Adapter (×2)**
  - Brand: NETGEAR
  - Model: WNDA3100 IEEE 802.11n

- Dual Band (operates at 2.4 and 5GHz)
- Backward compatible to 802.11 a/b/g

4.3Propagation Measurement Environments

Propagation measurements for this dissertation were performed on the ground floor, second floor, third floor, fourth floor and fifth floor in WT building at Auckland University of Technology (AUT). In a suburban residential home the recordings of the experiments were done in three different rooms which is a bedroom, lounge and in garage room. The floor plans and images for each room with description of propagation environment are presented in Figures 4.1 to 4.11.

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4.3.1 Suburban Residential Home

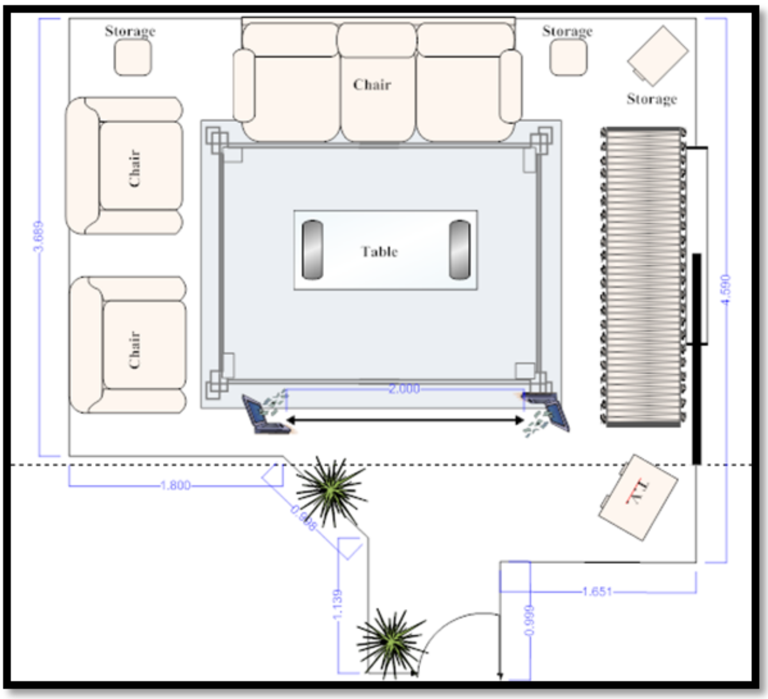

Figure 4.1: Lounge Room (Appendix N)

In the lounge environment propagation measurement is made to see all obstruction objects that can impact radio signal when data is being transferred between a pair of nodes. The lounge is not a pure rectangular room where the distance in meters is provided by the above image. There are no objects obstructing between the two laptops as seen in figure 4.1. But in the surroundings of the laptop there consist of a glass table, multiple leather chairs, fabricated foot stools, plant vases, display storage unit and a television (main objects in the lounge room). The lounge itself is made of timber wood, plasterboard, glass windows which can slightly reduce the signal strength during data transmission over the network. The placement of the laptop is also shown near the entrance door.

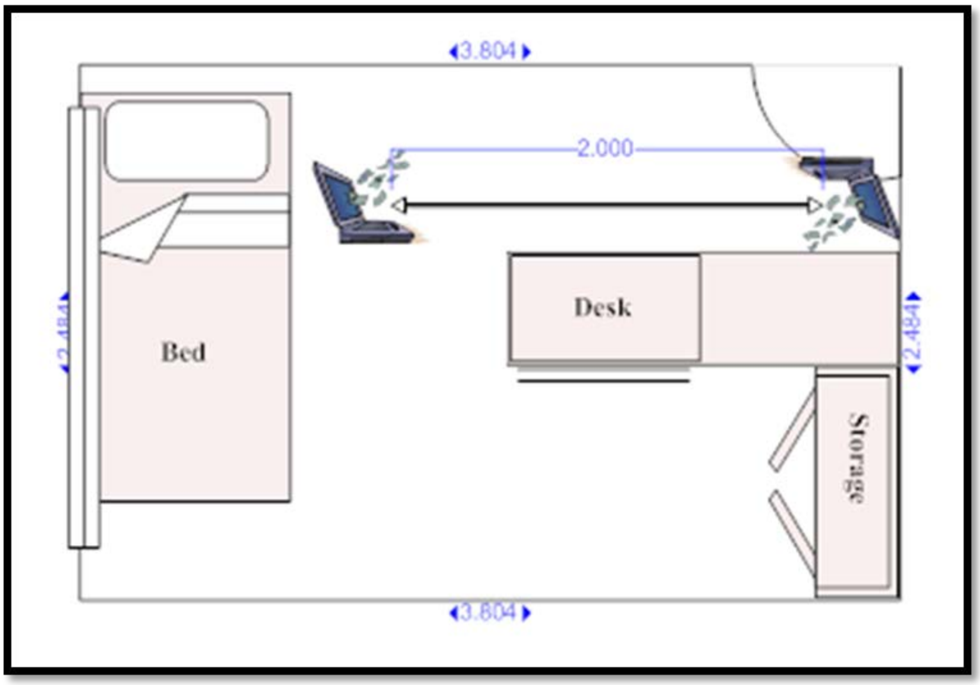

Figure 4.2: Bedroom (Appendix O)

In a bedroom environment, the room is a rectangular shaped where the area size is 3.804m × 2.484m (smallest room conducted in the suburban residential home). In the room there consist of several objects where radio signals can bounce when transmitting data over the network, the objects consists of a fabricated single bed, wooden desk made of timber and a wooden storage unit. The placement for the pair of laptops is placed next to the entrance door as it produced the highest signal strength average, and also the room is made up of plasterboard, timber frames and a piece of glass.

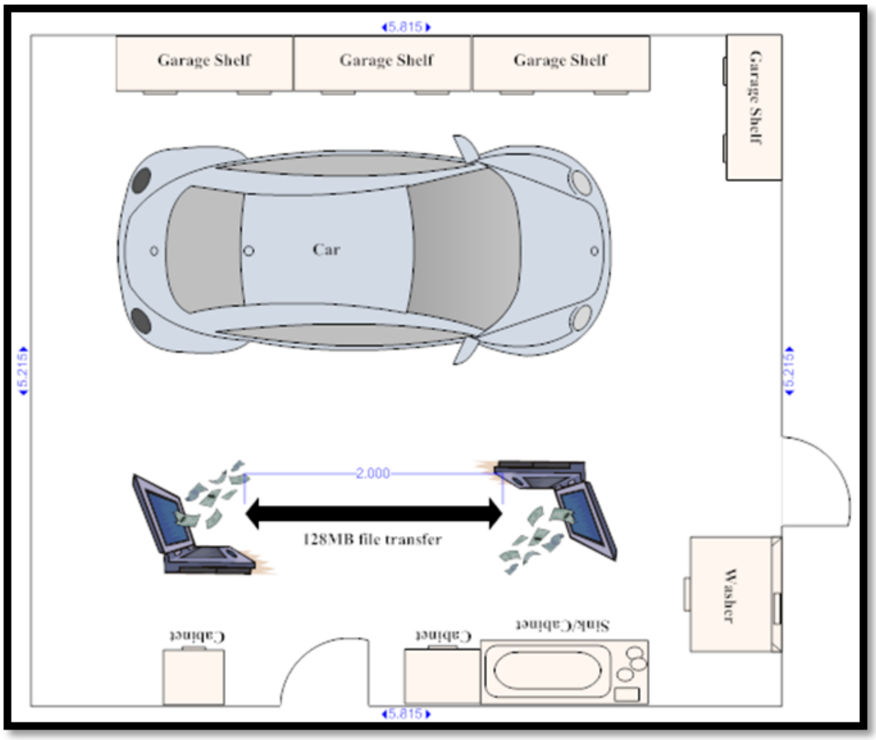

Figure 4.3: Garage Room (Appendix P)

There consisted many objects in the garage environment which can cause slight degrade in signal strength due to large clutter of object. The area size of the room is 5.215m × 5.815m where there was a car placed on one side of the garage. In the room itself, on the back side of the room consisted of multiple wooden storage units for hardware and appliances, one side consisted of an aluminium/plastic washing unit and wooden storage shelf's, the entrance door area had a two cabinets and an aluminium sink, and also the room is made up of plasterboard, timber frames and a piece of glass. The placement of the laptops where in the area between the car and entrance door which showed highest point of signal strength.

4.3.2 Laboratory

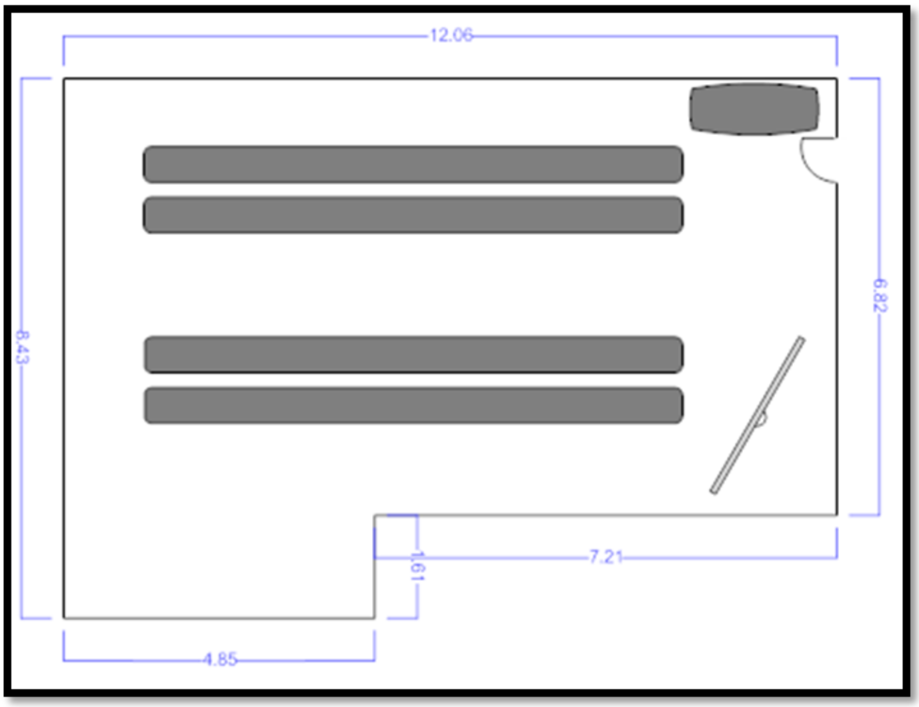

Figure 4.4: WT306 Laboratory (Appendix Q)

Room WT306 consisted of numerous number of Apple Mac computers running down the middle of the room. Sitting on a table near the entrance door consist a document scanner and a laser printer. The room is made up of concrete and the ceiling made of perforated particle boards for ventilation, however the window is made of translucent glass. Area size of the room was at an average of 12.64 × 6.09 where objects also placed in the room were two fixed white board and a mobile white board. On the ceiling of WT306 consisted of a projector for group discussions and presentation. The placement of the pair of laptops was placed near the back end of the lab where the signal strength was strong.

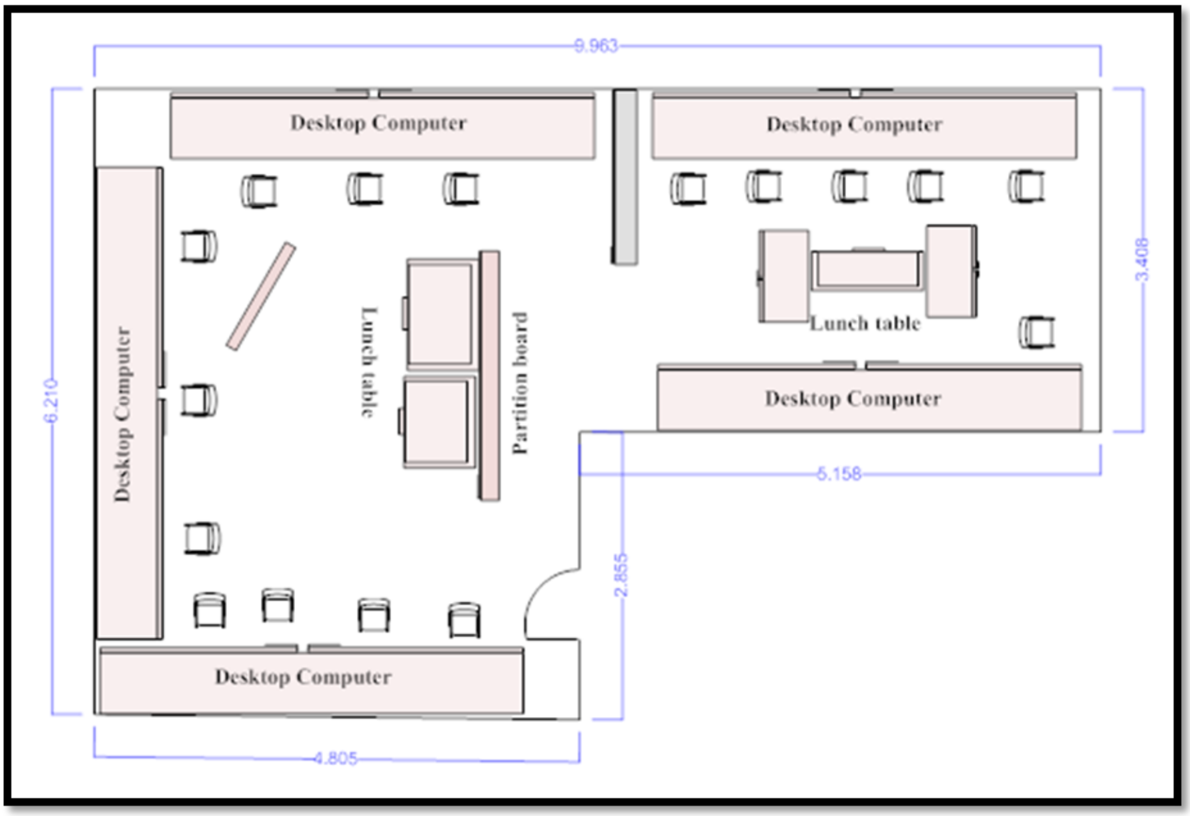

Figure 4.5: WT406 Laboratory (Appendix R)

WT406 laboratory consisted partitions walls in order to separate and privatise some sections of the room. There consisted large quantity of Windows based desktop computers which were placed along each side of the room. In the middle contained a wooden book shelf and by the entrance door consist two rubbish bins. Several computer desks consisted plastic drink bottles, school bags, lecture notes and books. End of the room had a white board marker for notices and two table placed slightly apart from one another. The building of the room was made up of translucent glass for the window, the false ceiling is made of particle boards and wall structure compromised of concrete and plaster board. In the environment of WT406 laboratory room the placement of the laptops were placed near the entrance door as this measured highest average point for signal strength.

