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(Analytical Case Study)

AN ANALYTICAL EVALUATION OF THE ROUTING PERFORMANCE OF P2P AD-HOC MOBILE NETWORK: A CASE STUDY OF NUST STUDENTS ON CAMPUS

Thesis submitted in fulfilment of the requirements for the degree of

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I, **Cephas Pahla** hereby declare that the work contained in the **thesis**/mini-thesis, entitled **An Analytical Evaluation of the Routing Performance of P2P Ad-Hoc Mobile Network: A Case Study of NUST Students on Campus** is my own original work and that I have not previously in its entirety or in part submitted it at any university or other higher education institution for the award of a degree.

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ABSTRACT

Mobile devices have changed from being terminal equipment for making voice calls, video calls, playing games and sending messages to including differing functionalities such as acting as a server and client for sharing information. Information sharing directly between modern mobile phones can be done using Bluetooth or WiFi functionalities. Such a network does not need a fixed infrastructure, thereby allowing people to create Opportunistic mobile phone networks when they need the service, thereby avoiding charges from established service providers. Packet routing in opportunistic wireless networks is a key function to ensure that intermediate nodes act accordingly to achieve end-to-end communication in continuously changing peer-to-peer network nodes positions. Movement and mobility of connecting nodes plays a crucial role in the performance of such a network.

Undoubtedly, designing or identifying routing and forwarding mechanisms is a big challenge in this area. In this study, movement of cluster mobile phones of moving students at a university campus was described and mobility models were identified. The main objective was to understand the patterns of mobile phone node cluster movement and derive a model that can be used to evaluate Opportunistic mobile phone network performance metrics like throughput, coverage and delay. Using 802.11 WiFi connection to connect participating mobile phones of moving students, we analysed and compared routing protocols; their features, functionality and benefits, and identified those parameters relevant to the group mobility of mobile phone users identified at NUST campus.

This initial study established an understanding of geographical paths of interest for a further study on optimal routing schemes for practical opportunistic networks that may occur at a High Education institution campus when students are moving around and between lecture rooms. Informed by the findings, a free non-fixed infrastructure network model utilizing mobile phones that suit the NUST campus setting, which is fairly affordable and effective for students and staff to communicate locally, is recommended. Some of the most used Proactive and Reactive routing protocols in opportunistic networks were discussed. Simulated results showed that conditions like deterministic, semi-deterministic and random mobility patterns often occur in a network type of the NUST campus setting with Reference Point Group Mobility model closely matching how the inter-lecture movements of students are conducted. Reactive protocols complemented with the mobility pattern identified for the NUST campus, especially when students move in groups. Considering that the number of students always increases each year due to new intakes, we found that the performance differs across different network sizes, if we consider the movement patterns of other schools/faculties at the NUST campus.

Keywords: Opportunistic network, Routing protocol, Simulation, Group mobility, Node, Peer-to-peer

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATION

AODV:	Ad Hoc On-demand Distance Vector
CSV:	Comma Separated Value
DSDV:	Destination Sequence Distance Vector
DSR:	Dynamic Source Routing
E2ED:	End to End Data Delay
FCI:	Faculty of Computing and Informatics
GMMM:	Gauss Markov Mobility Model
IS-IS:	Intermediate System to Intermediate System
MANET:	Mobile Ad-hoc Network
MPR:	Multipoint Relays
NS:	Network Simulator
NUST:	Namibia University of Science and Technology
OLSR:	Optimized Link State Routing
OSPF:	Open Shortest Path First
P2P:	Peer-to-Peer
PDR:	Packet Delivery Ratio
RERR:	Route Error
RO:	Routing Overhead
RPGMM:	Reference Point Group Mobility Model
RREP:	Route Reply
RREQ:	Route Requests
RWMM:	Random Waypoint Mobility Model
SciTech:	Science and Technology Building
SHAS:	School of Health and Applied Science
TC:	Topology Control
TCP:	Transmission Control Protocol
UDP:	User Datagram Protocol

CHAPTER 1: OVERVIEW OF THE STUDY

This chapter presents the research topic and gives a general overview of the study carried out on the topic at hand. It presents the research problem; the aims and objectives of the study, as well as the constraints and limitations of the project.

1.1 Introduction

Current mobile devices have a functionality of connecting to each other directly (peer-to-peer); bypassing the service provider, thus, no payments are required. Peer-to-peer (P2P) enables devices to connect to each other without a fixed infrastructure, allowing peers to create Opportunistic network and share information (Pietiläinen, 2010). With the increase of communication needs, users have a natural tendency to choose the less costly means and service. University students on a campus setting offer an ideal environment where opportunistic group networking can emerge. For example, to exchange study materials, students can form study groups to keep track of their respective locations. The performance of mobile P2P communication on different types of mobile phones in use varies greatly. The effectiveness of P2P network depends on varied factors that are device dependent or independent. They include but are not limited to the level of traffic, location of peers, access methods used by devices, response time, network health, and peer availability. The movement and communication of users can vary depending on their social relationships or physical locations, thus one has to understand the mobility of the peers in order to measure performance (Pietiläinen, 2010). Mobility of nodes dictates network and application level protocols (Gerla, Chen, Lee, Zhou, Chen, Yang & Das, 2005).

In Ad-hoc networks, the knowledge of node mobility is vital, owing to its features such as dynamic network topology, shared medium, limited bandwidth, multi-hop nature and security (Hassan, El-Aziz & El-Radi, 2010). Thus, there is need for an effective node mobility management scheme. If mobility is not managed well, it can bring challenges such path breakage, topology control traffic overhead, long lasting disconnections and routing congestion on the Opportunistic network protocols (Gerla et al., 2005). According to Wang, Jain, Martonosi and Fall (2005), routing becomes challenging in such networks because contact dynamics are not known in advance and no single path can be relied upon.

According to Boldrini, Conti and Passarella (2008), in P2P networks, a common routing protocol is used by nodes to exchange messages amongst them. The protocol requires that there exists a complete link from the sender node to the receiving node, thus multi-hop routing is used to provide network connectivity. If the route does not exist, the process is delayed until a valid route avails itself (Lakkakorpi, Pitkänen, & Ott, 2010). According to Boldrini et al. (2008), for two nodes wishing to communicate, no assumption is made on the existence of a complete path. Sender and receiver nodes might not be in the same network and connected at the same time (Basu, Khan, & Little, 2001). Nonetheless, opportunistic routing allows such nodes to exchange packets (Hu, Perrig, & Johnson, 2005).

We present some mobility models that have been proposed or used in the performance evaluation of Opportunistic networks. The models considered in this study are in line and or share the same trends with the mobility patterns of NUST students at campus. Models selected are the Random Waypoint mobility model, the Random Gauss-Markov model, and the Reference Point Group mobility model. We investigate how to adapt routing to situations where these conditions occur. In opportunistic networks, routing protocols are categorised as: Hybrid Routing Protocols, Reactive Protocols or Demand Routing Protocols and Proactive Routing Protocols or Table Driven Routing Protocols (Hemagowri, Baranikumari, & Brindha, 2013). Nodes contain regular and up-to-date routing information and this is maintained at each node in Proactive Routing Protocols. Reactive Protocols try to find the routes only on demand; they check the route discovery scheme to locate the link to the destination (Koliousis & Sventek, 2007). We present and simulate some of the routing protocols that work with a group mobility which falls under two categories of Proactive (table driven) and Reactive (on demand).

1.2 Background

Communication methods have improved dramatically over the years and mobile devices have been part of this transformation. Mobile devices have revolutionised the way people communicate and interact and this has allowed people to interact more (Ou, Tarng, Yao, & Chen, 2011). Mobile phones do not only provide connection to the public network, but they also give users flexible mobility, and these capabilities help explain why mobile phones have become an important tool in people's lives. People can now play music and games, download and upload information, attend classes and share information on their devices. The interest in mobile devices (specifically mobile phones) among young people has made mobile phones an ideal platform to cater for educational content informally, like educational games, and they can access information anywhere, anytime (McFarlane, Roche, & Triggs, 2007).

Mobile service providers enable data communication for their subscribed mobile users. However, not everyone can afford to pay every time one needs to communicate. Current mobile devices have a functionality for connecting to each other directly (peer-to-peer); bypassing the service provider, thus no payments are required. Peer-to-peer (P2P) enables devices to connect to each other without a fixed infrastructure, allowing peers to create ad-hoc/opportunistic networks and to share information (Pietiläinen, 2010). Ad-hoc/Opportunistic networks are general networks built solely by users' devices at any time, instance or environment, as long the required nodes are available.

The performance of mobile P2P communication on different types of mobile phones in use varies greatly. The effectiveness of P2P network depends on varied factors that are device dependent or independent. They include but are not limited to the level of traffic, location of peers, access methods used by devices, response time, network health, and peer availability. The movement and communication of users can vary depending on social relationships or physical locations, thus one has to understand the mobility of the peers in order to measure performance (Pietiläinen, 2010). Metrics for measuring P2P performance identified so far include throughput, fault tolerance, response time, packet loss and hops coverage. To contribute to the body of literature, this study evaluated the performance of P2P Ad-hoc mobile (Bluetooth/WiFi) mesh network. This research sought to investigate the quality of service that the opportunistic networks made of student mobile devices on the NUST main campus can be achieved.

1.3 The Research Problem

The movement and communication of mobile phone users can vary depending on their social relationships or physical locations, which makes it difficult to evaluate P2P performance. What therefore is the quality of service of "free" communication in an opportunistic mobile phone network that students can be using on NUST main campus setting? Can P2P mobile network be an alternative to a paid mobile service provision on a campus area setting?

Mobile operators charge a fee for using their services in order to generate income and enable the maintenance of the infrastructure so as to meet the needs of the clients. This increases the expenses that the users incur whenever they want to communicate or share information. P2P networks do not require any fixed infrastructure; peers can communicate whilst bypassing the mobile service provider. However, modelling and measuring the performance of the P2P communication has no unique and straightforward solution because of the many factors to consider such as the location of peers, access methods of devices, response time, network health, and peer availability just to name a few.

1.4 Purpose of the Study

The researcher wished to recommend a free non-fixed infrastructure network model utilizing mobile phones, which suits the NUST main campus setting, which is fairly affordable and effective so as to enable students and staff to communicate locally. The research will be of great benefit to the NUST main campus setting as students and lecturers will be able to share information without paying for the services. This kind of network will allow people to share information anywhere, anytime, as a moving mobile phone will be a server and a client at the same time. The study intended also to explore how the official use of mobile phones inside and outside the lecture room could influence student learning, participation, and engagement.

Now that most university students own personal mobile phones, it presents a unique chance to appreciate how mobile phones can be used for studying purposes both inside and outside the lecture rooms, an area that has been overlooked so far in research. This study explored some of the gaps in the literature that currently exist in an endeavour to provide the field with an understanding of how students can make use of their personal mobile phones for learning and share information with lecturers and fellow students utilizing opportunistic networks free of charge. The study explored possible learning opportunities that can be introduced with the most up-to-date technology.

1.5 Significance of the Study

The significance of carrying out this study is that the product; a free non-fixed infrastructure network model utilizing mobile phones which is fairly affordable and effective for students and staff to communicate locally will be used as an influential tool to fully implement an opportunistic network at the university campus, to help learners improve their communication using a cost effective setup, hence also help improve students' performance by enabling the convenient sharing of study materials. It aims to help fill up some of the gaps that currently exist in the network setup of NUST and also help complement the current structures used by the university. Other researchers have seen mobile devices delivering encouraging results on supporting teaching and learning, showing that students are now more likely to use their mobile phones to learn, and students are more involved and motivated when using mobile devices.

This study will also be significant in so much as it provides information about how mobile phones communicate in infrastructure-less environments. The study is expected to inform researchers and educators about the current capabilities of mobile devices at a university setup and help mentors and administrators to understand how the mobility or movement of students plays a crucial role in determining how they communicate to each other. The study is also expected to show the possible uses for mobile learning inside and outside the lecture room. The results of the study may help universities save costs on the implementation of networks.