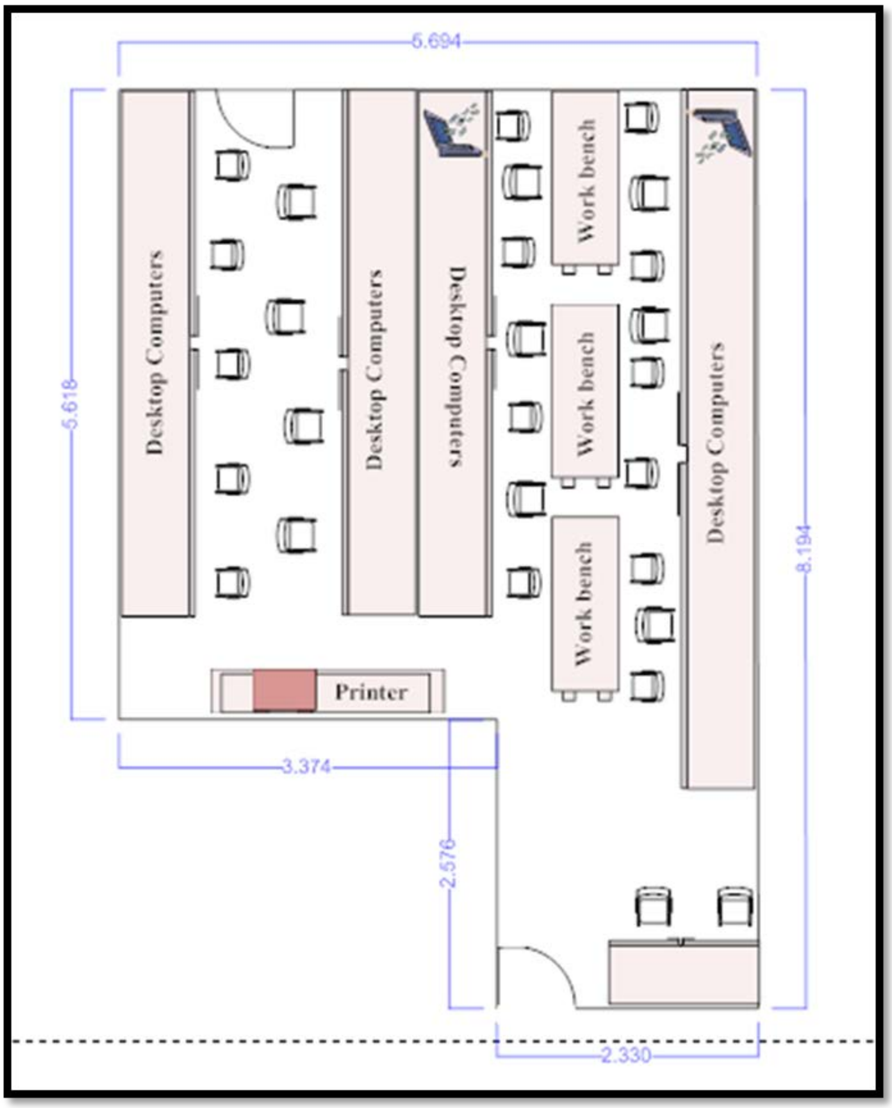

Figure 4.6: WT402 Laboratory (Appendix S)

Room WT402 laboratory was the simplest room consisting of laser printer several desktop computers, chairs and wooden tables to study on. Inside the lab room had to exit doors each located on both ends of the room. There was one rubbish bin near the entrance door and all computer where placed fixed on in the centre of the room and along the wall. The pair of laptops where placed near the back end of the room which showed higher signal coverage.

4.3.3 Common room

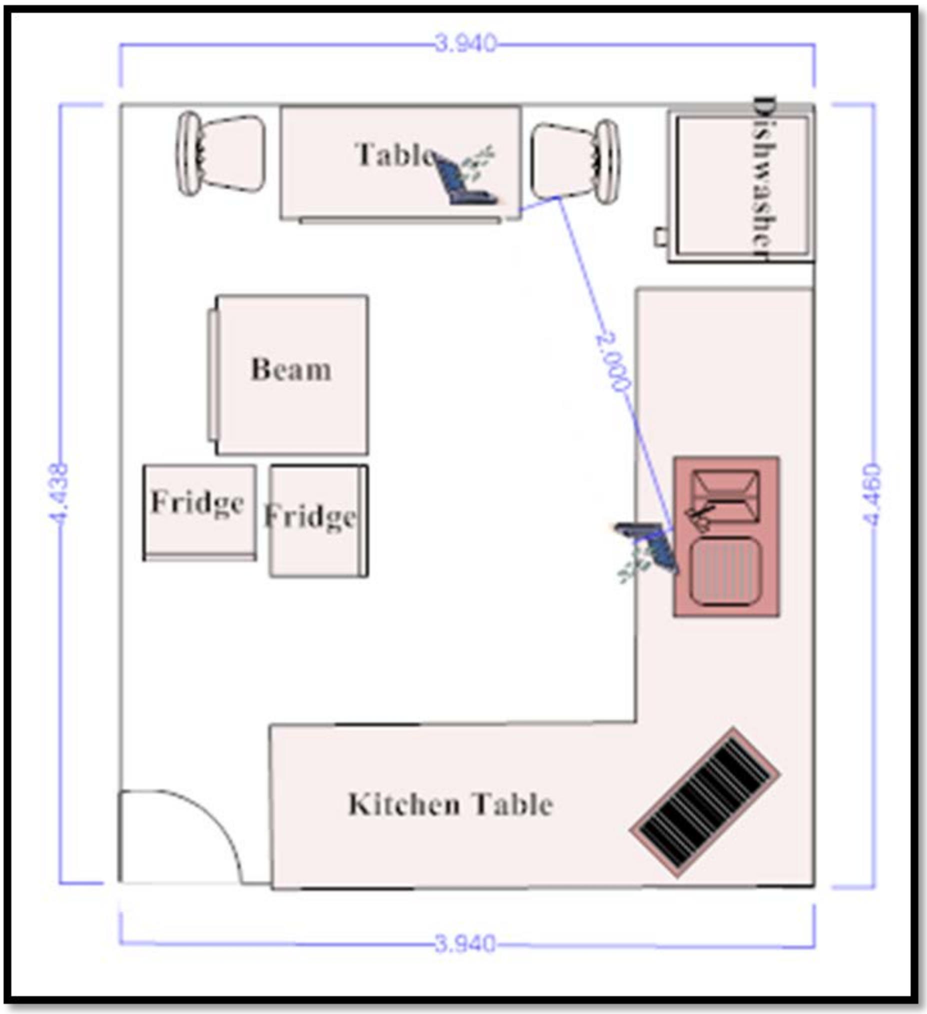

Figure 4.7: WT401 Lunch room (Appendix T)

Room WT401 was the smallest lunch room out of the three rooms the experiment was conducted in. Area size of the room is 3.35 × 4.42 where the room consisted of a microwave, two fridges', electric kettle and a wooden table for having lunch on. A thick concrete beam is placed next to the two fridges where on the opposite side placed a small seating arrangement in order to have lunch on the table. The room had one sink to wash dishes and multiple storage units to store kitchen utilities in. The placements for the pair of laptops were placed next to the kitchen sink and wood table where it showed high point for receiving signal strength. However the room was made up of plaster boards, timber wood for both door and shelves.

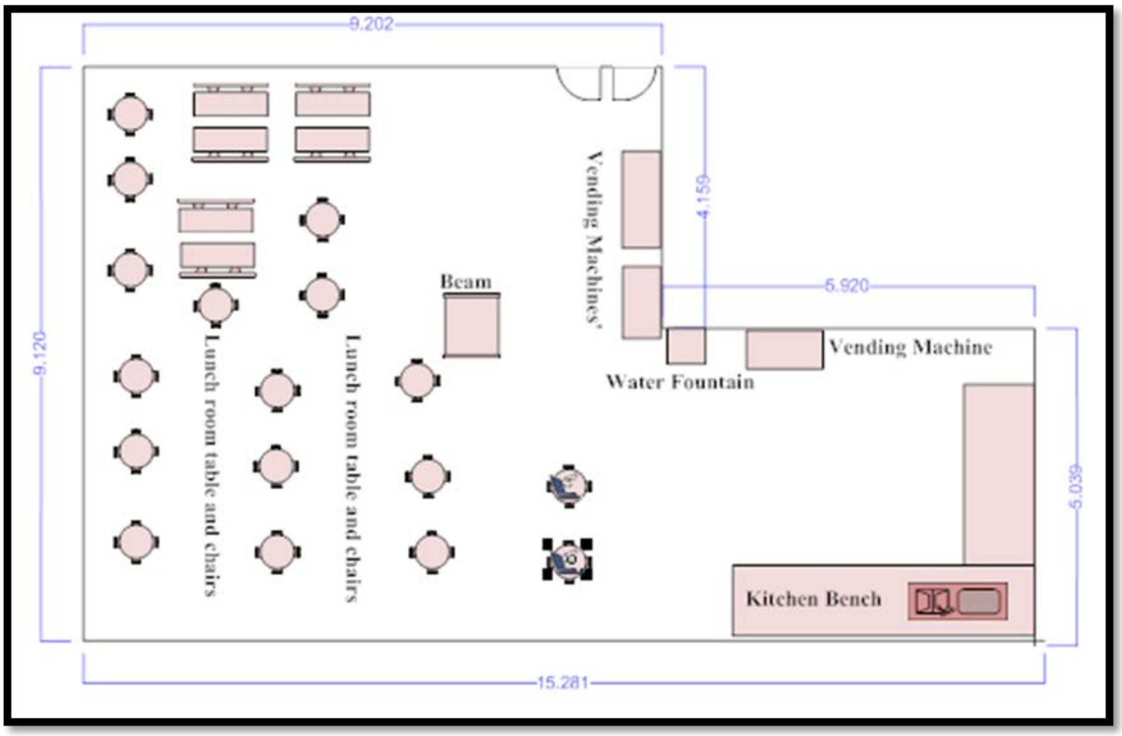

Figure 4.8: WT523 Lunch room (Appendix U)

WT523 lunch room was the largest of the three environments the experiments was conducted in, however in the room consisted of large number of seating chairs and tables for students to have lunch on, there where vending machines located next to the entrance door for students to have quick snacks, one water fountain located opposite the kitchen sink. Also in the room was a microwave, kitchen bench, storage unit for kitchen utilities and a kettle. The pair of laptops was located near the kitchen sink located at the back end near the room window, this section had showed good signal strength and no loss in connectivity.

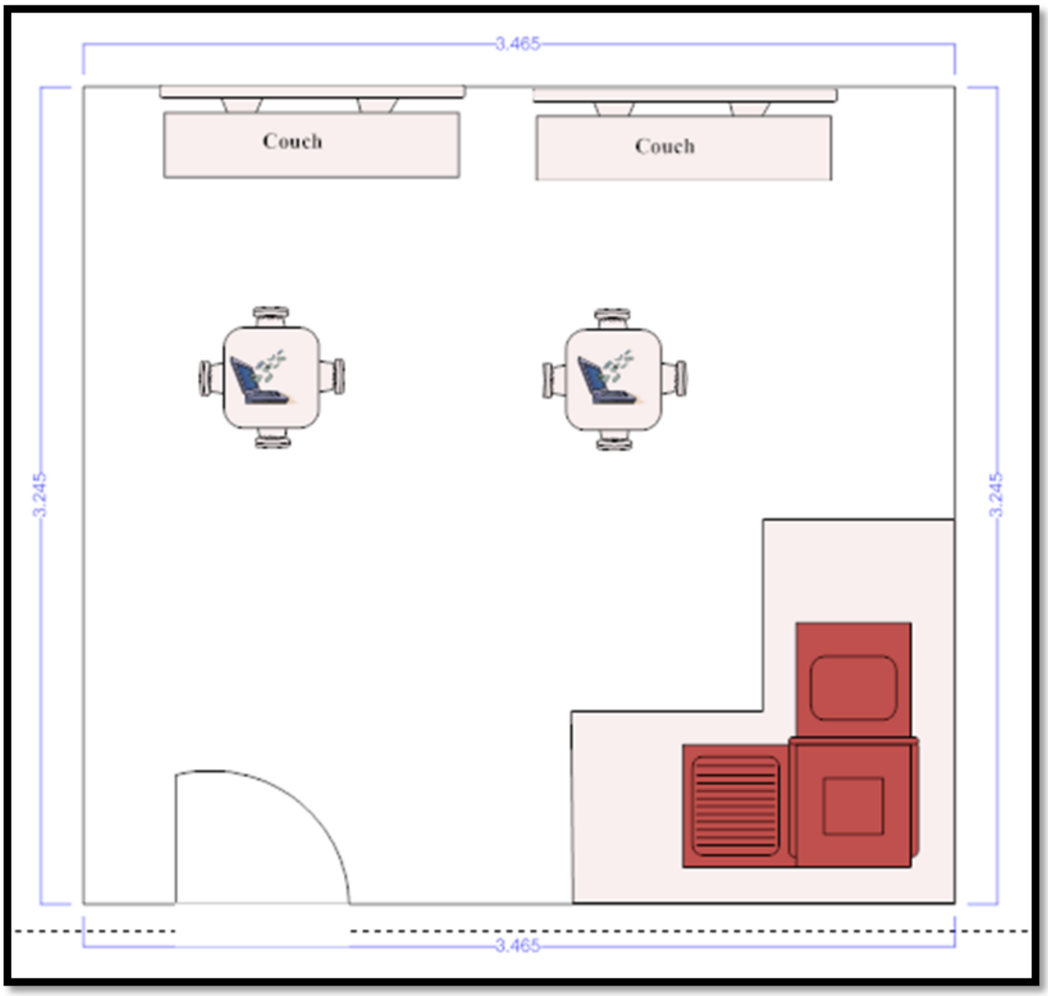

Figure 4.9: WT014 Lunch room

WT014 lunch room was located on the ground floor of WT building. The room consisted of kitchen utensils, a microwave, wooden table and chairs to sit and eat lunch on. The laptop placement was located near the entrance door which showed overall good signal strength. As the room is the base floor of the building, the materials that made up the room consisted of concrete frames, plaster board for the walls, translucent glass and perforated particle board for ventilation. Little storage shelves were also in the room for kitchen appliances to be placed on.