1.6 Definition of Terms and Constructs

The definitions of terms related to this study are as follows:

Ad-hoc network: an infrastructure-less arranged network that is composed of individual nodes communicating with each other directly for a certain purpose.

Applications: an installable or web-based program that provides access to information, content, gaming and/or allows users to perform tasks easily.

Data Packet: the unit of data that is routed between source node and destination node.

Ease of Use: the degree to which an individual believes that he/she is able to complete tasks with ease.

Mobile device: any mobile device with several functions and capabilities, specifically connecting to a network (Kroski, 2009).

Mobility: movement of participating nodes in a network.

Node: a participating mobile device in the network.

Opportunistic network: a form of ad hoc network that exploits the human characteristics or circumstances such as similarities, daily routines, work patterns, mobility patterns, and interests to communicate and share information (Ciobanu, Marin, Dobre, & Cristea, 2015).

Peer-to-Peer: wired or wireless communication of two or more nodes connecting directly without the aid of a central server.

Router: any node that can forward a packet to other nodes in the network.

Routing process: process of selecting a best path for moving a packet of data from source to destination.

Smartphone: a mobile phone with computer capabilities. Smartphones can download and upload to the Internet, for example photos, videos, as well as help compose and send emails. They can be used to download applications that allow users to easily complete various tasks (Poushter, 2016).

1.7 Research Objectives

The main objective of the research was to evaluate the performance of mobile device opportunistic networks (P2P) in an uncontrolled university campus environment.

To achieve this objective, the following (sub) objectives had to be met:

1. to investigate how the mobility of learners during inter lecture time slots can be modelled;
2. to investigate the capabilities of existing Ad-hoc routing protocols based on selected mobility models;
3. to determine network performance measures;
4. to identify a relevant routing protocol for the NUST main campus setting based on student mobility models; and
5. to apply network performance metrics to evaluate the proposed opportunistic traffic model.

1.8 Research Questions

1. Which existing mobility models can inform the movement patterns of mobile users at the NUST main campus setting?
2. Which opportunistic routing protocols can work with mobility models identified at the NUST main campus setting?
3. Which techniques and simulation tools can be used to compare models?
4. How can one design an opportunistic network that can emerge at campus level considering the unpredictable movement patterns?
5. How can P2P Ad-hoc network traffics in the uncontrolled campus environment be tested?

1.8.1 Assumption

1. On average the pattern of movement of students moving within the campus is similar every week during a teaching period of a semester since they will be following a semester timetable which is on average a week-based schedule.

2. The majority of students have WiFi enabled mobile phones.

1.8.2 Focus

Focus was on the NUST students' mobility on campus whilst using mobile devices, especially the movement when they attend classes from one venue to another. However, for enabling the simplicity of the study only a few days of the week were confined.

1.9 Limitations

1. The researcher had to follow the NUST semester allocated time frame; participants were available only during the semester and not on vacations.
2. The financial resources were of great concern because the research involved a lot of consultation on both equipment and the used methods, therefore requiring some financial resources.
3. Getting mobile phones for real world testing in a controlled environment take time due to constraints and limited access to the individuals participating.
4. NUST learners have their own schedule and this affected the completion of the project in the specified time. Not all learners went for next class and they cancelled classes due to public holidays or other unforeseen circumstances.
5. Voluntary use of mobile phones by students during the research took a lot of motivation to make them understand the importance of such research hence findings are restricted to the platforms used by self-selecting participants.

1.10 Chapter outline

The rest of the thesis is divided as follows.

Chapter 2 reviews existing literature on the importance of mobile devices, mobile learning, mobility models and routing protocols.

Chapter 3 covers the methodology used in the study. The methodology outlines the research design, population and sampling, instruments used for data collection, procedures and ethical considerations as well as the analysis of the data.

Chapter 4 presents the implementation of routing protocols in a simulated environment using identified mobility patterns and how the simulations were conducted.

Chapter 5 consists of the presentation of the findings as well as a comparison and analysis of the results.

Chapter 6 concludes the study with a summary, conclusion and recommendations.

CHAPTER 2: LITERATURE REVIEW

Researchers have been and are still working hard to try to bridge the communication gap between students and lecturers. Technology has evolved in a faster way and the use of mobile devices for free setting intercommunication is one of the areas which are still of interest to many authors and researchers. This literature review chapter looks at the work done by some of the authors and researchers over the years. This chapter divides the objectives such as investigating mobility patterns followed by students and capabilities of existing Ad-hoc routing protocols into topics and sub-topics, with each sub-topic containing a detailed analysis of the literature.

2.1 Background of the Study

According to Duh, Chen and Tan (2008), innovation in both the functionality and physical design of mobile devices has quickly risen. Over the years, connectivity via the mobile phone has changed from just being a gadget used for making calls and sending messages to a device that can be used for many functions such as Peer-to-Peer (P2P) communication, creating opportunistic mobile ad hoc networks. There has been admiration of and research interests in Peer-to-Peer methods and uses in recent years (Lakshminarayanan & Padmanabhan, n.d.). The triumph of P2P files sharing and VoIP applications has attested that the P2P model is an efficient solution to transport all kinds of content over the Internet (Silverston & Fourmaux, 2007). The mobility of the communicating peers is very important and several mobility models exist representing mobile nodes whose actions rely on other nodes, while others do not. Hence, the performance of an opportunistic network mostly relies on the movement of the nodes (Batabyal, 2012), which is the reason why simulation plays an important early role to understand this kind of connectivity, before evaluating real world scenarios.

2.2 P2P Communication

P2P allows people to create opportunistic mobile ad hoc networks. Opportunistic mobile ad hoc networks consist of mobile devices carried out by humans that connect with each other without any fixed infrastructure (Pietiläinen, 2010). According to Silverston and Fourmaux (2007), P2P is structured to support file sharing, content delivery, overlay routing and other capabilities. These kinds of networks can emerge at conferences, schools, university campuses, disasters area and so on. A combination of such a network at a university campus and mobile learning can help bridge a gap between lecturers and students and even among students themselves (Santamarina, Moreno-Ger, Torrente, & Manjón, 2010).

There has been admiration on the research interest in P2P methods and uses in recent years (Lakshminarayanan & Padmanabhan, n.d.). Opportunistic networking has received considerable interest from the research community over the years (Vahdat, Becker, & others, 2000). P2P communication has lately emerged as a new model for building distributed networked applications. P2P approach differs from the well-known client-server architecture in building networked applications in a number of key ways (Ge, Figueiredo, Jaiswal, Kurose, & Towsley, 2003). Over the years, connectivity via the mobile phone has changed from just being a gadget used for making calls and sending messages to a device that can be used for many functions such as P2P, bypassing the service provider, thus, no payments are required. P2P enables devices to connect to each other without a fixed infrastructure, allowing peers to create an Opportunistic network and share information (Pietiläinen, 2010).

With so many models and manufacturers emerging, people have many choices when looking for a mobile phone. Silverston and Fourmaux (2007) found out that applications create different traffic patterns and use different underlying tools. Furthermore, Vahdat, Becker et al. (2000) identified that the design of well-organised routing methods for opportunistic networks is usually a big challenge. According to Nguyen and Giordano (2009), in opportunistic networks, nodes transfer messages by taking advantage of the direct contacts, without the need of an end-to-end infrastructure. The interruption of nodes because of movements is a typical feature of opportunistic networks. Hence, routing is one of the key tests in this environment.

Studies in network connectivity measurement and performance evaluation between hosts on the Internet have been done by many researchers and these have mainly concentrated on well-connected computers using LAN network (Paxson, 1996). Many years of research have been spent in this field of opportunistic networks, but this technology has not yet fully come into the mass market (Nguyen & Giordano, 2009). According to Stefan, Gumaddi and Gribble (2001), limited latest efforts have tried to scrape together information on the network performance of the real world from an evaluation of common P2P applications originated from participating hosts. Despite the fact that these efforts have brought forth useful information, the indirect approach has hampered certain factors. For example, it has been a challenge to define accurately what the latency or Transmission Control Protocol (TCP) throughput between two peers is. However Lakshminarayanan and Padmanabhan (n.d.) argue that an attention-grabbing question is that; what is quality of service between connected peers in the real world.

Opportunistic networks are different from the Internet in that cutting off is the norm instead of the exception. Devices form small mobile ad hoc networks when nodes move close to each other, and according to Isaacman, Becker, Cacecers, Martanosi, Rowland, Varshavsky and Willinger (2012), mobility models that realistically reproduce the movements of real people can help answer questions in areas as varied as mobile sensing, opportunistic networking, urban planning, ecology, and epidemiology. Random walk, random waypoint, random direction, reference group model, and structured group are some of the mobility models that have been used to help measure performance (Qiu & Srikant, 2004). As a delay tolerant type of network, the opportunistic network is described by periodic connectivity between nodes, and communication mainly relies on the mobility of the participating nodes (Nguyen & Giordano, 2009). Hence, the performance of an opportunistic network largely depends on the movement of the nodes (Batabyal, 2012), which is why simulation plays an important role to understand this kind of connectivity.

Many simulation tools that work in different ways to achieve the same results exist, such as NS3, GRCMob, Glomosim, OMNet++, OpNet and many others (Frohn, Gübner, & Lindemann, 2010). In this particular work, the researcher is interested in measuring the performance of an opportunistic network as a free network if it can be used for local connections at NUST, avoiding paid services that are normally offered by mobile service providers. Innovation in both the functionality and physical design of the mobile phone has swiftly risen over the years and this has encouraged most learners to own a mobile phone.

2.3 Peer to Peer (P2P) Technology

In P2P communication, a node is both a client and a server. For example in P2P file-sharing, a node requests files from other nodes, and at the same time it can store and share with other nodes. In this case, a node generates workload for the P2P application, also providing the capability to process the workload requests of other nodes (Sen & Wang, 2004). Sharing of large video/audio files and software on P2P applications has grown dramatically due to the bandwidth intensive nature, which suggests that P2P traffic can have a significant impact on this type of network (Nordström, Gunningberg, & Rohner, 2009). Therefore, it is important to characterize and understand P2P traffic in relation to end-system behaviour and network impact in order to develop future workload models, also giving an insight in the engineering and capacity planning of network traffic (Nordström et al., 2009).

According to Ge et al. (2003), as a result of a rise in the number of nodes, there is an expansion in the workload, additionally an increased effort to make sure this workload is catered for. In the client-server architecture comparison to P2P, the servers process the workload, thus clients are not affected; when there is an clients increase, it simply increases the servers' workload and not clients (Li, Jannotti, De Couto, Karger, & Morris, 2000). Another vital distinction is that a node's lifetime in the system is momentary; a node may be active in the network for some time (acting as both client and server) and then disconnects from the network (Saroiu, Gummadi & Gribble, 2001).

2.3.1 Forwarding Protocols Challenges in Opportunistic Networks

The unpredictable movement of the participating nodes and resource constraints such as inadequate battery life, short connection period and small buffers poses a big challenge when it comes to packet forwarding in mobile opportunistic networks (Erramilli & Crovella, 2008). Distinguishing from the type of information they exploit when making forwarding choices and forwarding protocols can be classified as social-oblivious and social-aware (Phanse & Nykvist, 2006). Specifically, the social-aware approach has proven significantly to be the most effective way of forwarding packets by exploiting the social arrangement of the network of users in order to make forwarding decisions in an opportunistic network. The main reason being that social-aware approach permits the prediction of user encounters, which creates forwarding opportunities (B, 2012). Particular social-aware structures concentrate only on encounters between nodes. This approach is indeed effective because of the correlation between sociality and mobility, but typically difficult to model analytically (Boldrini, Conti, & Passarella, 2011).

According to Poonguzharselvi (2012), in opportunistic networks, quite a few routing algorithms have been proposed. For example Spyropoulos, Psounis and Raghavendra (2008) proposed a simple single-copy routing called direct transmission routing, which experiences least data transfers when delivering messages (B, 2012). Although simple single-copy has the least overhead, it may experience very long delays for message delivery since the delivery delay is boundless (Yao, Liu, Ren, & Wen, 2013).