4.3.4 Office Block

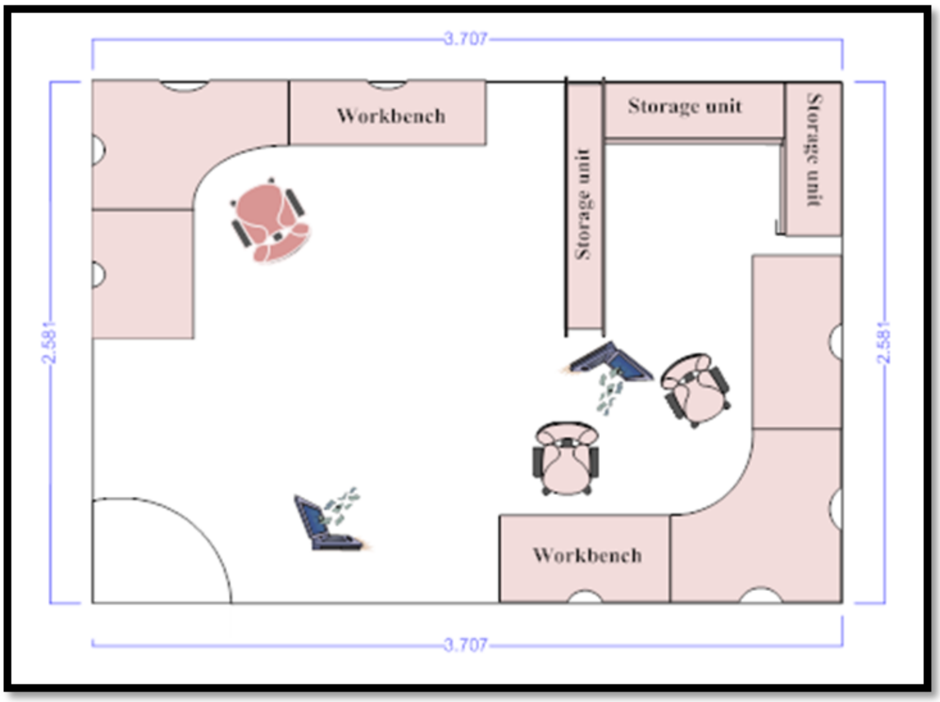

Figure 4.10: WT211 Office room (Appendix V)

Office room WT211 had a slightly large open area space during experimentation. A couple of desktop computers, wooden books shelves, wooden storage units were placed in the room for the lecture needs, also large number of books and lecture notes were also in the room during experimental study. The room was made up of plaster boards, concrete exterior, particle boards and translucent glass for the window. Laptop placements were located near the back end of the second computer where this produced good signal strength.

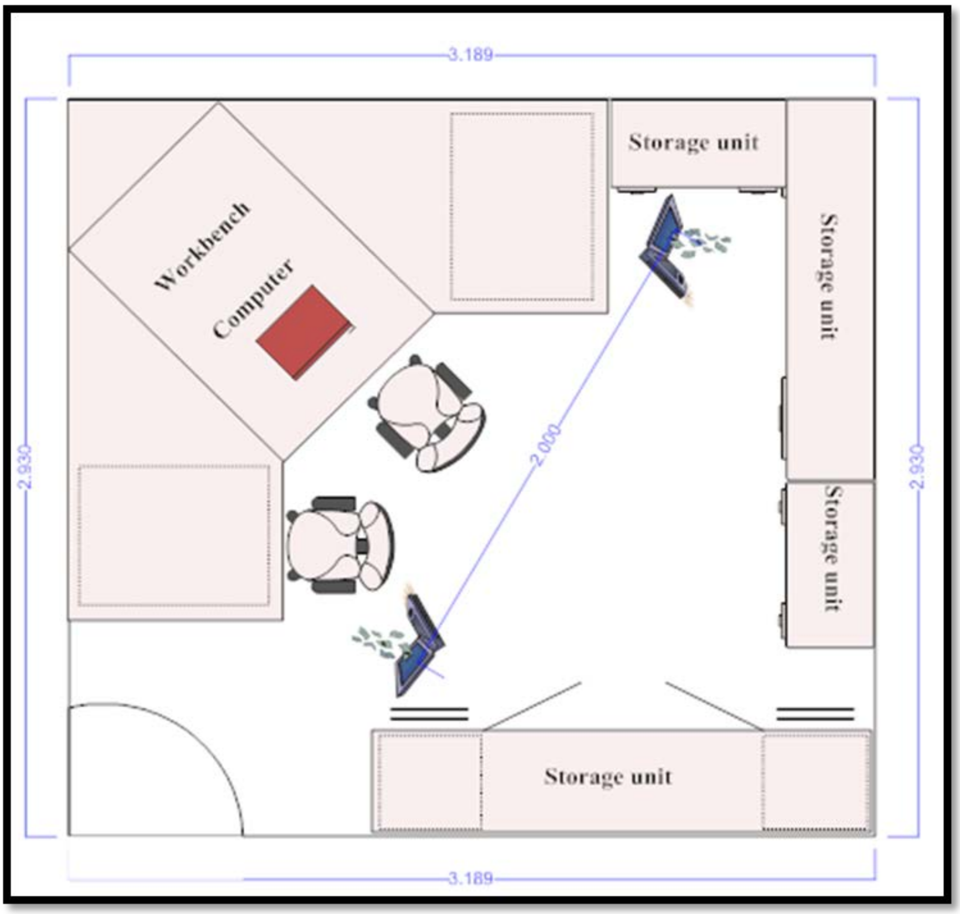

Figure 4.11: WT210 Office room (Appendix W)

WT210 office room was full of paper work, text books and electronic equipment, the room was full of clutter which only enabled us to do the experiment in the centre of the room. However when placing the pair of laptops in the centre of the room, this still showed good signal strength for data to be sent and received. There were also wood shelves where the text book was stored in and one desktop computer. The room size was designed for one user for operating the room. The office room was built with the same materials as all the other rooms experimented in WT building.

4.4 Measurement Scenarios

Propagation measurement is divided by 4 controlled stages for each experiment. The phases will consist of (1) preliminary measurement; (2) trial 1; (3) trial 2 and; (4) trial 3, where each trial will consist of no human, fixed human and random human movement between a pair of nodes. Detailed description for each scenario is described as follows. The pair of laptops are placed 2 meters apart to get optimum throughput results using an ad hoc network setup. Height of both laptops was 1 meter above the ground floor (this is to avoid Fresnel zone in all propagation measurements), pair of laptops is to be faced toward each other (LCD screen looking face to face) where the USB wireless adapter is placed on opposite sides on the USB laptop port. A stop watch was used to calculate the transmission time from TX to RX and used a fixed file size of 129MB for all experiments. Using the NETGEAR and Windows 7 hardware and software enabled us to windows file share (peer-to-peer) to calculate Wi-Fi throughput performance. All objects in the environment while experiments are taken will remain in the same place to ensure data collection remains accurate.

Also measuring signal strength will provide better performance results to identify best laptop placement in each room, therefore using software inSSIDer will output signal strength for different access points it can detected in the surrounding area of experimental study.

NETGEAR graphical user interface (GUI) will also output all nearby networks and also channels used when the ad hoc environment has been deployed. To avoid co-channel interference, we have set the channel number to 3, where this has been the same number throughout all experiments. The reason behind selecting this channel is because of multiple Wi-Fi networks in central Auckland CBD using 802.11g where channels constantly varied and channel 3 did not appear to be used by other wirelesses. I have also set the IEEE standard to be used at 802.11g (2.4GHz). 802.11n was not applicable due to availability and currently not widely deployed.

4.4.1 Preliminary Propagation Measurement

The first stage is to conduct preliminary test trials, the main purpose for preliminary measurement is to ensure that the data being transmitted between RX and TX is successful and ensure there is no drop in packets. Using the ping command *"ping –t<ip address>"* (Windows Command Prompt GUI using Windows 7 OS) on both nodes will address if there is any error in packet transmission. The test run for ping command lasts for two minutes to ensure no packets are being dropped when data is being transmitted before any further experiments can be done. Also measurement for best signal strength was used in the experiments by software inSSIDer, this software confirmed placement of the pair of laptops in an area with good signal strength. Once preliminary test have been completed, stage 2 can then be experimented where there is no human movement between a pair of laptops to record Wi-Fi throughput performance.

4.4.2 Scenario 1 – No human obstruction

Scenario 1 (stage 2) consists of no human movement between the pair of nodes. The environment will be in a controlled state where there will be no interferences from any objects between sender and receiver when data is being transmitted. The data collated provides a solid base for analysis and comparing other scenarios that will be used in the case study.

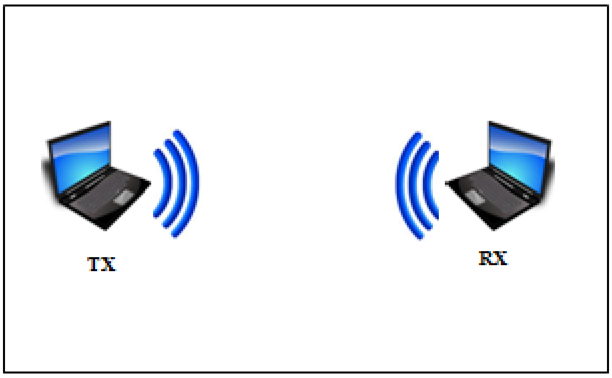

Figure 4.12: No human movement

4.4.3 Scenario 2 – Fixed human obstruction

Scenario 2 (stage 3) is based on fixed human movement between the pair of nodes. As there is only two human used in the test trials, humans will position face towards one another as the start point. From the start of transmission the two humans will be walking towards each other ending up on the opposite side, once they reach on the opposite side the humans will walk back to their original position from start of transmission, this completing 1 cycle. The cycle continues until the data has completed transmitting to RX. Below figure 4.5 illustrates fixed human obstruction between a pair of nodes.

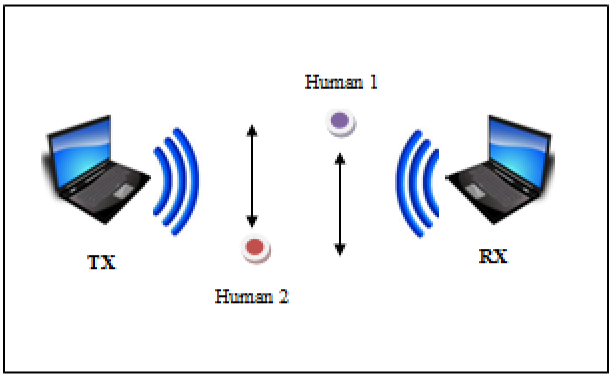

Figure 4.13: Link throughput measurements with fixed human movement

4.4.4 Scenario 3 – Random human obstruction

Scenario 3 (stage 4) is very similar to scenario 2 where instead of having fixed human movement there will be random human movement between the pair of nodes. Random human movement is where objects (human) move in various directions in the area of experimental environment. The random movement will be in between the pair of laptops when data is being transmitted from sender to receiver. Figure 4.6 shows random human movement.

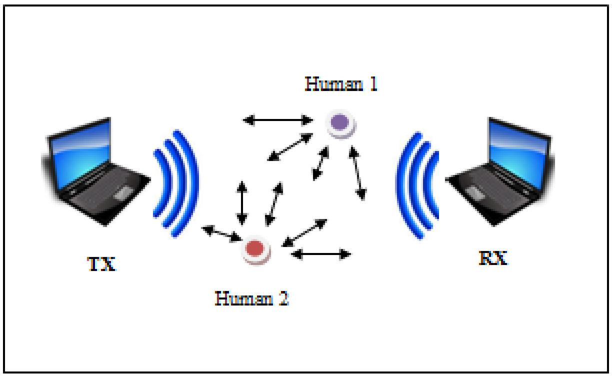

Figure 4.14: Link throughput measurements with random human movement

4.5 Measurement Validation and Accuracy

Knowledge of the measurement method is very important for interpreting results. The accuracy of the propagation measurement results was improved by addressing the following issues.

- **Co-channel interference:** During propagation measurements, there were large numbers of neighbouring WLANs being detected. This is due to experiments being conducted in the CBD of Auckland where there is heavy population density requiring users to access internet. To avoid co-channel interference on system performance, the AP was set to a different channel before experiments were conducted, and remained the same to ensure result accuracy.

- **Validation:** The propagation measurement was conducted three times per scenario to ensure correctness of measurements and results [20, 21]. The measured throughput was done using a stopwatch which was adopted by past research papers using this to calculate data transfer time between the pair of laptops.
- **People movement:** The measurements were conducted after hours/weekends to ensure consistency of human movement in the area of the experimental conduction. A constant of two humans where used to identify any significant impact in Wi-Fi throughput.
- **System configuration:** To ensure there is no effect of system configuration on WLAN performance, identical wireless adapters is being used between the pair of laptops. Firewall and anti-virus where also disabled to ensure no packets are being impacted by security settings.

4.6 Summary

Chapter 4 detailed experimental design, development and implementation of the experiments that is conducted in AUT University library room, laboratory room, office room, lunch room and a suburban residential home. Preliminary measurement would help identify if there is transmission issues in the Wi-Fi ad hoc network between sender and receiver. Also discussed is the measurement validation to ensure accurate data recording and implementation of the experiments is conducted successfully. Chapter 5 discusses Wi-Fi throughput results from the experiments conducted.

Chapter 5
Results and Discussion

The software and hardware requirements, detailed experimental design and deployment in a residential home and AUT environments have been discussed in chapter 4. Chapter 5 however discusses preliminary results in section 5.1. Experimental analysis for each environment is discussed in sections 5.2 to 5.6, and a cross comparison for Wi-Fi throughput is discussed further in section 5.7.

5.1 Preliminary Trials

All preliminary trials ran successfully except for Library environment where experiments could not be conducted properly, this is due to large number of surrounding networks and the interference it causes for the ad hoc. We experienced drop in network connectivity, loss of packets and long delays during packet transmission. Section 5.2 describes the scenario in more detail.

When testing each scenario before official experiments could be conducted, large numbers of access points were detected when using the software insider (version 2.1). This software recognised wireless networks operating around the area of the experiments allowing us to identify what frequency and channels are being used when the running the test. The average number of AP's in Auckland CBD (based around WT building) ranged between 50 to 60, the number of AP's can be unpredictable due to population size where the AP's can increase at any given point. Figure 5.1 and figure 5.2 shows a screenshot of the recorded access points operating in 2.4GHz and 5GHz range in the area of WT building.

Using the AUT-Unisurf infrastructure, the received signal strength indication (RSSI) was shown at an average of-69dBm using a Cisco System Wi-Fi router. This RSSI was good as throughput during preliminary trials were successful. We also saw commonality of channels used in the Auckland CBD environment which were numbers 1, 2, 6 and 11. Channel 1 and 6 showed large number of open networks (thus meaning no security encryption placed on the Wi-Fi router) which could lead to vulnerabilities.

Figure 5.1: AP's using 2.4GHz in Auckland CBD (from AUT WT building)

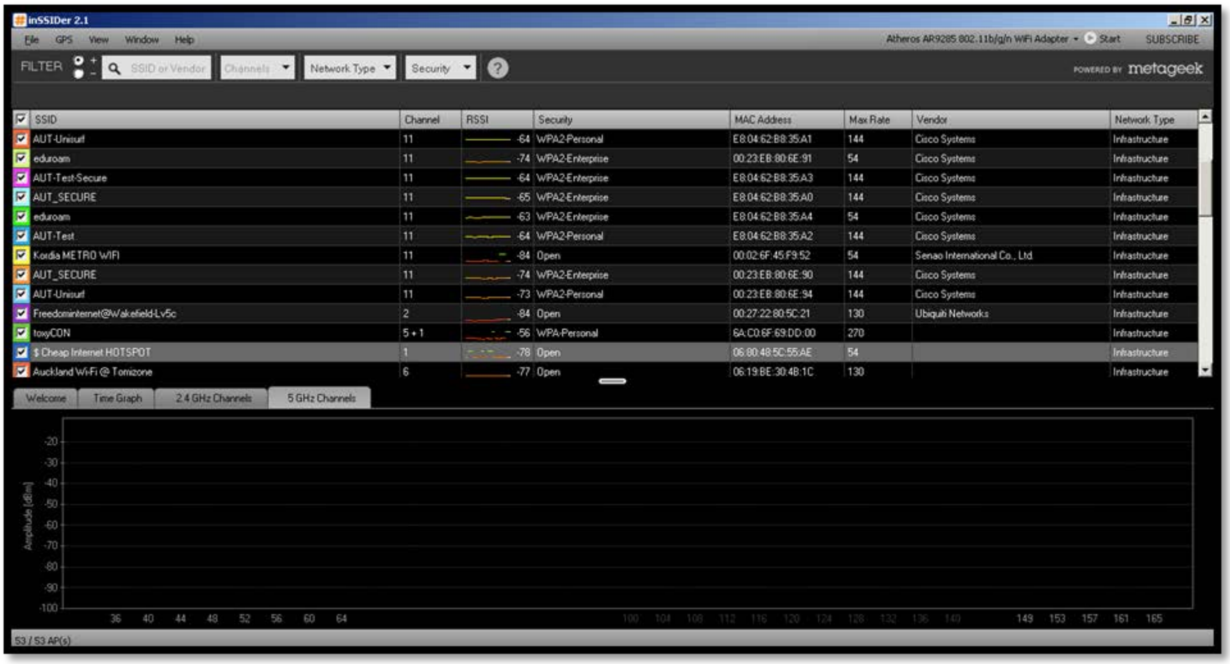

Figure 5.2: AP's using 5GHz is null in Auckland CBD (from AUT WT building)

In a suburban residential home, there are approximately four Wi-Fi modems all using the same frequency of 2.4GHz. The received signal strength in the home environment was at an average of -30 to -37dBm using a D-Link Cooperation wireless modem. Figure 5.3 displays a screen shot of nearby AP's using the same frequency but consist of different channels.

Figure 5.3: AP's using 2.4GHz in a suburban residential home area

Channels used by the wireless modems varied in the area as shown on figure 5.3. Channel 6 was the most common channel selected which could cause co-channel interference when data is being sent over the network; therefore I have set the channel of the D-Link wireless modem to 3 to avoid this effect.

Overall the preliminary results showed a positive outcome except for the Library environment which is further explained below.

5.2 Library Environment

Experiments in the library could not be conducted due to large amount of interferences within the vicinity. Multiple trials had been done to try and make the experiments work in an ad-hoc environment but still remained unsuccessful.

When we had the pair of laptops connected to the network, the communication would randomly drop out and then tries to reconnect. As the experiments were being conducted in the library, the signal strength was good, but even though we had good signal strength the pair of laptops continually dropped out of the network.

Trying the experiments on different levels and sections in the library resulted with unsuccessful tests where connection between the pair of laptops kept dropping out. The possibility of why the network dropped continually could be due to the density of the environment where material such as thick blocks of concrete which can reduce data transmission within the network.

Overall the experiment in the library could not be performed due to inconsistency and drop in network connection.

5.3 Suburban Residential House

(Appendix B, C and D displays data results)

5.3.1 Lounge

Placements for laptops in the lounge were located approximately two meters away from the door where the software identified high signal strength. During the trials there were no packet drop and network loss which identified good connection between the pair of nodes.

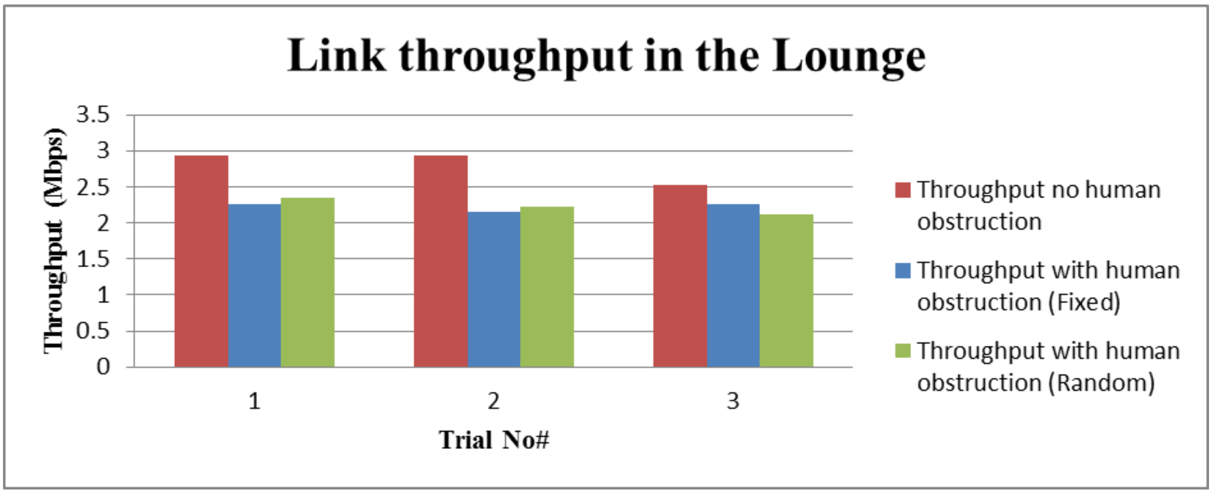

Figure 5.4: Lounge performance result

Results collected from the experiments in a lounge environment showed that there is little impact in throughput when human movement is made between the pair of laptops. The average throughput rate where there is no human obstruction is 2.8Mbps and the received signal strength was at an average of

-37dBm (thus identifies strong for a wireless networks). Trial 3 showed a drop in throughput where there was no human obstruction which could be due to radio signal refracting of objects causing slight delay in transmission.

By using no human movement as a benchmark for performance difference, we can further analyse between fixed and random human movement if there is any significant throughput differences.

By observing the two scenarios of fixed and random human movement (figure 5.4), there was a small drop in throughput when comparing it with no human obstruction. All three trials produced very close throughput results which signify very little impact when looking at human movement between two nodes. We did not see much change either when random movements were surrounding the omni-directional antennas which we thought it would have made large impact due to signal blockage and radio waves being absorbed by human body.

The average throughput for fixed human movement was calculated at 2.22Mbps comparing that to random human movement at an average of 2.15Mbps. From the collected data, we identified that random human movement does cause slower throughput which could be caused by refraction or diffracting of radio waves against human body, but does not poses a great deal in network performance loss in a real world scenario.

Overall the data collected from the experiments in the lounge environment did show a drop in performances when there is human movement between a pair of nodes compared to no human movement, this would be caused by radio waves being effected by diffraction, reflection or absorption through the human body, but did not cause a great impact in Wi-Fi throughput.

5.3.2 Bedroom

Impact of Wi-Fi throughput performance shows very little changes in performances in all three scenarios. The pair of laptops was placed between the bed and entrance door due to the recorded signal strength.

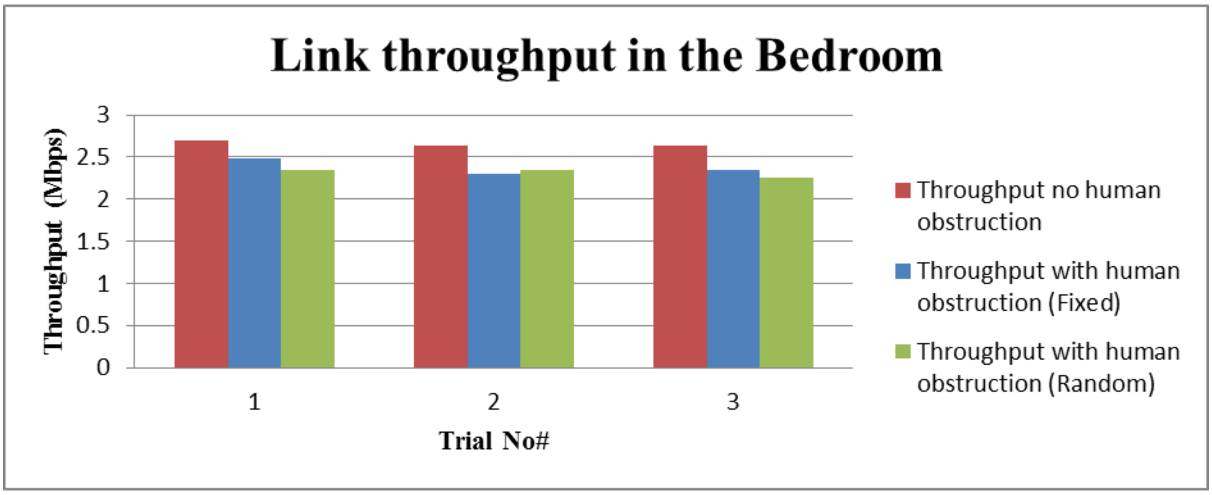

Figure 5.5: Bedroom performance result

By examining the collected data on figure 5.3 showed the overall average throughput was in the range of 2.5Mbps. The signal strength recorded from the software inSSIDer had range between -36 to -38dBm which identifies strong signal strength coverage, due to the signal strength being very strong there was no drop in packet transmission or network loss during all three scenarios.

The scenario for no human obstruction nodes was set as the targeted performance to define if there is an impact in throughput when there is human obstruction. The average throughput in this scenario was 2.65Mbps where trial one had the highest point in performance.

By viewing both fixed and random human movement (average throughput rate of fixed human movement is at 2.38Mbps and random human movement is 2.32Mbps) there seems to be no great deal of interferences, delay or drop in packet as all trial were consistent. Human obstruction provided no great deal of impact in the bedroom environment even when human was stationed near the wireless adapter. Having said that there is no great deal of performance impact could relate to the room being the smallest area size out of the three room used in the experiment. When being in a small room where data is being transferred between a pair of nodes, there could have been a higher chance of radio waves refracting of propagation objects a lot quicker than in a larger room.

Overall considering that the performance showed very little significant impact when there is human obstruction, we see that random human movement still tends to cause slight longer for data being transmitted between a pair of nodes.

5.3.3 Garage

Wi-Fi link throughput showed near identical throughput performances where data transfer rates between a pair of nodes averaged 2.3Mbps. Figure 5.6 shows the collected data output for all three trials.

The pair of laptops were placed near the entrance door where the signal strength showed a strong connection which average around -38dBm. By selecting no human obstruction as the foundation to identify if there is a significant impact in data transfer rate, we see an average throughput of 2.32Mbps for no human movement which is the lowest in the three environments in a residential home. This could be due to the density of obstructed objects and the room being very large where radio waves refract causing longer periods of receiving the signal from sender to receiver.

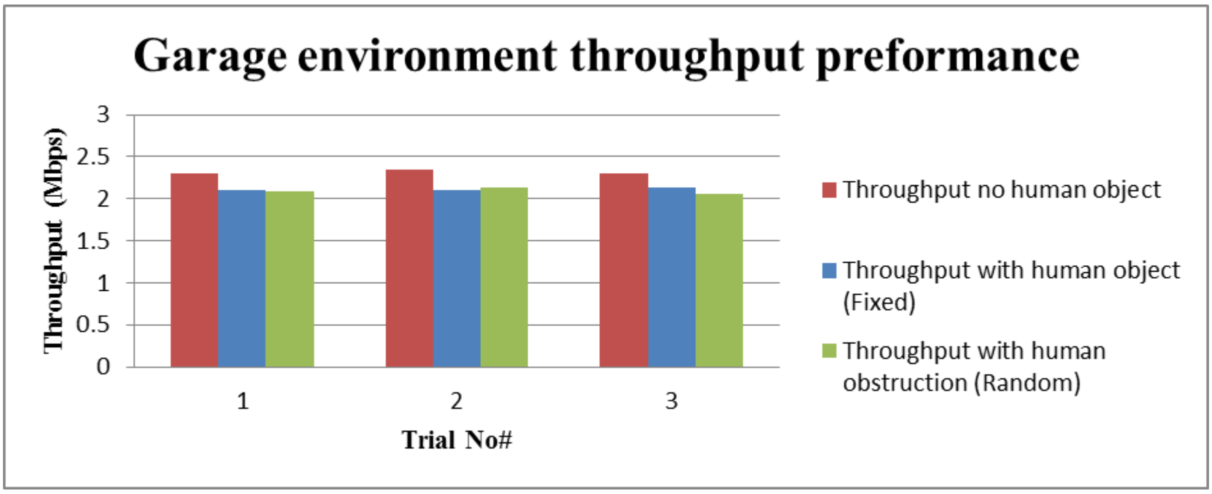

Figure 5.6: Garage performance result

Comparing the average throughput between fixed (2.12 Mbps) and random (2.09 Mbps) human movement we see a small difference of 0.03Mbps. This result does not pose a great deal of significant impact in the overall throughput performance. The slight delay in performance would be due to random human movement obstructing the omni-directional antenna where radio waves refracting and absorbing on the human object.