Burgess, Gallagher, Jensen, and Levine (2006) proposed Epidemic Routing that exploits the epidemic algorithm designed for synchronizing replicating databases to lessen the long delivery delay. The Epidemic Routing works by flooding messages on the network, thus it tries to send a message to everyone participating in the network, and because of this, there is high demand on both bandwidth and buffering (Poonguzharselvi, 2012). Motion Vector (MoVe) is another method which makes use of the motion of mobile nodes to calculate their future location. This method has less control packet overhead and buffer usage compared to Epidemic Routing ("IEEE Xplore Abstract - Trace Based Mobility Model for Ad Hoc Networks," n.d.).

Probabilistic routing protocol, called PROPHET (Probabilistic Routing Protocol using History of Encounters and Transitivity) is another way of forwarding, and according to Boldrini, Conti, & Passarella (2011), using delivery predictability, it estimates a probabilistic metric . Simulation results show that its communication overhead is lower compared to Epidemic Routing (Erramilli & Crovella, 2008). Thrasyvoulos, Psounis and Raghavendra (2005) suggested the Predict and Spread algorithm by merging both prediction and flooding methods to attain reduced message delivery delay and for effective routing. Burgess et al. (2006) proposed MaxProp, where it is used to plan packets transmissions to other nodes and to decide which packets should be removed when buffer space is fully occupied.

In this study we did not design nor evaluate new forwarding algorithms for opportunistic networks. However, our architecture deployed simple forwarding schemes, whereby data forwarding in opportunistic network follows the "Store and Forward" method (Anastasi, Conti, Passarella, & Pelusi, 2008). Since there is no guaranteed end-to-end connection between sender and receiver, intermediary nodes are used to forwarded information to the destination (Sundararaj & Vellaiyan, 2002). It is assumed that the sending nodes have the trace file information of the other participating nodes. Hence the source node knows the probable position of the destination from the trace file of the destination (Erramilli & Crovella, 2008). In addition, the data traces and Comma Separated Value (CSV) files collected in our simulations can be used to evaluate forwarding algorithms offline.

2.3.2 Opportunistic Wireless Communications

According to Mohapatra, Gui, and Li (2004), opportunistic networks are not limited by the end-to-end connectivity assumption, thus making them fault tolerant. Opportunistic also means being capable of utilizing locally accessed global information, where nodes indirectly deliver information strictly through local communication (Frodigh, Johansson, & Larsson, 2000). Control and management is mostly up to the individual node (Sun, 2001). The communication in such networks is self-organizing localized, i.e., routing decisions are made locally by the nodes (Kale, Gupta, & PRMIT, 2013).

A wireless opportunistic network is a self-distribution type of wireless network. The network is opportunistic because it does not rely on established infrastructure devices such as routers and switches (Kale et al., 2013). Every node in the network is actively participating in forwarding the data to the other nodes and the participation of intermediate nodes to forward data is made dynamically based on the connectivity of the nodes (Suri & Singh, 2014). According to Phanse and Nykvist (2006), opportunities of communication can come in different arrangements. They can be:

1. Deterministic: planned periodic connectivity, for example, space network based on the movement patterns of planets and satellites, or timed connectivity that is a function of time synchronization among devices thus a connection is known in advance;
2. Coordinated: using a particular location and certain time to meet as a group of users to share data;
3. Spontaneous: unplanned meeting of two or more devices, for example, two or more users meet at a soccer stadium because of a similar sport interest.

Different types of user interactions may prompt complex probabilistic patterns that, for example, closely monitor the social behavioural patterns of users. According to Lansford, Stephens, and Nevo (2001), to practice direct device-to-device opportunistic communications, two wireless technologies can be used: IEEE 802.15 (Bluetooth) and IEEE 802.11 (WiFi). The IEEE 802.15 standard is the foundation of Bluetooth wireless communication technology (Tjensvold, 2007). IEEE 802.15 Bluetooth is a communication used in links of radio of short space/distance, destined to replace wired networks between devices (Sairam, Gunasekaran, & Redd, 2002). 802.11 (WiFi) allows high-speed data transfer without wires or cables, and supports typical enterprise applications (e-mail, file transfer, audio/video conferencing, etc.) (Shoemake, n.d.). Bluetooth is not intended to compete with or replace 802.11, they are complementary technologies.

The 2G and 3G are the current popular cellular data interfaces including protocols GPRS, 1xRTT, EDGE, UMTS, HSPA, EvDO but they cannot be used for opportunistic communications and thus we will not explore them further (Suri & Singh, 2014). WiMAX (802.16) and LTE are latest 4G technologies which may completely change how we communicate but we leave them for future work as resources needed to support this technology are beginning to surface. In this study we emphasise on the use of 802.11 (WiFi) for opportunistic communications. Bluetooth is not suitable for high data rate applications; where high is defined to be >600kbps, which allows a suitable margin for re-transmissions although it plays a crucial role in opportunistic networks (Bakshi, Sharma, & Mishra, n.d.).

We considered using WiFi as the network interface for our study, the reason being that WiFi is advantageous to Bluetooth in many aspects: WiFi's transmission distance is 30 meters versus traditional Bluetooth's 10 meters; WiFi's maximum bandwidth is 54Mbps (802.11g) versus Bluetooth's 550kbps (Zhuang, 2012). The main advantage is that mobile devices these days come with this technology already programmed, thus a mobile device can act as a directive antenna for the network (Kale et al., 2013). Directive antennas can be used to concentrate energy in the direction of the receiver/ transmitter, they have lower power requirements and minimize interference to and from other antennas (Spyropoulos et al., 2008).

2.3.3 Popular P2P Applications

Self-organizing file sharing applications such as FastTrack, Gnutella, and DirectConnect are all decentralized, with data and index information distributed over a set of nodes, and each node can be both sender and receiver (Sen & Wang, 2004). Nodes can connect and leave often at own will, and they are organized in a distributed style into a point-to-point application-level interface between a node and a set of other nodes (its neighbours) (Gupta & Awasthi, 2012a). At the time Sen and Wang (2004) conducted some experiments and discovered that default well-known ports are primarily used for all communications. The process of getting a shared file can be divided into two parts. In the first part a node uses the P2P protocol to search the nodes in the network for a specific file, gets one or more replies, and locates one or more possible target nodes from which to get that file from (Qiu & Srikant, 2004).

The search requests as well as the replies are communicated via the overlay connections using specific P2P routing protocol. According to Ripeanu, Foster and Iamnitchi (2002), all nodes are treated equally in Gnutella and they all partake in requests processing. In the second part, a node initiates a query by flooding it to the entire network. The nearest nodes in turn flood it to their nearest neighbours and they manage the query flooding using a scoping mechanism (Li et al., 2000). In contrast, for both FastTrack and DirectConnect respectively, special nodes (SuperNodes and Hubs) forward to and handle queries, thus nodes are not treated equally like in Gnutella (Sen & Wang, 2004). These special nodes receive an index of content from transmitting nodes in their network. Using P2P specific routing protocol, special nodes forward the query to other nodes in their respective networks. Newer versions of the Gnutella protocol have adopted a similar style with its special nodes called Reflectors, Defenders, or Ultrapeers (Rowstron & Druschel, 2001).

Most popular P2P applications such as Utorrent, Bittorrent, Ares, Deluge, GigaTribe and Sharest have no limits on how much large files one can upload or download (The Pro Review of Technology, 2017). One can stream an audio/video while downloading to preview them, and also chat with other users who are sharing files online. Most of these applications work with both computers and mobile phones, so they can be downloaded and installed on the devices. At a university setup, sharing files with the chat option is key for both the learner and the instructor as this makes communication and the availability of study materials much easier, which implies that studying is no longer limited to a classroom setup. One can now study 24/7 because of these applications.

2.4 Mobility Models used in Opportunistic Networks

Mobility models in Opportunistic networks represent mobile users' movement patterns and in what manner their location, direction, speed, velocity and acceleration change over time (Subramani & Krishnan, 2011). Two nodes can only yield effective communication results if they are in a similar communication range; if not in the same range intermediate nodes can be resolved with routing (Deshmukh & Ambhaikar, 2010). Thus, routing is important in Ad-Hoc/Opportunistic networks where mobility models must be evaluated with respect to the data delivery ratio and communication efficiency. Mobility models can be classified into different groups based on the scale of randomness, mobility, destination oriented, geographical constraints, and by changing parameters (Subramani & Krishnan, 2011). According to Roy (2011), generally Trace based mobility models and Synthetic mobility models are most common because they focus on mobility generation compared to some which focus on social behaviour or statistical analysis.

Trace models offer mobility patterns that are practical in real life systems, thus everything is deterministic. Traces provide accurate information about the users' mobility traces. Realistic movements of mobile nodes are presented by Synthetic models (Hong, Kwon, Gerla, Gu, & Pei, 2001). Based on the portrayal of the mobility patterns in opportunistic networks, synthetic mobility models can also be classified as individual and group mobile movements (Musolesi & Mascolo, 2008). Since trace models are yet to be applied and distributed on a large scale, finding realistic mobility traces turn out to be a challenge at some level (Sharma, Singh, & others, 2013). Therefore, synthetic models have been suggested. Table 2.1 gives a comparison of the two category types of models.

Table 2. 1 - Trace vs Synthetic Mobility Model

Trace Mobility Model	**Synthetic Mobility Model**
1. Deterministic approach is used provide mobility patterns (Gerla et al., 2005). 2. Periodic movements are required in predicting movement patterns' history, stability of the nodes, and monitoring (Divecha, Abraham, Grosan, & Sanyal, 2007). 3. A degree of stability in the network is maintained by path availability of mobile node through movement patterns (Pazand & McDonald, 2007).	1. Realistic manner depicts movements of mobile nodes (Pazand & McDonald, 2007). 2. Synthetic approach is the only one which the researcher can currently follow with ad-hoc (Roy, 2011). 3. Very close to real life situations because of its realistic manner and exists two types Entity and Group based mobility model (Divecha et al., 2007).

Based on the information presented in table 2.1, this study focused on three Synthetic models namely, Random Waypoint, Reference Point Group Mobility and Gauss Markov Mobility to evaluate student mobility. A semester timetable that determines the lecture schedules for a group of students was used to analyse the mobility patterns.

2.4.1 Synthetic models

Random Waypoint

In the research community, the Random Waypoint model is the most frequently used mobility model. According to San Ting and Deters (2003), at every instant, a node randomly picks an endpoint and moves near it with a speed selected randomly from an unchanging distribution (recesses are introduced between changes in speed or direction) [0,V_max], where V_max is the maximum permissible velocity for every participating mobile node. The node halts for a duration of time after reaching the destination, defined by the "pause time" parameter. After every duration, it selects a random destination again and repeats the whole procedure till the simulation finishes (Isaacman et al., 2012). In this model, a node selects a random destination, consistently spread over a predefined region like in a building, and moves to that destination at a random speed that is also consistently spread between a predefined lowest and highest speed upon getting to the final point (Subramani & Krishnan, 2011). According to Panda (2009), it can be used to simulate the realistic pattern of movement, for example in a conference setting or a museum.

Reference Point Group Mobility (RPGM)

In RPGM, each node belongs to a group and follows a reference point (group leader) that controls the group's movements and behaviour (Saroiu et al., 2001). Initially each group member is consistently distributed in the proximity of the group leader. Afterwards, every node has speed and direction at each instant that is derived by randomly deviating from that of the group leader (Divecha et al., 2007). Using their own mobility model, different nodes are then added to the group leader, making them move in relation to the direction of the group. Group mobility depiction can be used to produce different models for different types of mobility applications. Such mobility can be used in disaster relief, a military battlefield and a university campus (Deshmukh & Ambhaikar, 2010).

Gauss Markov Mobility Model

According to Roy (2011), the model was designed to uphold different levels of randomness by using one changing parameter alpha (which lies between 0 and 1) in mobility patterns, and the status of the next position is premeditated based on the present position. In the Gauss Markov Model, for every mobile node, two distinct values are upheld instead of one speed vector: the mobile's direction and its speed of movement. The general method of managing mobile nodes that tends to deviate from the simulation is that beyond the boundary area the nodes may continue to walk which causes not only the vector update of the next movement to be based on the previous position, but on a position that brings the deviating nodes back onto the permissible proximity (Gupta & Awasthi, 2012b). Hence, after scenario generation the field size is automatically adjusted to the node movements. Through normal distribution, new speed and direction of movement are chosen with a mean of the respective preceding node position (Deshmukh & Ambhaikar, 2010).