Overall by conducting the experiment in the garage environment there posed no great deal in Wi-Fi throughput, and noticed that the throughput is slightly slower compared to bedroom and lounge environments.

5.4 Laboratory Environment

(Appendix E, F and G displays data results)

5.4.1 WT402 Laboratory

Room WT402 consisted of Wi-Fi throughput results which is very close and had very little impact in the overall performance. Figure 5.6 illustrates the result from WT02 collected data.

Running experiments in WT402 laboratory showed a close throughput result in all trials conducted. The placement of the pair of laptops where located near the back wall as the software inSSIDer showed the highest average point in signal strength. When roaming around with the laptops to identify the best position to place the pair of laptops showed an average of -64 to -76dBm signal strength.

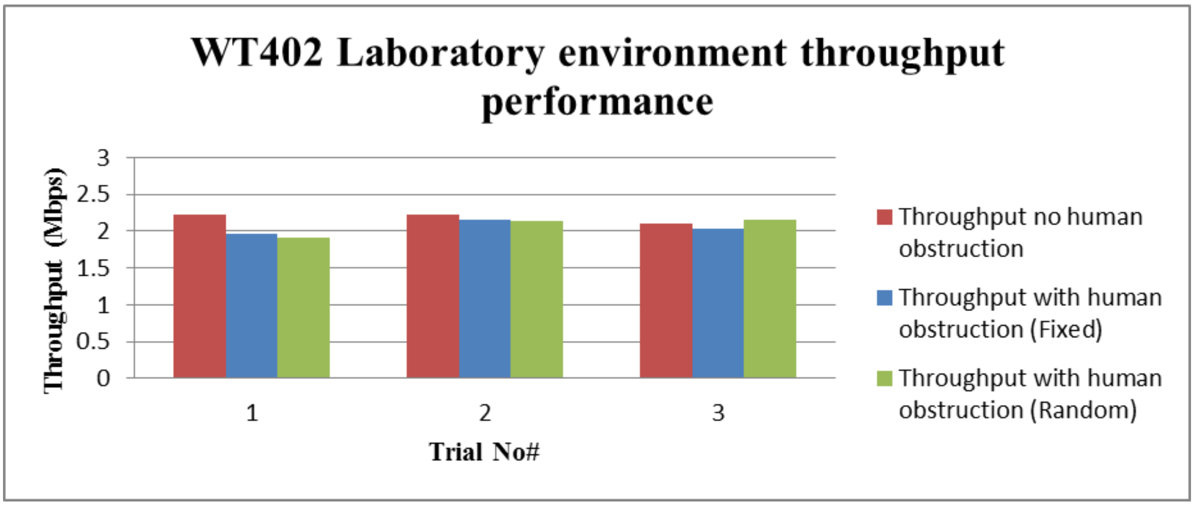

Figure 5.7: WT402 Laboratory performance result

Figure 5.7 illustrated above shows all three trials that have been conducted consists similar Wi-Fi throughput and had overall average throughput rate of 2.09Mbps. There was no significant impact in performance when comparing no human, fixed and random human movement, but what was noticeable is when there is random human movement standing next to the omni-directional wireless adapter, the data being transmitted had a slight degradation in performance which dropped to an approximately 0.5Mbps, and when the human moved out from the blockage of the antenna the transmission speed went back to normal speeds. From this occurrence we can identify that the radio waves have slightly absorbed or refracted of the human body, this slowing speed at small rate.

5.4.2 WT406 Laboratory

Experiments conducted in room WT406 laboratory showed a small variation in throughput performance which produced little difference in Wi-Fi throughput. An interesting finding that we see in figure 5.8 identified that random human movement at one point had the higher throughput performance.

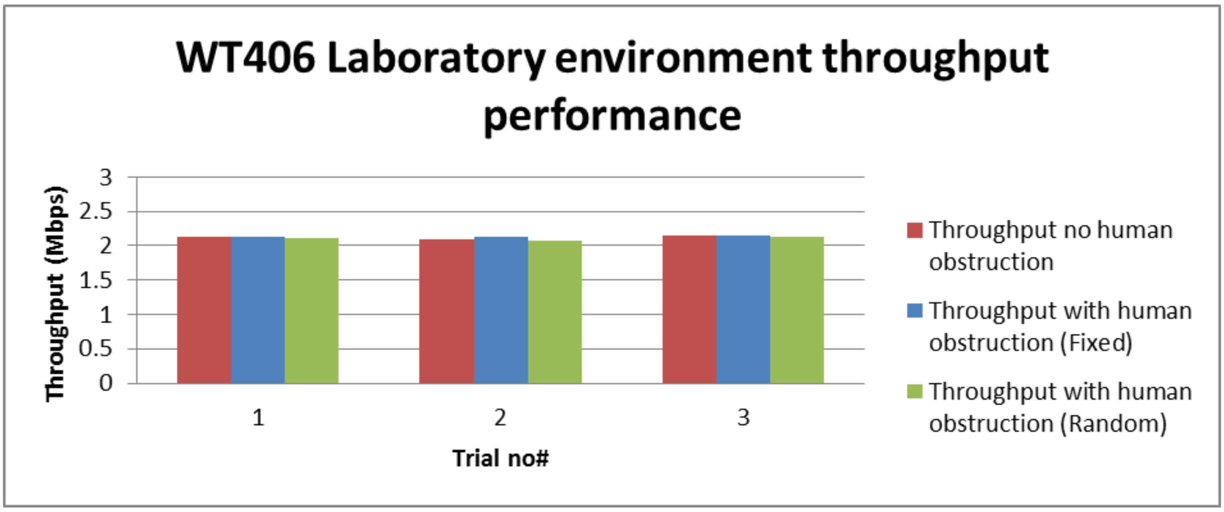

Figure 5.8: WT406 Laboratory performance result

Even though the experiments conducted showed large changes in Wi-Fi throughput, we still saw the signal strength at a good range where it average between -64 to -76dBm which ranged the same as room WT402 laboratory.

The average throughput result where there is no human obstruction consisted of 2.18Mbps, this transmission rate is good compared to all other trials conducted where there is no human obstruction. Fixed human movement showed a slight slower data transfer rate between a pair of nodes with an average of 2.05Mbps. The collected data suggests that there would have been external factors that would have affected scenario performance where it could be the cause of human movement, external radio interference where there may have been wireless mobile devices and portable wireless laptops sharing the same frequency of the AUT wireless modem outside the experimental scenario. However the average throughput rate with random human movement was at 2.07Mbps which is very similar to fixed human movement.

Overall the results showed large variation in performance as there might be a possibility when experiments are conducted in a laboratory may vastly differ in throughput.

5.4.3 WT306 Laboratory

The data collected when experimenting in the laboratory showed results that consisted of slight significant impact. Figure 5.8 illustrates the variation is performance where fixed human movement showed the lowest rate of throughput. Signal strength recorded was at an average of -65 to -74dBm which produced good connection. Even through the results conducted showed variation in performance for one scenario, the signal strength still remains strong with no network loss during transmission and packet loss.

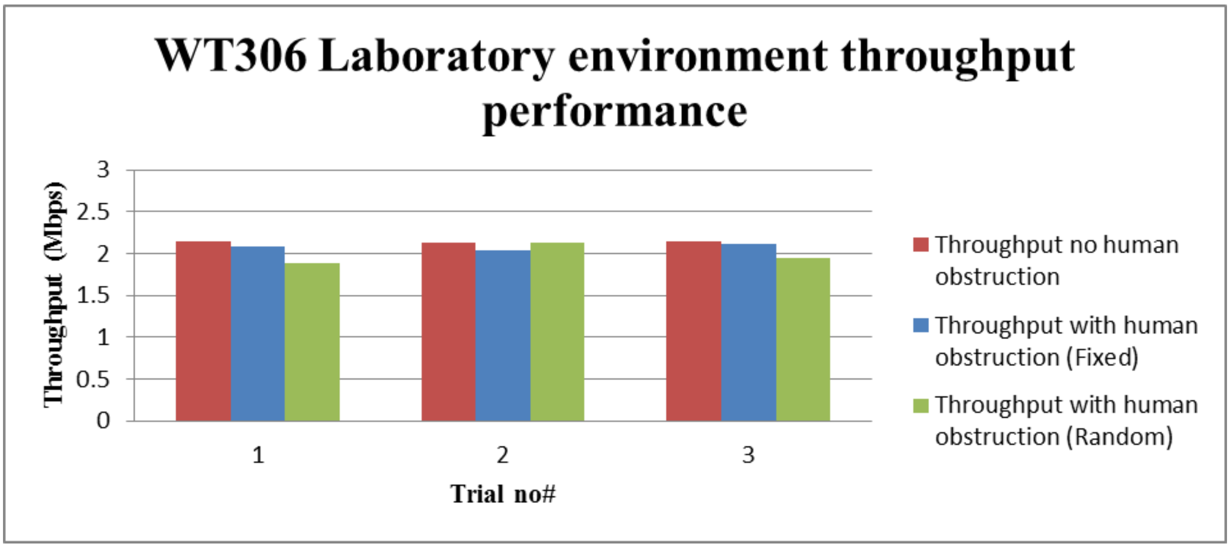

Figure 5.9: WT306 Laboratory performance result

The above illustration of the collected data from the experiments conducted, we see a significant performance difference in both scenarios where there is a great drop in throughput during human obstruction. The average throughput performance had produced an outcome of 2.14Mbps where there is no human interference compared to the scenario where there is human with a rate of 2.01Mbps. The Wi-Fi throughput performance again very small impact when there is human movement occurring in a laboratory environment.

5.5 Lunchroom

(Appendix H, I and J displays data results)

5.5.1 WT014 Lunchroom

The experiment conducted in room WT014 is located on the bottom floor near the faculty of Design and Creative Technology where we saw little impact in Wi-Fi throughput in all three scenarios.

The signal strength was slightly different compared to the laboratory environment even though all rooms are located in the same building. The RSSI averaged between -60 to -65dBm and did not see any drop in packets or network connectivity.

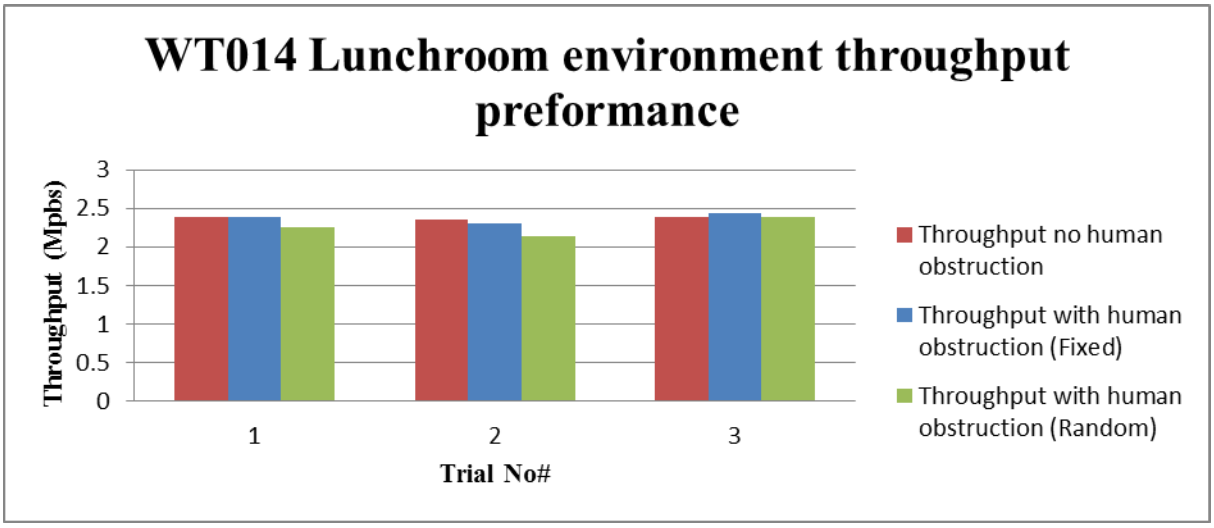

Figure 5.10: WT014 Lunchroom performance result

From the data collected the highest average throughput recorded was where there is no human obstruction and random human movement at an average of 2.38Mbps. The performance was very much the same where human movement did not cause a great deal of significant impact. Comparing results with no human and random human movement, we see fixed human movement had an average of 2.37Mbps which showed little change but not enough to make a differential conclusion.

Even though there was human interference, it seems to pose no significant contribution to the final outcome where the difference in both scenarios is 0.01Mbp/s. Overall we see no significant outcome through using Wi-Fi link throughput.

5.5.2 WT523 Lunchroom

Room WT523 was the largest room compared to the all three rooms where the experiments have been conducted. Before running the experiments during the preliminary trials we noticed that in some areas there was bad connectivity when trying to set up the ad hoc network, this resulted in black spots, packet loss and long delays causing time outs to occur. When placing the pair of laptops near the kitchen bench we noticed strong connection with no packet loss and high throughput time.