Out of the models described above, the RPGM model can be adapted to characterise the group mobility of students moving between lecture buildings at NUST's main campus. Students tend to move in groups according to social or class related relationships and in most of these groups there tends to be a leader(s). For example IT students might move together because they do the same subjects and normally lecturers choose group leaders whom they share information with (group leader shares this with the rest of the class), which applies to other study areas like engineering and hospitality. The group leader or the lecturer becomes the reference point, which makes it easier whenever there is information or files to share. Table 2.2 shows the main features, advantages and disadvantages of the three investigated mobility models.

Table 2.2 Advantages and Disadvantages of the three models

Random Waypoint Mobility Model	Reference Point Group Mobility (RPGM)	Gauss Markov Mobility Model
Advantages – The most commonly used mobility model, because of its simplicity (Roy, 2011). A building block for developing a variety of mobility models (Shukla & Iyer, 2001). – Easy theoretical analysis (Panda, 2009). Disadvantages – Lack of regular movement modelling (Panda, 2009). – Exhibits speed decay (Roy, 2011). – Memory-less movement behaviours (a common problem for all random waypoint variations) (Roy, 2011). – Highly impractical in real world networks (Shukla & Iyer, 2001)	Advantages – Easy to implement and verify, it provides a general and flexible outline for describing task oriented and time limited mobility patterns (Hong, Gerla, Pei, & Chiang, 1999). – Using proper selection of participating nodes, one can easily model many realistic situations (Panda, 2009). – Disadvantages – Complete information about the groups that includes number of member nodes and their movements must be known (Saroiu et al., 2001). – Since RPGM represents the mobile nodes by their physical coordinates; it is difficult to discern the group's movement pattern and the trend in the network topology changes (Atsan & Özkasap, 2006)	Advantages – With one tuning parameter, it can adjust to different levels of randomness (Panda, 2009). – Sharp turns and unexpected stops are excluded (Deshmukh & Ambhaikar, 2010) Disadvantages – Gauss Markov Mobility Model has high computational overhead and node non-stopping problems (Isaacman et al., 2012).
<u>Main Features</u>		

Isaacman et al. (2012) gives the following features; 1. Node moves directly to a randomly chosen destination 2. Node chooses speed uniformly from [Vmin , Vmax] 3. For a predefined recess time, a node stays at the endpoint/destination 4. Random Way point model includes pause time 5. If V_{min}= 0 then the average speed decays over the simulation time (Hassan et al., 2010)	1. Generic method for group mobility 2. Each node belongs to a group and follows a reference point (group leader) that controls the group's movements and behaviour (Isaacman et al., 2012). 3. Random Waypoint Mobility Model supports the implementation for both the movement of the group leader (for each group), and random movement of individual nodes in their respective groups (Alharthi & Taha, 2014). 4. While the group is moving, individual nodes do not use pause times. It is only used when the group leader reaches the destination and fellow group nodes pause for that exact period (Isaacman et al., 2012).	1. Most realistic mobility model 2. With one tuning parameter it can adjusted to different points of randomness (Isaacman et al., 2012). 3. Recent direction and speed is initially assigned each node (Roy, 2011). 4. Speed and direction of each node movement are updated at static intervals of time (Subramani & Krishnan, 2011). 5. Using current location's speed and direction of movement the node's next position is premeditated at each time interval (Subramani & Krishnan, 2011). 6. Sharp turns and sudden stops are excluded (Subramani & Krishnan, 2011).

2.5 Routing Protocols used in Opportunistic networks

Routing is the process of determining a path and moving information from a sender to a receiver in a network. The main objective of P2P routing protocols is to optimally transport packets of data among nodes in an infrastructure-less topology or decentralized control (Malik, Mittal, & Aggarwal, n.d.). P2P routing is therefore needed in end-to-end routing every time a packet requests to be transported to a receiver from a sender that presents multiple possible paths via a number of participating nodes. Therefore when mobile nodes wish to communicate outside their communicating range (Nishat, Pothalaiah, & Rao, 2011), some optimal decisions have to be made with regards to some predefined performance criteria such as efficiency and cost for resource allocation of the routing process. Various routing protocols for opportunistic networks have been suggested (Shivahare, Wahi, & Shivhare, 2012). Studies on Routing Protocols have been and will continue to be an interesting and active area of research for many years (Choi & Ko, 2004), as conditions and the complexity of data communication continue to change.

The mobility analysis mentioned in section 2.4.1 from group mobility on campus suggested that their classification can be made in three mobility models; Random Waypoint Model (RWM), Reference Point Group Mobility (RPGM) and Gauss Markov Mobility Model (GMMM); and the need to investigate the relevance to these campus scenarios of some Proactive (Destination Sequence Distance Vector – DSDV and Optimized Link State Routing – OLSR) and Reactive (Dynamic Source Routing - DSR and Ad hoc On-demand Distance Vector -AODV) Protocols. Pirzada, Portmann, and Indulska (2006) identify AODV as a reactive protocol if it is using its minimum features. However, Abdule, Hassan, Ghazali, and Kadhum (2010) consider it a hybrid protocol if there are additional features like Ant. The hybrid nature is also supported by Ducatelle, Caro, and Gambardella (2005) if it is adapted in hybrid Ad-hoc networks. The following sections will describe each of these protocols in detail.

2.5.1 Table Driven or Proactive Protocols

According to Hemagowri et al.(2013), in Proactive or Table-Driven Routing Protocols, every node constantly keeps latest routes of every other active node in the entire network. From time to time routing information is disseminated on the entire network in order to uphold Routing Table reliability (Sharma & Singh, 2012). Thus, if there is already an existing route on the network, traffic transmission happens minus delay. Otherwise, packets wait in queue till the node receives updated routing information matching to its respective destination(Ade & Tijare, 2010). Medium to high routing overhead characterise Proactive protocols but they present low latency (Malik et al., n.d.). To keep up-to-date and reliable routing information in a greatly dynamic network topology, a significant amount of resources is required (Piccolo, Neglia, & Bianchi, n.d.).

These resources include local memory space, processing power and message broadcast capabilities and data transmission bandwidth. Demand for resources directly depends on the frequency of network dynamics and data traffic (Prasad, n.d.). Up-to-date routing table information and constant exchange of control messages can better address the security threats posed in Proactive protocols (Sharma & Singh, 2012). Scheduled updates compensate for a loss or modification of any route update that may have been missed (Khandakar, 2012). Proactive Routing Protocols are DSDV, OLSR, Wireless Routing Protocol (WRP), Global State Routing (GSR) and Cluster-head Gateway Switch Routing (CGSR)(Ade & Tijare, 2010).

The Wireless Routing Protocol (WRP) is a table-based protocol based on the distributed Bellman-Ford algorithm for upholding routing information across all nodes in the network (Jayakumar & Gopinath, 2007). The main benefit of WRP is that the number of routing loops are reduced (Kilinkaridis, n.d.). It has a complicated table structure, and four tables are maintained on every node in the network; distance table, routing table, link-cost table and message transmission-list table. As in many other table-driven protocols only two tables are needed and this demands larger memory and more processing power (Toh, 2002). Being based on the Link State (LS) routing method, each node in GSR floods the link state information into the whole network (global flooding) once it realises that links change (time triggered) between itself and its neighbours (Behera & Panigrahi, 2015).

The delay information of each of the neighbours is included in link state information. When a node obtains all link information, it gets the picture of the whole topology (Palaniammal & Lalli, 2014). GSR works well in networks with static topologies. According to Behera and Panigrahi (2015), when links change quickly, however, frequent global flooding will inevitably lead to huge control overhead, the large size of the update messages consume a sizeable amount of bandwidth. In this category, we evaluate two proactive protocols, namely DSDV and OLSR because of their constant use for most of the P2P studies done before and because of their ability to allow moving nodes to act as routers, and use the information they store to deliver packets to the destination even when nodes are not in the same range.

Destination Sequence Distance Vector (DSDV)

The DSDV was developed by Perkins and Bhagwat (1994). The DSDV is based on the Bellman-Ford Algorithm. It allows a collection of mobile nodes even far from any source node to transmit data by using other nodes as routers in the network. By assuring a loop free path to each destination, DSDV is now considered to be a replacement of the distance vector in wired routing protocol (Malik et al., n.d.). According to Kaur, Sahni, and Bala (2013), in this protocol the routing table that holds next hop entry is consistently maintained at each node and a number of other hops needed for all accessible destinations. The destination node generates a sequence number that is tagged at each route table entry.

The regular broadcasting of routing information stored in the routing table on every neighbour upholds the routing table of the nodes in the network (Rani, Sharma, & Sharma, 2012). According to Choi and Ko (2004), the destination IP address, new nodes' sequence number and destination are assigned a new sequence number and the required number of hops to get to the destination, which are some of the fields found in the broadcasted routing information. If there is any request to forward the information again or not, the latest destination sequence number is used to make the decision. All the nodes are updated with the latest sequence number as the information is communicated within the network (Mastorakis & WSEAS Organization), 2009).

Other ways of transmitting routing information in DSDV are Full dump and Incremental dump (Aslam & Rashid, 2011). In Incremental dump only the changed information from the last full dump is broadcasted, while in Full dump the entire routing information is transmitted to all nodes. The unit of disseminating routing information on a network is called Network Protocol Date Unit (NPDU) (Lye & McEachen, 2007). Only one NPDU is required for the Incremental dump to fit in all the information compared to the multiple NPDU required for a Full dump. When no movement of mobile hosts is occurring a Full dump can be transmitted relatively infrequently (Aslam & Rashid, 2011). When an Incremental dump nears the size of aN NPDU due to a high frequent activity on the network, then a Full dump can be organised (Chroboczek, 2011).

Each node passes on updates from time to time so as to uphold stability in the dynamic environment (Pandey & Swaroop, 2011). This is because with time as shown on Fig 2.1 (“Routing in Ad Hoc Networks of Mobile Hosts,” n.d.), advertisements must be done often as entries in the list may change occasionally to update its current neighbour (Sharma & Singh, 2012).

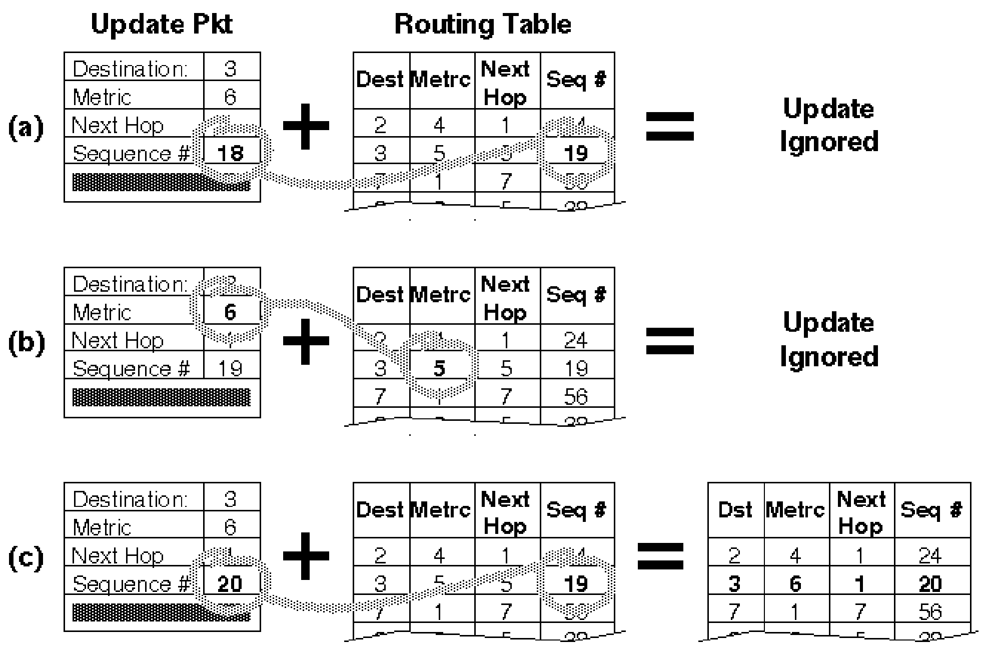


Fig 2. 1 A node receiving three update packets. (“Routing in Ad Hoc Networks of Mobile Hosts,” n.d.)