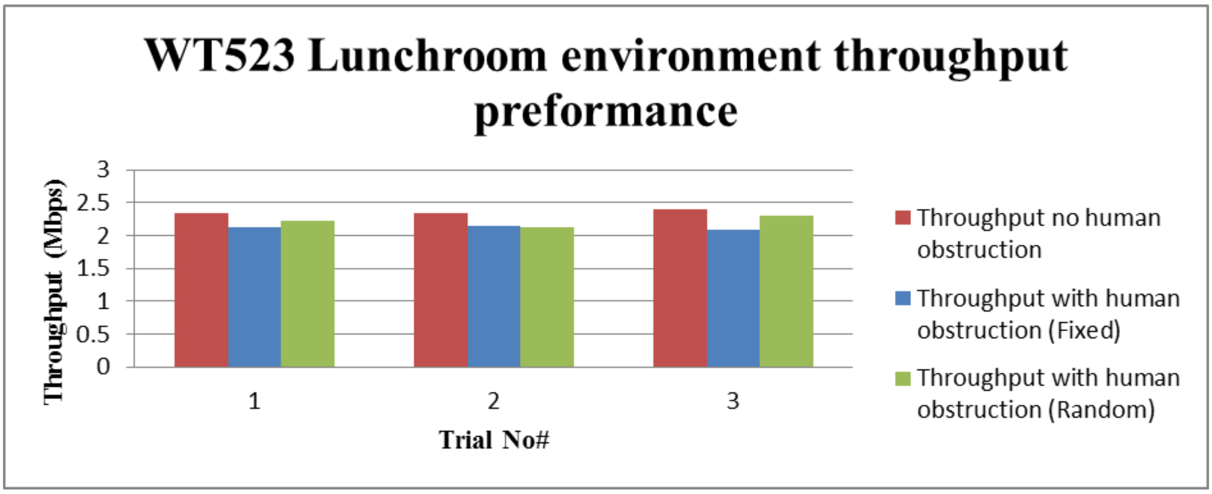

Figure 5.11: WT523 Lunchroom performance result

Figure 5.11 illustrates no human interference where this is the benchmark for throughput performance to see if there is a great deal of significant impact. The scenario with no human obstruction had an average throughput result of 2.37Mbps. The signal strength was strong where there were no packet delay and packet loss during transmission of data. Average RSSI recorded was constant at -76dBm when conducting experiments in the WT523 lunch room.

By investigating both fixed and random human movement scenarios, we have identified that the average performance showed higher throughput with random human movement at 2.22Mbps compared to fixed human obstruction at 2.12Mbps. As the performance difference between the two scenarios is 0.10Mbps, it did not pose a great deal of significant impact in the overall data transfer rate. Considering the room was the largest out of all the lunchrooms the experiments produced good throughput rate which was interesting as we thought it would take a considerable amount of time for radio waves to receive signal from the sender node due to large area coverage.

Another interesting factor to be looked into is internal radio frequency such as microwave where it did not cause a great deal of impact for data transfer rate between the pair of nodes.

Overall from the data collected there was no great deal of significant impact in Wi-Fi throughput performance, where random and fixed human movement showed very close result in a larger room.

5.5.3WT401 Lunchroom

WT401 was the smallest room for experiments conducted in all experimental environments where the results shown from figure 5.12 illustrate that Wi-Fi throughput performance is very close. The benchmark (no human movement) throughput consisted of an average of 2.55Mbps.

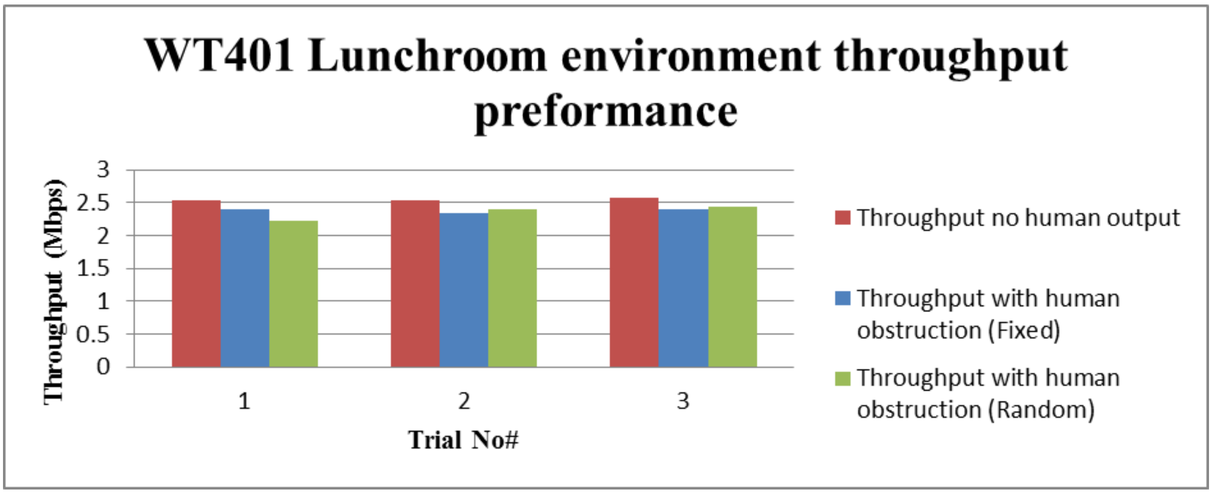

Figure 5.12: WT401 Lunchroom performance result

When experimenting in the WT401 lunchroom the signal strength was strong and we noticed that during data transmission between the pair of nodes there were no time out when packets were being sent. The average signal strength recorded was between -64 to -76dBm. Comparing the performance between fixed and random human movement there was very little difference. Fixed human obstruction showed throughput rate at 2.38Mbps compared to random human movement at 2.35Mbps.

Considering this showing higher throughput rate compared to the other rooms could be due to the fact that this room is the smallest and is very dense, causing radio waves to reflect of walls slightly faster than it being in a larger room.

Overall the results show very little impact when there is fixed and random human movement which shows that in a real world environment impact of people movement poses not great deal in network performance.

5.6 Office Environment

(Appendix K, L and M displays data results)

5.6.1 WT211 Office room

Room WT211 was the smaller room out of the office block environment, this room consisted a lot of clutter with vast amount of text books, shelves for book storage and technological equipment. From the data collected during the experiment, we produced an illustration to identify if there is a significant impact in performance. Figure 5.13 shows throughput performance difference in both scenarios.

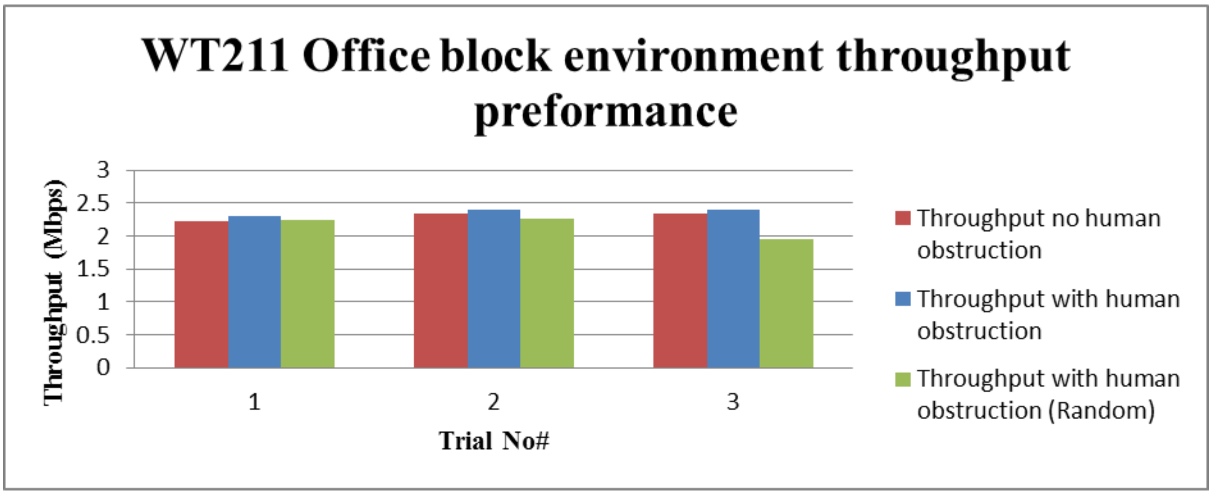

Figure 5.13: WT211 Office Block performance result

There is very little impact in human interference when there is fixed and random human movement. The average data transfer rate for no human obstruction is 2.31Mbps where when there is fixed human obstructions for the first time out of all scenarios the throughput is higher at 2.36Mbps. Even though the performance difference is very small, there could be some attributes that could have affected the transfer rate to be slightly faster. Factors which could have contributed to slight increase of throughput could be due to the omni-directional antenna where the radio waves bouncing of some objects travelling slightly faster for the receiver to receive the data.

Random human movement showed an overall throughput of 2.16Mbps which is slower than both scenarios (fixed and random human movement) which was to be expected. The last trial had a slight drop in performance as human object remained near the omni-directional antenna which reduced the speed of data transmission.

Overall the results show an interesting result as we see for the first time when there is human obstruction that the throughput is slightly higher than no human interference, but poses no great deal of impact in a real life Wi-Fi network environment.

5.6.2 WT210 Office room

Office room WT210 showed an outcome where random human movement consisted of higher throughput compared to no human and fixed human movement (where they both had near same throughput). Figure 5.13 shows a graphical representation of the data collected when the experiments were conducted.

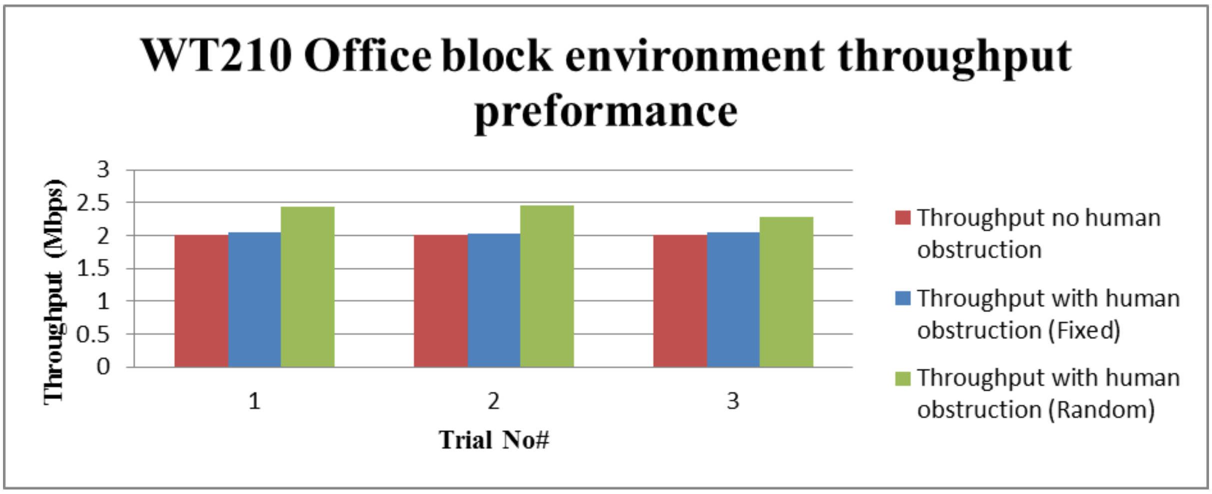

Figure 5.14: WT210 Office Block performance result

When the experiments were conducted the received signal strength was good at an average of -70 to -78dBm. There were no losses in packet transmission when data was sent from one node to another which provided strong network coverage.

The average throughput result for no human obstruction was at 2.01Mbps, fixed human interference consisted of throughput of 2.04Mbps which is slightly slower but poses no great deal in performance difference. When there is random human movement there was an increase in throughput rate which resulted to an average of 2.39Mbps. This increase in performance could be due to radio waves refracting from random human movement which could have possibly resulted in faster data transfer rate.

Overall the performance showed an interesting result where random human movement showed higher throughput performance compared to fix and no human movement, but again provided no significant impact in a real life environment.

5.7 Cross Comparison

In order to distinguish the overall impact on Wi-Fi throughput performance, cross comparison has been designed to analyse any significant performance issues in a wireless network.

Table 5.1 presents information for each scenario in the environments the experiment has been conducted, this showing individual and average Wi-Fi throughput performance. The measurement unit for each experiment was recorded in megabytes per second (Mbps), cross comparison chart also provides the degradation results for throughput in each scenario.

To identify any significance in data transfer, no human movement was the base of all experiments to see if fixed and random human interference caused lower throughput. On average where there is no human movement during the experimental trials we saw overall Wi-Fi throughput rate of 2.12Mbps. The major issue during transmission of data between sender and receiver nodes is in a library environment where data could not be transmitted due constant drop in network connectivity.

Using no human movement as the benchmark to distinguish performance impact on Wi-Fi, we can further discuss impact on fixed and random human movement. Considering fixed human movement stationing in one position and walking alternatively to each end of the room, throughput slightly dropped due to obstruction of human interference. Comparing the results in a residential home environment the drop in overall performance was 13.2% (from 2.59Mbps to 2.24Mbps). In a lunch room environment the impact of throughput was slightly lower but resulted with no great deal of significant impact, overall degradation between no human and fixed human movement in the lunch room was 5.9%, which is not very big to identify that there is a great deal of throughput change. However again we see that in the laboratory environment the throughput varies in different room. Out of the three rooms (fixed human movement) some trial had slight higher throughput than when there is human movement even though multiple test trial were done, but did not provide a great deal of Wi-Fi throughput impact in the overall performance. Office block environment produced interesting results when there are fixed human impact during transmission of data through a Wi-Fi network compared to no human movement. As human movement results consisted a slight greater throughput, the difference in throughput performance between the scenarios is 0.04Mbps which is not very big.

Table 5.1: Throughput degradation

Location	Without human movement	With human obstruction			
		Fixed human		Random human movement	
		Throughput (Mbps)	Degradation (%)	Throughput (Mbps)	Degradation (%)
Residential Home					
Lounge	2.8	2.22	20.7	2.23	20.4
Bedroom	2.65	2.38	10.2	2.32	12.5
Garage	2.32	2.12	8.6	2.09	9.9
Average	2.59	2.24	13.2	2.21	14.3
Lunch Room					
WT014	2.38	2.37	0.4	2.38	0
WT523	2.37	2.12	10.5	2.22	6.3
WT401	2.55	2.38	6.7	2.35	7.8
Average	2.4	2.29	5.9	2.32	4.7
Laboratory					
WT306	2.15	2.05	4.7	2.07	3.7
WT402	2.22	2.14	3.6	2.10	5.4
WT406	2.11	2.08	1.42	1.99	5.7
Average	1.51	2.09	3.2	2.1	4.9
Office Block					
WT211	2.31	2.36	-2.2	2.16	6.5
WT210	2.01	2.04	-1.5	2.39	-18.9
Average	2.16	2.2	-1.85	2.28	-6.2

From the presented cross comparison between no human and fixed human movement above, comparative analysis must also be done between no human and random human movement to identify performance of Wi-Fi throughput.

Due to random human movement in each trial consists of humans moving in all directions in the environment of the experiment during data transmission, we see that in a residential home environment, the throughput rate is slightly slower in all rooms where the experiments have been conducted. By calculating the degradation of human movement as shown on table 5.1, we see an overall 14.3% difference in impact when there is random human movement between a pair of nodes. Even though the performance is small we still see throughput being impacted due to human obstruction. Lunch room environment also had lower throughput outcome during experimental phases, by comparing results the overall performance difference is 0.06Mbps which is only a small 4.7% change in Wi-Fi throughput. However in the laboratory environment the outcome in throughput was also showed no impact in the overall performance when there is random human movement. Considering results from fixed human movement where there was greater impact in throughput, having random human movement produced near opposite results where data transfer rate was very quick over the wireless medium. In the office block environment the overall comparison between no human and random human movement was very small. We again see the overall average throughput consisting of better throughput compared to having no human.

From the analysis conducted between no human and random human movement we see very little impact in Wi-Fi throughput.

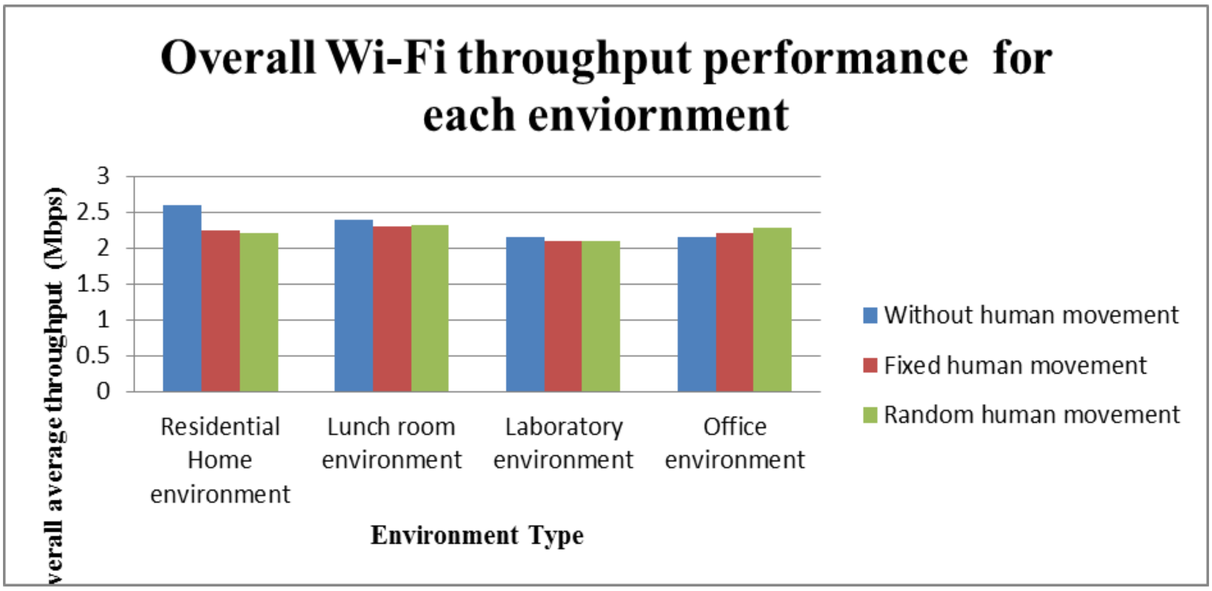

Figure 5.15: Overall Wi-Fi throughput average for each environment

Throughout the experiments conducted the average throughput for each scenario averaged over 2Mbps. However the case study has identified that people movement posed very little difference in throughput performance when comparing it to no human movement, therefore considering in a real life environment human movement poses very small impact in Wi-Fi throughput.

Overall several interesting points have been analysed from the findings made through this research. This chapter has provided discussion and analyses from the data collected through heavy experimental study. The next chapter discuss further about the finding and possible future work.

Chapter 6

Conclusion and Future Work

In chapter 5, we have discussed the propagation measurement results and provided analysis for each scenario. This chapter concludes a summary of each chapter for research and possible direction for future work.

We investigated the impact of people movement on Wi-Fi Link throughput performance using propagation measurements. Due to the simplicity and low cost of wireless technologies, WLANs have been widely deployed in small offices too suburban residential homes in order to provide suitable network performances. Challenges faced when deploying WLAN is a lot different from wired local area network due to the random changes of propagated environments. This study investigates specifically on Wi-Fi link throughput performance in indoor environments where there is no human, fixed and random human movement.

Chapter 2 reviewed IEEE 802.11 standards, protocols used in 802.11 and radio propagation. In order to utilize 802.11 technologies, basic knowledge is required for designing, deploying and testing for best throughput performances. Currently 802.11b and 802.11g are the most common standards being used in indoor environments (i.e. small offices and suburban residential homes),whereas 802.11n in recent times have been designed for better data transfer rate mainly for large organisations. Protocols of 802.11n have also improved greatly on PHY and MAC layers.

Radio propagation was also discussed which can effect RSS and throughput on the wireless network. It is very difficult to stay clear of radio interferences in an everyday environment due to numerous devices sharing the same frequencies, radio waves being absorbed, refracted and diffracted of object which could result to a loss in throughput performance. Therefore placement for APs and nodes in a dense environment should carefully be considered to optimize best performances for the wireless network.

Propagation measurement is the research methodology used in this dissertation which is talked about in Chapter 3. It is very difficult to use computer simulations and analytical modelling when there is human movement between pair of wireless nodes to gain real understanding on Wi-Fi throughput in a real life environment.

Chapter 4 looked into the design and planning phases of propagation study. Hardware and software used in the experiments was also discussed where past researchers have notified it is best to use the same equipment in all test trials. Also avoidance of propagation interferences was also talked about in order to have trials repeated in exact conditions.

Data collection and analysis from experiments are discussed in Chapter 5. All experiments where tested with three different scenarios, using no human, fixed and random human movement in different environments. Preliminary trials were conducted first to find if data transfer can be done between two nodes in a wireless environment. Preliminary trials showed that in ad hoc environments signal coverage in all experiments were good except for AUT library rooms.

Experiments in the library could not be conducted due to interferences within the vicinity. Various preliminary trials have been conducted in different sections and levels in the library but found that the setup would always drop out from the network. We also had experienced the pair of laptops which was connected where packets being transmitted (from sender to receiver) would constantly delay and also drop out this causing incomplete transmission. Therefore we came to a conclusion that in a library environment data cannot be transmitted consistently between a pair of nodes using ad hoc setup.

Once the preliminary testing had been completed, measuring Wi-Fi throughput performance was conducted in three different rooms for each environment (except for office room as this was two). Using the data collected, analysis had been discussed where few finding have been discovered which is as follows: (1) random and fixed human movement does not pose great significant difference in Wi-Fi throughput when comparing it with no human movement in the environments the experiments were conducted, therefore identifying that there is no a great deal of impact where there is people movement between two nodes during data transmission, and (2) in AUT library environment it can be difficult to get good Wi-Fi throughput rate due to external radio interferences. These interferences are mainly caused by wireless devises sharing the same frequency and also the surrounding materials the library is made off, this reduced signal strength and loss in network connectivity.

6.1 Future Research

As we have investigated human movement on Wi-Fi link throughput using propagation measurements, exploration of similar study is still required as there are considerable amount of factors that can affect data transfer rates. A few research investigations that could be considered for future work is to investigate human movement on Wi-Fi link throughput using 2.4 GHz and 5 GHz under propagated environment. Using a similar approach used in my research can identify if frequency changes produce large impact on Wi-Fi throughput.

Also another consideration is to experiment Wi-Fi throughput performance in outdoor environments and seeing if the surrounds cause data transfer rates to slow down. Considering these topic can help improve the understanding of human impact on wireless throughput under various conditions.

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Appendix A

NETGEAR ad hoc system configuration

This section will give an overview of the configuration for the NETGEAR wireless adapter device.

When a pair of NETGEAR wireless adapters is connected to a pair of laptop, the configuration (MFC application) must be configured to have both computers being able to send information across the network.

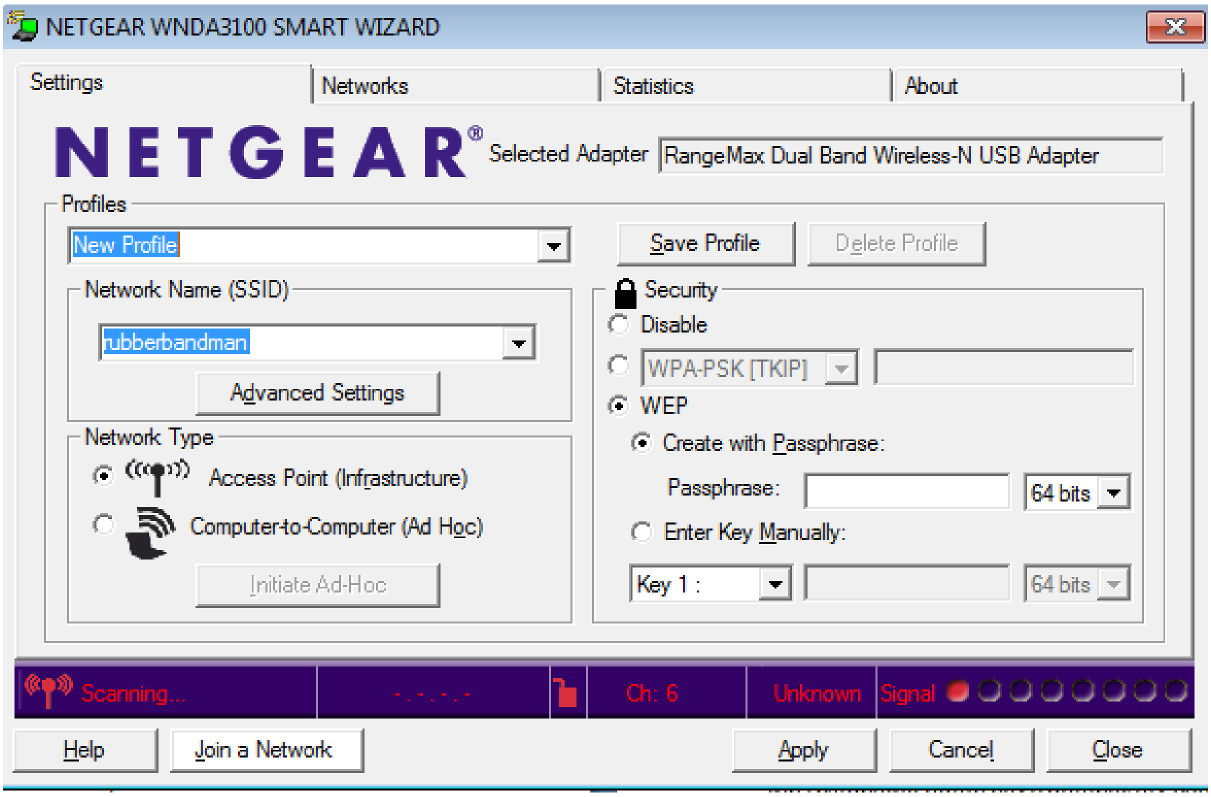

Figure A.1: NETGEAR GUI

The SSID network name must be changed to the one that is being used, for instance in a residential home environment we use SSID as “rubberbandman”. The current connection method is selected as Access Point (infrastructure mode), this will need to be changed to Computer-to-Computer (ad-hoc). Once Computer-to-Computer is selected, we require selecting ad-hoc transmission type and wireless channel determining on the wireless modem.

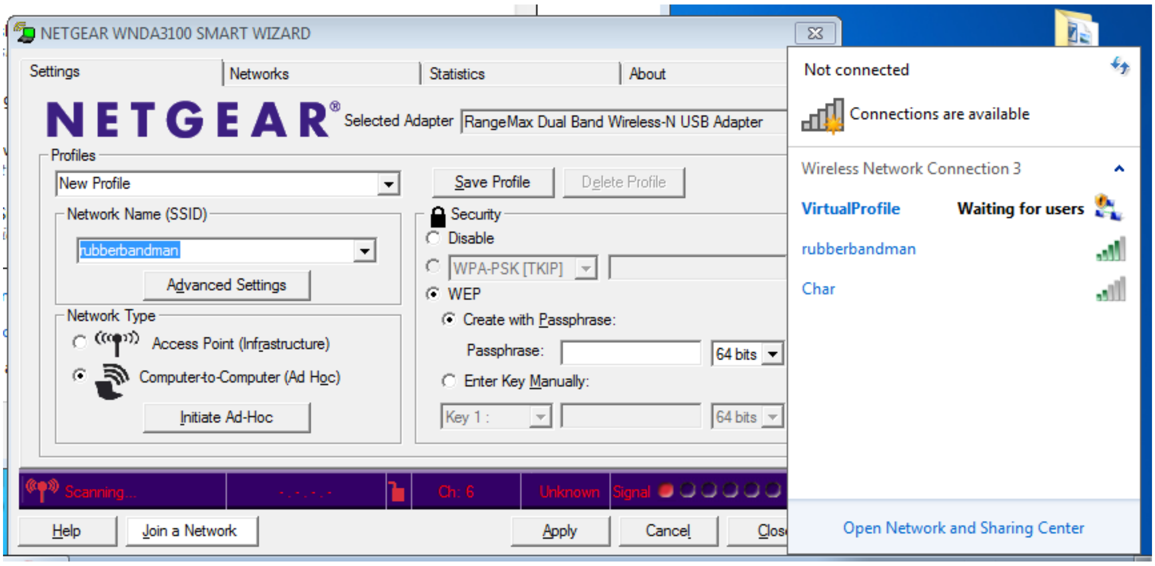

Figure A.2: NETGEAR ad hoc setup/waiting for user to connect

Once I have initiated the ad-hoc environment, a "VirtualProfile" is created for the receiver to connect to a computer. In order for the VirtualProfile to be active, there needs to be another wireless device which has the capability to connect to the VirtualProfile.