According to Hemagowri et al.(2013), an existing routing table is used to compare any new routing information received in the network. If there is a route with the recent sequence number then it is used and any older sequence number found will be thrown away (Narra, Cheng, Cetinkaya, Rohrer, & Sterbenz, 2011). According to Malik et al.(n.d.), such updates are broadcast to the entire network, leading to network overload and the bandwidth is affected. Preferably the User Datagram Protocol (UDP), which is compatible with the packet broadcast - sending to all on a network and multicasting – sending to all subscribers is used (“RFC 768 - User Datagram Protocol,” n.d.). With more nodes the network load increases and deteriorates the situation (Koliousis & Sventek, 2007).

Optimized Link State Routing (OLSR)

Identified as a link-state routing protocol and with immediately available routes when needed, OLSR uses Hello and Topology Control (TC) messages (optimized through the use of Multipoint Relays unlike route errors in reactive protocols) to determine and then transmit link state information to the entire network (Malik et al., n.d.). According to Pandey and Swaroop (2011), OLSR uses Hello messages to discover link status information and locate its neighbours on the network. Key features of OLSR is the capability to flood topology information making use of link state routing protocols on every link such as Open Shortest Path First (OSPF) and Intermediate System to Intermediate System (IS-IS) (Paila, Walsh, Luby, Roca, & Lehtonen, 2012). According to Moy (n.d.), OSPF is used to find the best path for packets as they pass through a group of connected nodes. Nodes learn of a change to the routing table or detect the network change and notify all other nodes in the network. IS-IS enables nodes to flood topology information throughout the network so that every node has up-to-date topology information of the network (Smit & Li, 2004).

To broadcast information about own advertised neighbours, TC messages are used, which include at least the Multipoint Relays (MPR) Selector list so as to reduce possibilities of routing overhead (Sharma & Singh, 2012). To reduce flooding, MPR is used to reduce the same broadcast in some segments of the network (Ade & Tijare, 2010). According to Nishat et al.(2011), this topology information is used by each node to figure out the next hop destinations for the whole network using the shortest hop sending paths. Routes to all possible destinations are known and maintained before use on the network for proactive protocols. For some systems it can be very useful and effective to have all the routes readily available within the routing table to eliminate route discovery delay associated with finding a new route (Kaur et al., 2013). However, as a drawback, OLSR protocol gets an increased bandwidth usage because each node frequently sends its updated topology information to the entire network, thus flooding the network, although this is minimized by the MPRs, which only forwards topological messages (Kaur et al., 2013).

According to Prasad (n.d.), OLSR throughput is greater than DSDV, since normally DSDV protocol throughput increases even with the high density of nodes both in TCP and UDP traffic conditions when there is less randomness. With fewer nodes moving, DSDV will perform better under RWM but it deteriorates when the number of communicating nodes increases under RPGM and GMMM compared to OLSR. This is attributed to the distance between communicating nodes. End to end delay is higher in DSDV and less in OLSR among proactive protocols (Aslam & Rashid, 2011) in RPGM and GMMM, and it gets worse when more nodes connect to the network. Nodes take time trying to update the routing tables and when updated, neighbouring nodes might not have updated information because of overloading requests from other nodes. But with the increase of nodes and when compared to proactive protocols, OLSR has got higher efficiency in delay. The packet drop rate is less in OLSR compared to DSDV (Tyagi & Chauhan, 2010). RPGM was identified as the suitable mobility model in the preliminary study, as both DSDV and OLSR work well with the model when nodes are less, but performance deteriorates when more are connected for DSDV compared to OLSR.

2.5.2 On Demand or Reactive Protocols

Only when on demand a node sends requests throughout the network, thus invoking a route discovery mechanism (Patil, 2012). According to Ade and Tijare (2010), this mechanism is based on flooding algorithm where a node just broadcasts the packet to all the nearest nodes and these nodes further forward that packet to the nearest nodes till the destination is reached. This process is completed once a route is discovered or all possible combinations have been observed (Dhakal & Gautam, n.d.). As long as the route is available and established, the route maintenance process upholds it until either the destination is out of reach along every route from the source or until the route is not needed. This is a repetitive technique until it reaches the destination (Singh, Singh, & Kumar, 2011).

If a destination node is not known, a route search is required, and once discovered nodes maintain the routes to active destinations. According to Nishat et al.(2011), theoretically there is a communication delay because of the route search process but less overhead as there is not much updates to flood the network. Reactive protocols tend to have smaller routing overheads but they have greater latency (Tyagi & Chauhan, 2010). Other well-known Reactive Protocols are Associativity-Based Routing (ABR), Cluster Based Routing Protocol (CBRP), AODV, DSR, Temporally Ordered Routing Algorithm (TORA), Signal Stability Routing (SSR) and Location Aided Routing (LAR). In this category, we assess two reactive protocols, called DSR and AODV because of their ability to dynamically discover routes and flood packets on the network. This suits well in a campus setup where nodes might be far from each other but need to communicate;

Dynamic Source Routing - DSR

According to Johnson, Hu, and Maltz (2007), with DSR, the network is entirely self-managed and configured; it uses a reactive unicast protocol that makes use of source routing algorithm, thus no existing network infrastructure or administration is required (Dhakal & Gautam, n.d.). Routing information of nodes is maintained through cache technology and two major stages, namely Route discovery and Route maintenance are part of this technology (Khandakar, 2012). The two stage operation is designed to support unidirectional contact and asymmetric paths which are characterised by additional features such as the increased spreading of route error messages, cache routes to reply route requests, route call hop restriction, packet recovering, routing information caching, automatic route shortening, flow establishment, crash recovery and route error handling (Nishat et al. 2011).

A route cache is consulted first whenever a source node wants to send a packet (Ade & Tijare, 2010). According to Johnson and Maltz (1996), the source node sends the packet if the required route is available, otherwise the route discovery process is initiated by the source node and it broadcasts route request packets. On the network a limited number of intermediate nodes are allowed to participate on the forwarding copy of the Route Request, and this is achieved through a "hop limit" contained on each Route Request (Patil, 2012). The Time-to-Live (TTL) contained in the IP header of the packet carrying the Route Request is used to implement the hop limit. According to Johnson et al. (2007), if the limit reaches zero before discovering the intended target as the request is forwarded, the request packet is discarded. Otherwise, a node checks its route cache after receiving a route request packet. If routing information for the intended destination is not available, it tags its own address on the route request packet to show other nodes on the network and then it forwards it to its neighbours (Raut & Ambulgekar, 2013).

A route reply packet is produced once the route request packet reaches the destination or an intermediate node with the required information to the destination (Khandakar, 2012). Nodes on the network check their cached routes in order to deliver the route reply packet to the initiator. A node receiving a route request for which it is not the destination searches its own route cache for a path and if established only a route reply is returned to the target rather than forwarding another route request (Johnson et al., 2007). According to Shivahare et al. (2012), the route reply packet created by the destination consists of addresses of all the nodes that have been passed through by packet including intermediate nodes. This is possible because each node attaches its address on the Route Request Packet (Ade & Tijare, 2010). There is reduced route discovery overhead with the use of the route cache but a packet header size increases the route length due to source routing (Raut & Ambulgekar, 2013). The DSR protocol supports opportunistic network density of up to about two hundred nodes and is aimed to work well with varying rates of mobility (Johnson et al., 2007).

Ad hoc On-demand Distance Vector – AODV

To keep up routing information, AODV combines two techniques, namely on-demand and table-driven, thus making it loop-free when network topology changes (Ade & Tijare, 2010). It adopts flat routing tables, one entry per destination(Aggarwal, Savita Gandhi, & Chaubey, 2011). According to Dhakal and Gautam (n.d.), each node on the network keeps a routing table which stores the receiver address, possible routes address (neighbours/intermediate nodes) and the receiver's sequence numbers. The routing table keeps information like distance to destination, next hop, destination address, precursor nodes list and lifetime (Hemagowri et al., 2013). The AODV main feature is the ability to manage the sequence number, which is crucial to avoid routing loops, even when there is communication breakdown and a node cannot give any information about its sequence number. The normal destination node becomes difficult to get to when there is link interruption or if it is disabled (Perkins et al., 2003). Route repairs and TTL restrictions reduce network-wide flooding (Longjam & Bagoria, 2013).

In AODV, a node generates a route request (RREQ) packet to initiate the route discovery process. The packet comprises the sender's and receiver's IP address (Aggarwal et al., 2011). All RREQs have a broadcast ID, and each time the sender initiates a RREQ , the ID increments (Dhakal & Gautam, n.d.). A combination of the broadcast ID and the sender's IP address forms a Unique identifier for the RREQ (Khandakar, 2012). When the sender broadcasts a packet to the network, it waits for a unicasted route reply (RREP) message. If an intermediate node gets a RREQ, it examines it for any repetition before using the sender and broadcast ID of that packet (Ade & Tijare, 2010). It discards the packet if it has been seen before. Otherwise the RREQ packet is processed. A reverse route entry containing the neighbour's ID received from the RREQ packet is set-up for the sender in its route table in order to process the packet (Dhakal & Gautam, n.d.).

According to Raut and Ambulgekar (2013), to determine the current status of routing information and to evade routing loops, AODV uses destination sequence numbers created by and preserved at each destination and shared with each route requesting node. All routing packets carry these sequence numbers (Tyagi & Chauhan, 2010). Another AODV key feature is its capacity to keep timer-based states in each routing table (Khandakar, 2012). When the routing table entry is stagnant for a long time then the routing table entry is expired (Patil, 2012). The Route Error (RERR) message notification is issued when the next-hop communication link breaks down, and each predecessor node forwards the RERR to its own set of predecessors, thus efficiently removing all routes using the damaged link (Sharma & Singh, 2012). The AODV routing protocol supports network density with populations of tens to thousands of mobile nodes (Perkins et al., 2003). AODV is designed to handle different data traffic levels, low, moderate, and relatively high mobility rates.

The DSR is based on source routing in which all the routing information is kept at the mobile nodes (Prasad, n.d.), and it computes the routes and also updates them. According to Sharma and Singh (2012), AODV uses a combination of on demand and table driven routing mechanisms. It uses the route maintenance and route discovery from a DSR and hop-by-hop routing, periodic advertisements and sequence numbers from DSDV (Perkins & Bhagwat, 1994). Easily overcoming the counting to infinity and Bellman Ford problems, AODV also provides quick convergence whenever the ad hoc network topology is changed (Ade & Tijare, 2010). According to Longjam and Bagoria (2013), in the RPGM model, AODV performs better and it has the maximum packet delivery ratio than in other models compared to DSR. DSR has less routing overhead in most mobility models like RWM, RPGM and GMMM than AODV (Pandey & Swaroop, 2011). This is because DSR computes the routes and also updates them quicker than AODV. AODV has better performance for both GMMM and RPGM than DSR in higher-mobility scenarios. For RWM, the lesser the nodes the better the performance, and DSR has less frequent route discovery processes than AODV (Kaur et al., 2013). Table 2.3 gives summarised information of Proactive and Reactive routing protocols

Table 2.3 Summarised information of Proactive and Reactive routing protocols

Proactive Routing Protocol	**Reactive Routing Protocol**
Ade and Tijare (2010) describe proactive routing; 1. Routing table is used by this protocol 2. The addresses of nodes are periodically updated in the routing tables of all nodes throughout the network 3. Nodes transmit hello messages periodically to update the routing table <u>Advantages</u> • Fast route discovery • Good reliability in packet delivery	Singh et al. (2011), describes reactive routing; 1. This protocol does not have any pre-determined routing table, it is otherwise called On Demand Routing Protocol 2. A route discovery process is initiated by a node throughout the network only when necessary 3. Route discovery is done by using flooding of route request packets <u>Advantages</u>

<u>Disadvantages</u> • It needs large routing overhead • It requires periodic hello message to find routing changes	• It requires less routing overhead • It consumes less resources due to the absence of large routing tables <u>Disadvantages</u> • Route finding process gives high latency • Congestion caused by excessive flooding

2.6 Importance of Mobile Devices for Opportunistic Knowledge Sharing and Learning

Mobile learning is likely to be defined by the environment in which it is used; some platforms apply gaming options to engage learners while others apply the points awarding format where one can challenge other learners and win a prize after getting the highest points. Some definitions emphasize on the technology or the flexibility of the technology, others on the size and functionality of the device. Table 2.4 explains some definitions of mobile learning;

Table 2.4 Definition of Mobile learning from different authors

Definition	Author and Paper	Emphasis
A new phase where mobile and portable devices are used to access e-learning through wireless network and communication technologies for teaching and learning	(Doneva, n.d.) Towards Mobile University Campuses	Technology
A way to communicate with fellow students, instructors or the institution using mobile devices as well as using it to access and share study materials	(Ally, 2009) Mobile learning: Transforming the delivery of education and training	Functionality of the device
Taking advantage of mobile phone technologies to facilitate, support, enhance and extend the reach of teaching and learning	(Attewell, 2005) The impact of Mobile Learning	Technology, size and functionality of the device
Using a portable device (e.g. phone, tablet) that the individual carries on a regular basis to be more productive, interact, and share information	(Wexler et al., 2008) Mobile Learning: Landscape and Trends	Flexibility of the technology
The merging of mobile computing and e-learning to facilitate and support education through the use of information and communications technology	(Corbeil & Valdes-Corbeil, 2007) Are you ready for Mobile Learning?	Flexibility of the technology and functionality of

		the device
Maybe mobile learning can be defined as any technologies used to deliver education where the sole or leading devices are mobile phones or palmtop devices	("Mobile Learning," n.d.) Mobile Learning: More than just Mobile + Learning Social Learning Blog	Technology
By nature mobile learning was born from the merging of existing distance learning and electronic learning	(Georgiev et al., 2004) M-Learning - a New Stage of E-learning	Flexibility of the technology
It is when learning opportunities and flexibility offered by mobile technologies are explored by the learner	(Mehdipour & Zerehkafi, 2013) Mobile Learning for Education: Benefits and Challenges	Technology and flexibility of the technology
The ability to use mobile devices to complement teaching and learning is considered Mobile learning	(Brown & Mbati, 2015) Mobile Learning: Moving Past the Myths and Embracing the Opportunities	Functionality of the device

We can define mobile learning in the context of P2P communication **as information sharing in a practical context through a P2P mobile device.** Learners can connect to each other directly and share study materials anywhere at any time in an infrastructure-less environment with the aid of routing protocols. All the authors'in Table 2.4, point the same point that a form of a device is used to participate in this form of learning, the environment or setup might be different but at the end there learning done through a device with flexible mobility and convenience.

2.6.1 The Benefits of Mobile Learning

Mobile phones have changed people's conduct; information has never been easier to access, and the Internet provides powerful ways to collaborate, communicate, and create. Mehdipour and Zerehkafi (2013), identified people who have used mobile learning programs and techniques and they made the following value statements in favour of mobile learning;

- Mobile devices are relatively inexpensive compared to PCs and laptops
- Support different types of media with creating options

- Continuous and situated learning support
- Reduced training costs as materials and learning methods are readily available
- A new learning experience as learners are more engaged when using mobile devices
- Improved literacy levels and participation in education amongst the young
- Sharing study materials across different platforms

In the context of this study we consider "immediacy" and "connectedness" as the potential benefits to learners and lecturers.

2.6.2 The Challenges of Mobile Learning

Although mobile learning has been seen as a future tool in improving learning, still learners face a great dilemma (Brown & Mbati, 2015). Many believe these versatile technologies of the mobile phone have potential as a learning tool but the unintended consequences also cause problems. Mehdipour and Zerehkafi (2013), list technical, social and educational challenges that may be brought by mobile learning;

Technical Challenges

- Battery life and connectivity
- Screen and keypad size
- Limited bandwidth
- Not all file formats are supported
- Copyright and licencing issues (Brown & Mbati, 2015)
- Compatibility of different operating systems and accommodating different standards
- Restructuring current E-Learning resources for mobile applications (Asabere, 2013)
- Memory size to cater for files and applications

Social and educational challenges

- High cost price of the devices
- Finding methods to assess learning outside the classroom
- Securing resource and pirating issues
- Regular changes in phone models, technologies and functionality etc.
- Complex technology design to support a lifetime of digital learning
- Tracking and assessment of results

- Disruption of students' personal and academic lives
- Financial resources to access and use the latest technology in developing countries

There are other barriers that include the huge costs involved in acquiring equipment, connectivity, upkeep, training and support; health issues posed; a lack of policy support; destructive social approaches that see mobile phones as a disturbing device that students use mainly to play games, chat and possibly engage in wrong behaviours such as slandering, flaming, cheating and cyber-bullying (Mehdipour & Zerehkafi, 2013).

2.7 Strengths and Limitations of the Current Research and Implications for the Study

A major setback in the study is the lack of the ability to keep up with up-to-date technology of mobile phones where the operating software is always updated and changing the versions. With many researches that exist focusing more on possible benefits, technology is changing quickly and we are yet to understand all the possibilities that can emerge with opportunistic networks. Although studies in the area of opportunistic networks is drawing much interest, there is still a lot of exploration that needs to be completed in order to not only create a solid groundwork for the area, but to be able to keep up with improvements in technology to enhance the potential use of mobile devices for educational use at university campuses.

One of the potential problems with the current study is that much of the current research explored the possibility of opportunity networks for NUST' main campus setting only and it did not explore other university campuses as setups hence operability may differ and an examination of the technology used in studies even two to five years ago, would be considered totally outdated when compared with devices today. The most important aspect or advantage is that previous studies can be used as frameworks or models to help understand emerging technologies.

2.8 Summary

Connectivity via the mobile phone has changed incredibly to the extent of being used for functions such as Peer-to-Peer (P2P) communication. This kind of functionality allows people to create opportunistic mobile and ad hoc networks. This kind of network needs one to understand the movement/mobility of communicating with mobile phones as many mobility models exist but for this study, the researcher focused on the models which closely imitate university campus level movements and of the existing models only three were selected. The same applies to routing protocols, where the most used and popular were chosen. Some of the routing protocols do not suit the targeted environment which needs to be investigated because of the specific geographical location, costs and mobility of nodes. With most university-aged students owning personal mobile devices and having more than one manufacturer of mobile phones, the features tend to differ, with some not even having the features one gets on other mobile phones. This study focused on mobile phones with the capability of using IEEE Bluetooth/WiFi to communicate. The next chapter presents the research design applicable to this research.

CHAPTER 3: RESEARCH DESIGN

3.1 Introduction

This chapter describes and explains the methodology and research methods used in this study. Section 3.2 presents the research method; followed by an overview of the research strategies. The research design used is presented in section 3.3, whereas section 3.4 presents instruments used in the data collection, whilst the procedure for data collection and the method for data analysis is presented in section 3.5. Finally, the summary is presented in section 3.6.

3.2 Research Methodology

The experimental methodology was used as it gives the researcher greater control over the research environment and in this case some variables are manipulated to suit different conditions (Kicinger & Wiegand, 2013). Considering the complexity, time and commitment needed to apply mobility models, routing protocols and to mobilize the students to participate in this study, the analytical simulation method was used to guide on how worth it is to embark on a real field test using the Design Science Research (DSR) framework. The assumptions stated in section 1.8.1 were used, that is, the majority of students have WiFi enabled mobile phones. To evaluate the performance of P2P communication, quantitative data was used. The primary aim of the quantitative method was to collect, count, measure, and assess the meaning behind specific variables. It reduces and restructures a complex problem to a limited number of measurable variables. Visual basic programming was used to simulate the daily distribution of students personally attending lectures to all possible lecture venues that exist at NUST's main campus in Windhoek. Data focused on the real capacity values of the actual building that exists. NS-3.24.1 was used to simulate students' mobility and the effect of routing protocols under investigation, and only the identified mobility models and routing protocols were used. NS-3.24.1 has the ability to program, test, and simulate routing protocols and mobility models at the same time and animate their behaviour, thus giving a realistic view/picture in a simulated environment.

Simulation is an important tool in the development of mobile opportunistic networks; it provides an excellent environment to test and verify routing protocol accuracy. The developer controls the whole system in simulation. However, there is no guarantee that it works in the real world because a simulated environment contains assumptions and streamlined models that might not actually respect the real world network operations. The most encouraging reason to use simulation is the challenges associated with creating real implementation. The code is well-defined and manageable in simulation and it is confined within a single logical program.

On the other hand, creating a realistic environment requires the use of a complex system with many components, with some components having little or no documentation. By using simulation to thoroughly test a protocol, understandably an implementation is the next logical step. Testing opportunistic network implementations in a simulation environment also presents a number of challenges such as testing the effects of node mobility on routing protocols and applications. The developer must understand the routing protocols, system modules and their complex interactions. Additionally, since opportunistic routing protocols are different from traditional Ethernet routing protocols, a new set of features must be familiarised with and explored further to support the routing protocol.

Some of the real world implementations done on opportunistic routing protocols so far are in-kernel implementation; whereby a routing module is implemented in the kernel to modify IP layer management of the operating system of the participating node and split kernel-user implementation. The idea of this approach is to move the part of routing functionality to user space in order to reduce the kernel complexity and memory requirement and keep the minimum amount of modifications to the kernel. Most of the current mobile phone technologies restrict/prohibit users to tamper with the kernel.

3.3 Research Design

This study made use of an analytical-experimental design guided by Design Science Research framework to investigate the movement patterns of students at NUST, at the main campus in Windhoek. The targeted movement was only when changing lecture venues as this is the suitable time for communication between students. An initial sample number of 200 first year students from the Faculty of Computing and Informatics (FCI) was simulated and distributed across the lecture buildings to find the different types of traffic that can be generated. Students doing computers are more likely to own mobile phones because of their study area which involves more technology studies (e.g. mobile networks, software etc.) and they tend to use the devices for studies. The sample was used to simplify the calculations and represent a model that can emerge at NUST campus. An artificial environment which imitates learners' movement was constructed and relevant information and data were generated, permitting an observation of the dynamic behaviour of a system under controlled conditions. The same was applied for testing how routing protocols operate on the different traffic that was generated from the movement of learners. We used NS-3.24.1 with NetAnim 3.106 to create the artificial environment on the communication of mobile phones, thus simulating events such as receiving, sending, dropping and forwarding packets. Given the conditions, values, parameters and required variables, a simulation was run to depict the conduct of the mobility models and routing protocols over repeated time. In this study a simulation approach can be efficiently used in building models to appreciate future work.

3.4 Sampling and Sampling Procedures

The main target was Namibia University of Science and Technology students. The student population is approximately 15000. A second semester lectures timetable (see Appendix 1) for the School of Computing and Informatics first year students doing day lectures at the NUST main campus was purposely selected to trace the movement of students from one lecture to another. A sample of 200 learners was randomly used to simplify the calculations, representing a model for evaluating P2P opportunistic mobile network performance. Using the semester timetable, seven buildings including Office building, Lecture building, Library, Auditorium, Engineering building, School of Health and Applied Sciences (SHAS) building and Science and Technology building (SciTech) were identified, each building having varying lecture capacities as shown in Appendix 6. The main focus was to find the movement patterns that students follow during a lecture day from building to building and not when they are in class. Later in the study, the sample covered all possible cumulative capacities of each building totalling approximately 7900 learners that may emerge on all of the 7 buildings that are used as lecture venues, thus covering all possible movements on all the buildings in a day. Visual basic programming language for simulating distribution, Microsoft Access database for storing scenario result, Notepad to capture log files, Microsoft Excel to generate graphs and capture routing information, and NS-3.24.1 for animating mobility and routing protocols are some of the instruments used to fulfil the objectives of the study, that is objectives 1, 2 and 4.