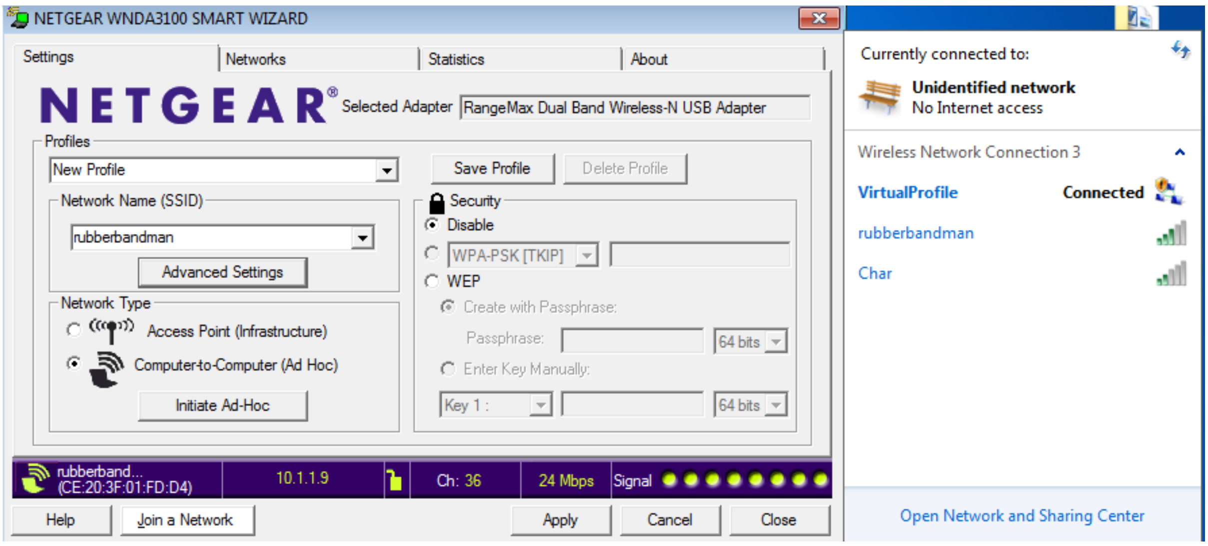

Figure A.3: Ad hoc connection established between a pair of nodes

Figure A.3 shows and example of an ad-hoc being initiated and connected to the "VirtualProfile" using the access point "rubberbandman". As it is connected we can see that the NETGEAR GUI shows a green notification at the bottom, this identifying that a pair of computers is connected rather than having a red notification notifying it is disconnected or there is no communication between the nodes. Another identification that we can confirm that the pair of laptops are connected by using windows operating system “Network & Sharing Centre”, which is also GUI based and can be viewed on figure A.3 above located on the right hand side of the above image.

Appendix B

Data collection with no human movement in a suburban residential home

Location: Lounge

Table B.1: No human movement in the lounge (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.44	2.93
2	129	3	8/8	0.44	2.93
3	129	3	8/8	0.51	2.53
Average					2.8

Location: Bedroom

Table B.2: No human movement in the bedroom (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.48	2.69
2	129	3	8/8	0.49	2.63
3	129	3	8/8	0.49	2.63
Average					2.65

Location: Garage

Table B.3: No human movement in the garage (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.56	2.30
2	129	3	8/8	0.55	2.35
3	129	3	8/8	0.56	2.30
Average					2.32

Appendix C

Data collection with fixed human movement in a suburban residential home

Location: Lounge

Table C.1: Fixed human movement in the lounge (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.57	2.26
2	129	3	8/8	1.00	2.15
3	129	3	8/8	0.57	2.26
Average					2.22

Location: Bedroom

Table C.2: Fixed human movement in the bedroom (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.52	2.48
2	129	3	8/8	0.56	2.30
3	129	3	8/8	0.55	2.35
Average					2.38

Location: Garage

Table C.3: Fixed human movement in the garage (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	1.02	2.11
2	129	3	8/8	1.02	2.11
3	129	3	8/8	1.01	2.13
Average					2.12

Appendix D

Data collection with random human movement in a suburban residential home

Location: Lounge

Table D.1: Random human movement in the lounge (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.55	2.35
2	129	3	8/8	0.58	2.22
3	129	3	8/8	1.02	2.11
Average					2.23

Location: Bedroom

Table D.2: Random human movement in the bedroom (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.55	2.35
2	129	3	8/8	0.55	2.35
3	129	3	8/8	0.57	2.26
Average					2.32

Location: Garage

Table D.3: Random human movement in the garage (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	1.03	2.09
2	129	3	8/8	1.01	2.13
3	129	3	8/8	1.05	2.05
Average					2.09

Appendix E

Data collection with no human movement in a Laboratory

Location: WT402

Table E.1: No human movement in WT402 laboratory (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.58	2.22
2	129	3	8/8	0.58	2.22
3	129	3	8/8	1.02	2.11
Average					2.22

Location: WT406

Table E.2: No human movement in WT406 laboratory (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	1.01	2.13
2	129	3	8/8	1.03	2.09
3	129	3	8/8	1.00	2.15
Average					2.11

Location: WT306

Table E.3: No human movement in WT306 laboratory (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	1.00	2.15
2	129	3	8/8	1.01	2.13
3	129	3	8/8	1.01	2.15
Average					

Appendix F

Data collection with fixed human movement in a Laboratory

Location: WT402

Table F.1: Fixed human obstruction in WT402 laboratory (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	1.09	1.97
2	129	3	8/8	1.00	2.15
3	129	3	8/8	1.06	2.03
Average					2.05

Location: WT406

Table F.2: Fixed human in WT406 laboratory (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	1.01	2.13
2	129	3	8/8	1.01	2.13
3	129	3	8/8	1.00	2.15
Average					2.14

Location: WT306

Table F.3: Fixed human obstruction in WT306 laboratory (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	1.03	2.09
2	129	3	8/8	1.05	2.04
3	129	3	8/8	1.02	2.11
Average					2.08

Appendix G

Data collection with random human movement in a Laboratory

Location: WT402

Table G.1: Random human movement in WT402 laboratory (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	1.12	1.92
2	129	3	8/8	1.01	2.13
3	129	3	8/8	1	2.15
Average					2. 07

Location: WT406

Table G.2: Random human movement in WT406 laboratory (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	1.02	2.11
2	129	3	8/8	1.04	2.07
3	129	3	8/8	1.01	2.13
Average					2.10

Location: WT306

Table G.3: Random human movement in WT306 laboratory (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	1.14	1.89
2	129	3	8/8	1.01	2.13
3	129	3	8/8	1.11	1.94
Average					1.99

Appendix H

Data collection with no human movement in a Lunchroom

Location: WT014

Table H.3: No human movement in WT014 lunchroom (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.54	2.39
2	129	3	8/8	0.55	2.35
3	129	3	8/8	0.54	2.39
Average					2.38

Location: WT523

Table H.2: No human movement in WT523 lunchroom (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.55	2.35
2	129	3	8/8	0.55	2.35
3	129	3	8/8	0.54	2.39
Average					2.37

Location: WT401

Table H.3: No human movement in WT401 lunchroom (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8	0.51	2.53
2	129	3	8	0.51	2.53
3	129	3	8	0.50	2.58
Average					2.55

Appendix I

Data collection with fixed human movement in a Lunchroom

Location: WT014

Table I.1: Fixed human movement in WT014 lunchroom (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.54	2.39
2	129	3	8/8	0.56	2.30
3	129	3	8/8	0.53	2.43
Average					2.37

Location: WT523

Table I.2: Fixed human movement in WT014 lunchroom (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	1.01	2.13
2	129	3	8/8	1.00	2.15
3	129	3	8/8	1.03	2.09
Average					2.12

Location: WT401

Table I.3: Fixed human movement in WT014 lunchroom (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.54	2.39
2	129	3	8/8	0.56	2.35
3	129	3	8/8	0.53	2.39
Average					2.38

Appendix J

Data collection with random human movement in a Lunchroom

Location: WT014

Table J.1: Random human movement in WT014 lunchroom (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.57	2.26
2	129	3	8/8	1.01	2.13
3	129	3	8/8	0.54	2.39
Average					2.38

Location: WT523

Table J.2: Random human movement in WT523 lunchroom (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.58	2.22
2	129	3	8/8	1.01	2.13
3	129	3	8/8	0.56	2.3
Average					2.22

Location: WT401

Table J.3: Random human movement in WT401 lunchroom (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.58	2.22
2	129	3	8/8	0.52	2.39
3	129	3	8/8	0.53	2.43
Average					2.35

Appendix K

Data collection with no human movement in an obstructive Office

Location: WT211

Table K.1: No human movement in WT211 office room (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.58	2.22
2	129	3	8/8	0.55	2.35
3	129	3	8/8	0.55	2.35
Average					2.31

Location: WT210

Table K.2: No human movement in WT210 office room (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	1.03	2.01
2	129	3	8/8	1.03	2.01
3	129	3	8/8	1.03	2.01
Average					2.01

Appendix L

Data collection with fixed human movement in movement in an obstructive Office

Location: WT211

Table L.1: No human movement in WT211 office room (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	0.56	2.3
2	129	3	8/8	0.54	2.39
3	129	3	8/8	0.54	2.39
Average					2.36

Location: WT210

Table L.2: No human movement in WT210 office room (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	1.05	2.05
2	129	3	8/8	1.06	2.03
3	129	3	8/8	1.05	2.05
Average					2.04

Appendix M

Data collection with random human movement in a Office room

Location: WT211

Table M.1: Random human movement in WT211 office room (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	57.4	2.25
2	129	3	8/8	56.9	2.27
3	129	3	8/8	1.10	1.95
Average					2.16

Location: WT210

Table M.2: Random human movement in WT210 office room (recorded data)

Trial no#	File Size (MB)	Channel no#	Signal Strength	Recorded Time in Minutes (RX to TX)	Throughput (Mbps)
1	129	3	8/8	53.1	2.43
2	129	3	8/8	52.4	2.46
3	129	3	8/8	56.3	2.29
Average					2.39

Appendix N

Lounge environment

Figure N.1: Lounge environment image 1

Figure N.2: Lounge environment image 2

Appendix O

Bedroom environment

Figure O.1: Bedroom environment image 1

Figure O.2: Bedroom environment image 2

Appendix P

Garage environment

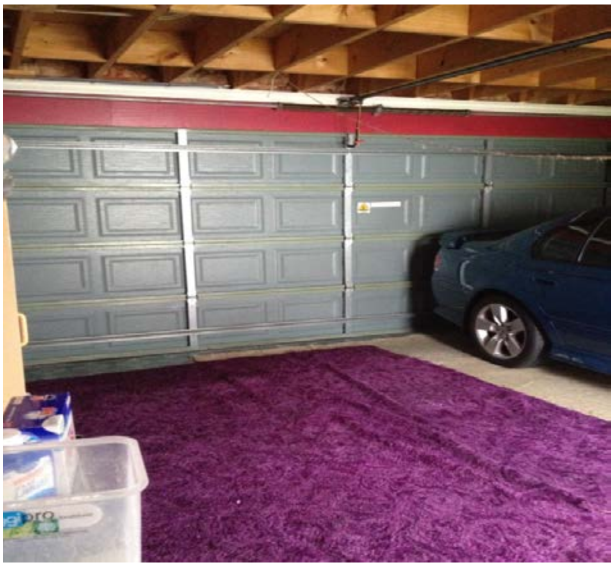

Figure P.1: Garage environment image 1

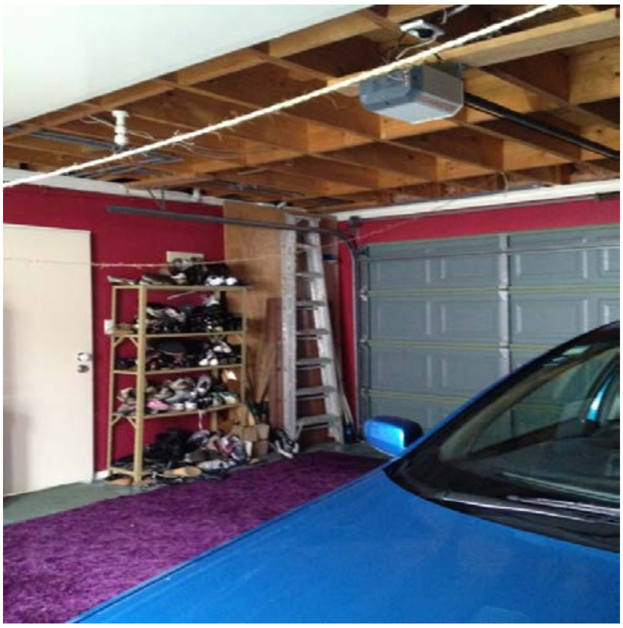

Figure P.2: Garage environment image 2

Appendix Q

WT402 Laboratory environment

Figure Q.1: WT406 laboratory environment image 1

Figure Q.2: WT406 laboratory environment image 2

Appendix R

WT406 Laboratory environment

Figure R.1: WT406 laboratory environment image 1

Figure R.2: WT406 laboratory environment image 2

Appendix S

WT306 Laboratory environment

Figure S.1: WT306 laboratory environment image 1

Figure S.2: WT306 laboratory environment image 2

Appendix T

WT523 Lunchroom environment

Figure T.1: WT523 lunch room environment image 1

Figure T.2: WT523 lunch room environment image 2

Appendix U

WT401 Lunchroom environment

Figure U.1: WT401 lunch room environment image 1

Figure U.2: WT401 lunch room environment image 2

Appendix V

WT211 Office room environment

Figure V.1: WT211 Office room environment image 1

Figure V.2: WT211 Office room environment image 2

Appendix W

WT210 Office room environment

Figure W.1: WT210 Office room environment image 1

Figure W.2: WT210 Office room environment image 2