3.4.1 Mobility Data Collection

The data was collected in a case site, the Namibia University of Science and Technology was selected as such. The Windhoek main campus comprises of eight (8) Faculties and ten (10) units/centres. Student lectures are conducted in seven of the eight available buildings. The geographical location of the seven identified buildings for the study was retrieved from Google maps as shown in Fig 3.1; each building was given an identification number from 1 to 7, for example 1 – Office building. Office building and Lecture building are located at the main campus with an average distance of 50 meters apart.

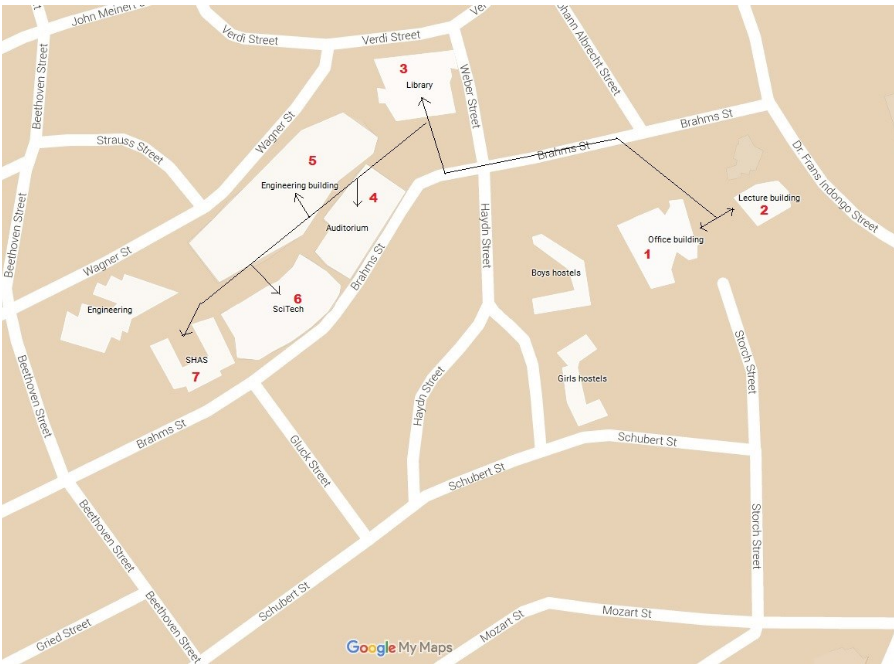


Fig 3.1 NUST Campus Map –Main directions taken by students from one lecture building to another.

The other buildings are located at the lower campus and their distance apart varies between 150 – 250 meters to the nearest. The longest distance is between the main campus and lower campus, which is approximately 620 meters to the furthest building which is SHAS. The pattern of movement on average of students moving within the campus was similar every week during a teaching period of a semester since they follow a semester timetable.

Students may move from one lecture room in the Lecture Building to the Science Tech building during the lecture break from 8:20am to 8:30am. For the same or similar time periods, students may move from one building to another remote building.

Fig 3.2 represents an abstract view of possible routes students (called nodes) can take from one building to another. For simplification purposes, for each building, the main gate is considered and it is representative of the building identification as elaborated in Table 3.1, where source and destination buildings will be represented by i and j . Also for clarification purposes, the term "node" was used to represent the moving mobile device of a student.

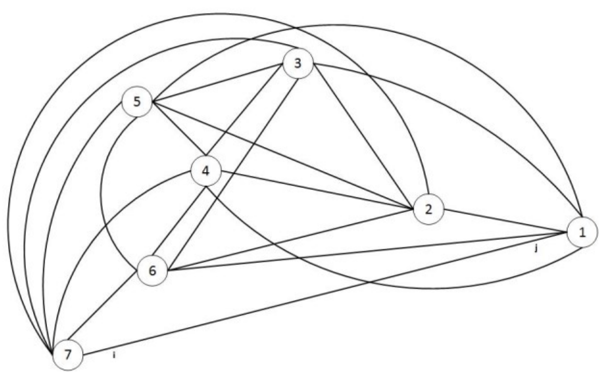


Fig 3. 2 Abstract view of possible student movements between lecture buildings at NUST Campus

Table 3. 1 Corresponding identification number of building i and j

No.	Building
1	Office building
2	Lecture building
3	Library
4	Auditorium
5	Engineering building
6	SciTech building
7	SHAS building

Mobility Metrics and Setup

Let us define Δs, ij as the inter-distance between building main gates. Δt as the lecture break duration as time break between consecutive lecture slot; and T_{ij} the traffic between i and j where i, and j represent two building main gate locations, and ij can be any building in Table 3.1.

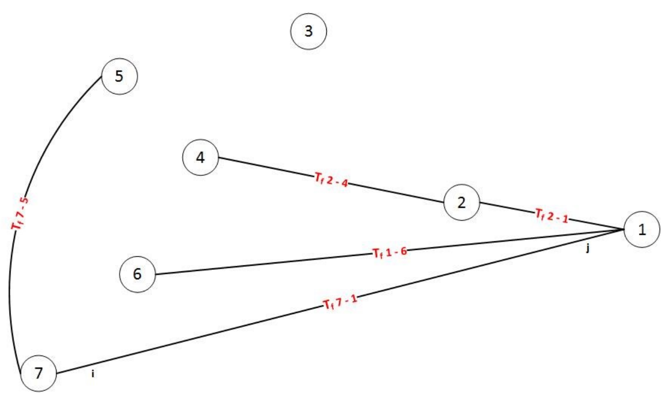


Fig 3.3 Simplified traffic represented in Fig 3.2

The movement between main gates i and j (Fig 3.3) contributes to define mobility between buildings i and j, including the position, movement, direction, time and speed. For example, if we compare traffic between buildings 7 to 1 and assuming a steady movement, the mobility direction, space, time and speed can then respectively be set as:

Δij = inter-distance between i = 7 and j = 1

= 620 meters

Δt = time break between consecutive lecture slots = 8:30am – 8:20am

= 10 minutes

and the average velocity Δv of walking from building 7 to 1 will be

= 620/10 = 62m/min

Node movement differs when moving from one building to another. Nodes have different ways of reaching the same destination therefore node relationship varies greatly (even if it is a group or individual nodes).

3.4.1.1 Group Mobility Metrics

Given the scenario using a sample S of 200 nodes moving from 1 to 7 as shown in Fig 3.3, we assume for simplification sake that any movement passing near a main gate of a lecture building is considered as reaching or starting from that building's main gate; which is for example the case of buildings 2 and 4 due to their central positions relative to other buildings. Group mobility is the overall mobility of a group of nodes moving in a given route at a constant average speed. Group mobility metric is defined by a route direction, and the time interval of the group's time break between a consecutive lecture slot is 10 minutes assumed to be moving steadily at an average velocity.

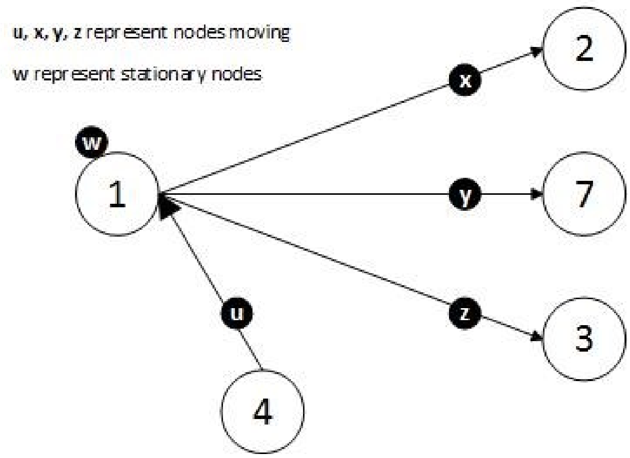


Fig 3.4 Example of distribution of outgoing and incoming Nodes to building 1, and defining one traffic segment for route

In Fig 3.4 corresponding traffic intensity in a given route between buildings during an inter-lecture break is defined as a summation of all individual nodes passing steadily through that route from that building's exit point using outgoing nodes. Table 3.2 indicates how traffic intensity from building 1 can be calculated with arbitrary numbers of node group size (40, 80, 65, 15) when 40 nodes move to building 2; 80 nodes move to building 7; 65 nodes move to building 3; and 15 are considered stationary nodes, and no traffic is generated as they remain in building 1.

Table 3.2 Examples of the calculation of mobility metric and traffic intensity

Node groups out of S =200 nodes from building 1 to	Node group quantity/size	Route distance	Group average velocity	Traffic intensity in respective route
Unit	Nodes	Metres (m)	m/min	node/ min
Building 2	40	50	5	40/10 = 4
Building 7	80	620	62	80/10 =8
Building 3	65	340	34	65/10 = 6.5
Building 1	15(stationary nodes)	0	0	(infinity)

The average mobility speed in one direction in a given route is considered to be the arithmetic average of speeds of traffic segments passing through that route weighted to the number of corresponding nodes. For simplification sake, vectorial speed is not considered so as to avoid a null average speed which would not be of additional value in keeping with inter node connectivity between 2 nodes moving in the opposite direction. Ideally the closeness of nodes moving in one direction would normally increase node density, therefore improving the internode communication routing performance of an opportunistic network. Traffics in opposite directions are calculated from the building's exit points that generate them. These traffics have a cumulative effect in terms of nodes density; however at a local group level they may increase cluster instability and impair connectivity (Basu et al., 2001);

3.4.1.2 Mobility Simulation Design

Visual basic programming in Appendix 3 was used to design interfaces and compute all possible scenarios for different cumulative lecture building capacities at NUST as shown in Appendix 2 as "Interface Screenshots". Hundreds of thousands of rounds were processed. The interface represents only a scenario and shows a number of possible nodes leaving the source building and nodes are distributed across all 7 possible destination buildings. When nodes are randomly distributed, traffic is generated between source and destination building. One scenario had several rounds depending on cumulative capacities of the NUST lecture buildings. The total number of Traffic intensity between the seven buildings considering TTij = TTji, is given by the formula Combin (7,2) = ($^7{}_2$) = Permut (7,2) = [(7!)/ 2! * (7-2)!], for example from building 1 to 2 we can have combination 1 - 2, and 2 - 1. For all scenarios, the data was stored in Microsoft Access database with a unique scenario identifier as shown on the database schema on Appendix 4. Fig 3.5 shows how the scenarios were processed. For the seven NUST buildings, the capacity and distance between them is defined, where for each building capacity the cumulative capacities are generated, for example if the capacity is 150, possible cumulative capacities are 50, 100, and 150. During lecture time breaks, slot nodes are distributed between the seven buildings generating Route Traffic RT_{ij} vice-versa, and considering cumulative capacities, this creates different scenarios to be calculated. For each scenario, total traffic $TT_{ij} = TT_{ji}$ between buildings is calculated and results are stored in a database until all possible cumulative capacities are finished and the average traffic for each scenario is calculated.

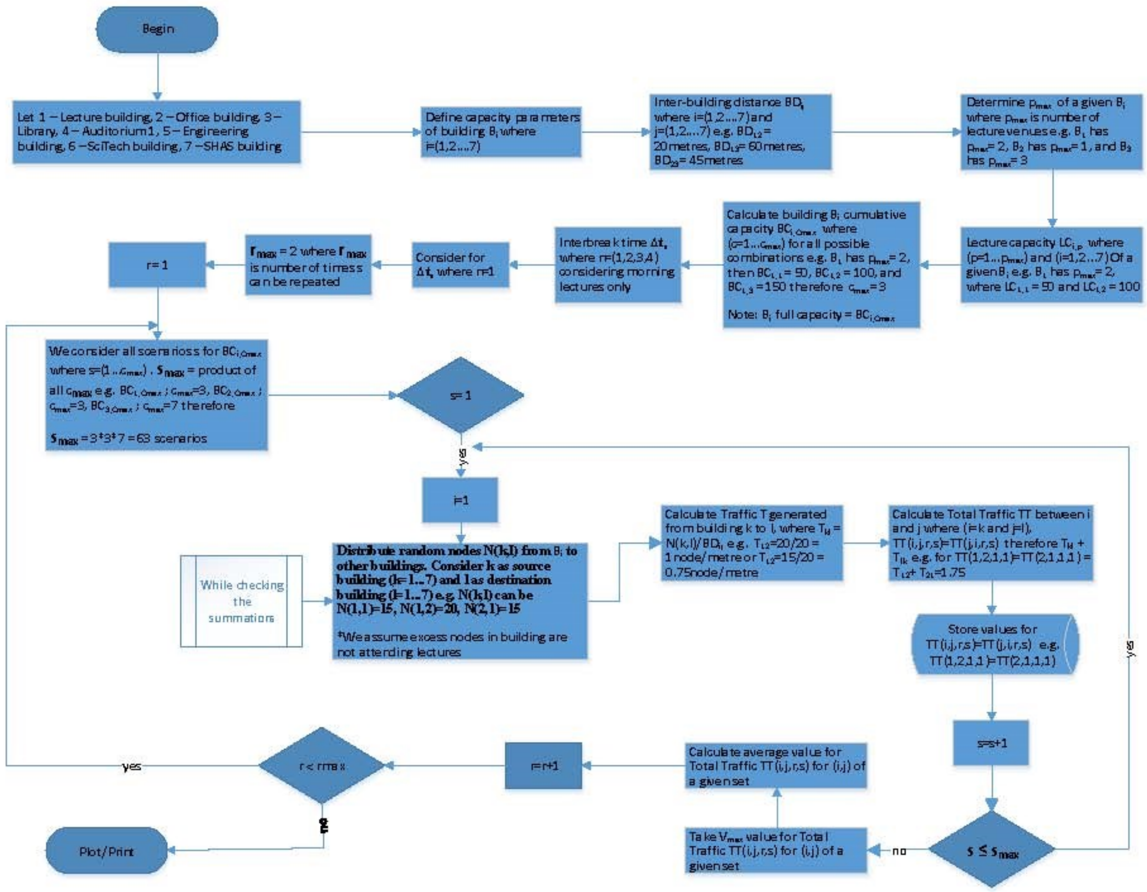


Fig 3.5 Flowchart of simulated mobility of nodes and total traffic of routes between NUST lecture buildings

3.4.1.3 Routing Protocols Simulation Design

The review of literature shows that many simulations have been carried out on the performance of routing protocols from such works of Deshmukh and Ambhaikar (2010). They compared the Packet Delivery Ratio of the two reactive routing protocols AODV and DSR, with reference to varying network size of 100 to 150 nodes. Kumar (2009), studied the impact of mobility on the performance of two mobile routing protocols, AODV and OLSR as part of a master's degree fulfilment. In our study we have used NS-3.24.1 with NetAnim 3.106 ("ns-3," 2015) for our analysis using Ubuntu 15.10 operating system. NS-3.24.1 simulates events such as receiving, sending, dropping and forwarding packets. Our simulation time was 600 seconds (10 minutes of NUST lecture inter-break) which is inter-break time when students are changing from one lecture to another, considered as inter-communicating period. The inter-break time was constant throughout as a NUST semester timetable was used. The pavement width for all the buildings was 100 metres for simplification sake, although some walking pavements are more or less that size.

We used between 10 and 150 (measured as nodes/m) number of nodes for testing and they were identified from different traffic intensities generated between NUST lecture buildings. A constant packet of 256 bytes size was used in the simulation because we considered a minimum file size that students can share at a particular time considering the less time they have to communicate. A pair of nodes exchanging UDP data at a rate of 64 byte packets per second (modern mobile phones have the technology to transmit data at faster speeds), with maximum WiFi connections of 80% nodes participating (assuming that not all nodes will be willing to participate or some of the nodes might be off e.g. battery dies), and for all mobility models an average speed is used; total distance travelled divided by the total time taken to cover this distance. Table 3.3 gives a detailed view of simulation parameters. Considering the node unpredictability and less connection time, UDP was a suitable communication protocol for these scenarios because it can send packets in chunks to neighbouring nodes and its stateless nature is also useful for nodes that answer queries from huge numbers of clients ("RFC 768 - User Datagram Protocol," n.d.).

Table 3. 3 Simulation Parameters

Parameter	**Value**
Routing Protocols	OLSR, DSDV, AODV, DSR
Simulation Time	600s
Number of Nodes	10 - 150
Network Load	64 bytes / sec
Node Coverage	80%
Network type	802.11
Environment Size	Max distance 620m
Velocity	Max 62 metres/minute
Network Simulator	NS-3.24.1
Animation	NetAnim 3.106
Operating system	Ubuntu 15.10
Mobility Model	RWMM, RPGMM, GMMM

We compared DSR, AODV, OLSR and DSDV protocols by applying group mobility models Random Waypoint Model (RWM), Reference Point Group Mobility (RPGM) and Gauss Markov Mobility Model (GMMM) using the C++ libraries ("aodv-module.h", "olsr-module.h", "network-module.h" etc.) and NetAnim 3.106 for representing the graphical view of mobility models that exist in NS3.24.1 software ("ns-3," 2015). The NS-3.24.1 supports simulation for routing protocols such as DSDV, OLSR, DSR and AODV. As recommended by Rohrer (2011), C++ was used as a base code but it was modified to suit NUST routing and group mobility requirements, and routing protocols were represented by numbers 1,2,3, and 4 as indicated in Appendix 5. Performance evaluation parameters included end to end delay, routing overhead, and packet delivery ratio (Ehsan & Uzmi, 2004).

In this simulation, we generated four (4) out of 21 scenarios from the Group Mobility analysis done at the NUST campus. We simulated the highest, moderate, lowest and average traffic generated during inter-breaks of lecture classes during a semester period. Highest, lowest and average values are calculated from the results that are stored in the database using functions, that is, MAX function to get highest traffic, AVERAGE function, MIN function. The moderate value is defined as the most repeating number in the results, and in this study we did not consider zero (0) as it represents no traffic. The graph in section 4.3 illustrates the average traffic intensities of all [Combin (7,2) = $(^{7}{}_{2})$ = Permut (7,2) = [(7!)/ 2! * (7-2)!] 21 scenarios of groups of students moving from one of the seven lecture buildings to another, with the assumption that they are willing to share information through their mobile phones (moving nodes). We also assumed for simplicity that traffic in a given route is made of movement in a single direction at an average speed.

Metrics

The following quantitative properties were used to evaluate the performance of the protocols;

a) Routing Overhead (RO): we define it as the proportion of routing packets sent, accounting for dropped packets and this is calculated as "the ratio between the number of routing packets sent to the number of packets actually received" (Sharma & Singh, 2012):

$$RO = \frac{\text{Routing Packet Received - Routing Packet sent}}{\text{Routing Packet Received}}$$ (Hassan et al., 2010)

It estimates how efficient a routing protocol is and how well the protocol keeps the routing information updated (Kumar & Hans, 2015).

b) Packet Delivery Ratio (PDR): it is calculated as “the ratio of total number of packets successfully received by the receiver to the number of packets sent by the sender” (Sharma & Singh, 2012):

$$PDR = \frac{\text{Sum of packets received by destination}}{\text{Sum of packets generated by source}}$$ (Rohal, Dahiya, & Dahiya, 2013)

According to Aggarwal et al.(2011), this estimate guides us on how successful the protocol is in transporting packets to the application layer. A high value of PDR is a good indicator of the network performance (Sharma & Singh, 2012).

c) End-to-end data delay (E2ED): efficiency, considerations that increase delay and the minimization of data throughput can be revealed by this metric (Kaur et al., 2013). E2ED is defined as “the average delay in the transportation of a packet between sender and receiver”;

E2ED = Time Data Packet Leave Source - Time Data Packet Reach Destination

A congested network can be caused by high E2ED value, meaning that the routing protocol does not perform well, also affecting data throughput (Sharma & Singh, 2012).

3.5 Quantitative Data Analysis

Quantitative data gathered throughout the study included route traffic and total traffic generated between investigated NUST buildings. They were analysed in both Microsoft Access and Excel. They both have functionalities that include generating different types of graphs/charts, tabling the data, exporting (as Word, PDF, Excel, SPSS) and printing. Functionality of pivot table was very useful in manipulating the figures and presenting them. Some data were presented in percentage (%) format and numbers and chart/graph in the form of column charts.

3.5.1 Group Mobility

For all the nodes randomly distributed across all the buildings, the data gathered was stored and analysed using the Microsoft Access in build system. Data was stored in tables linked to each other with relationships as shown on the database schema on Appendix 4. The tables are the backbone and the storage container of the data entered into the database. Visual Basic program was linked to Microsoft Access to post all the data generated. Microsoft Access automatically calculates the lowest, maximum and average values generated by different types of graphs according to choice and graphs can be generated and exported to excel to generate more advanced graphs (Microsoft SQL Server vs Microsoft Access Database, 2016). Another useful tool was the PivotTables, whereby large amounts of data from a database are summarised using the concept of first row and reserved for headings and the other rows keep the values (Excel Pivot Table Tutorial, 2016). Pivot Table values are summed over some or all of the categories through Excel, thus summarising the data in a more flexible way.

3.5.2 Routing Protocols

Microsoft Excel was used to open the CSV file generated in NS3.24.1 for each scenario and the values were integrated and further processed to understand the performance of the network. To highlight errors and to detect important data patterns, Excel uses a feature such as conditional formatting which also helps on focusing on important aspects of the spreadsheet. Basic math functions such as addition, division and multiplication were also used to manipulate the numbers. The comparison of data was done using logical operators and column charts were generated to present the data in a more meaningful way.

3.6 Summary

The case study of node mobility was done at NUST and a semester lectures timetable was used to model students' movement. Using experimental methodology which gives greater control over the research environment, variables were simulated in a controlled environment. To evaluate the performance of P2P, the quantitative method was used with the primary aim to collect, count, measure, and assess the meaning behind specific variables. Visual basic programming was used to design interfaces and compute all possible scenarios for different cumulative lecture building capacities. NS-3.24.1 with NetAnim 3.106 were used to create the artificial environment on the communication of mobile phones thus simulating events such as receiving, sending, dropping and forwarding packets. Microsoft Access and Excel were used to quantitatively analyse the data generated both by the mobility of learners and the effects of routing protocols on these models.

CHAPTER 4: EXPERIMENTATION

4.1 Introduction

This chapter describes and explains how the experiment was conducted to find different traffic densities and how they were used to create scenarios to test on routing protocols. Section 4.2 presents the search for the minimum, maximum and average that can be generated across the 7 buildings and Section 4.3 gives an overview of the scenarios that were investigated, and finally the summary is presented in section 4.4. First we needed to investigate group mobility and the result was used to create scenarios for testing routing protocols.

4.2 Search Algorithm for Optimal Group Mobility

In order to find out scenarios of mobile nodes that offer the highest traffic intensity over highest distance route (assuming long coverage through multi-hop nodes, i.e. to clarify we use an example of distance between building 1 and 7 = 620m) between lecture buildings, and considering the movement of all students from all buildings during an inter-lecture break. A simulation was run based on the algorithm described in section 3.4.1.2. No specific time table was considered; it is assumed that at the break each building would release during any inter-lecture break some groups of students who attended lecture in certain lecture venues. For example, a building with 3 lecture rooms of 50, 100 and 150 capacities, may release a total number of 50, 100,150, 200, 250 or 300 students. Some of these outgoing students are assumed to move to other buildings for the next lectures (See Appendix 6 with a list of all possible lecture venues at NUST, Windhoek campus - this was done before the new Engineering buildings were in use).

During each inter-lecture break Δt_n(n=1,2, n_{max}) and for each exit building j (j=1, to 7), traffics T_{ji} generated towards building i are calculated using selected numbers S_j of nodes (Table 3.2). These numbers correspond to the possible accumulative capacity of lecture rooms (BC_{ic}) within that building i. In the example of a building with three lecture venues given above, the numbers 50, 100,150, 200, 250, and 300 were considered. From each selected number which determines a given scenario, the random number of outgoing nodes is assumed been moving towards all other buildings i, i≠j with possible stationary nodes (nodes remaining in building j).

Table 4.1 Example of scenario: Random nodes exiting one building towards another at a given inter-lecture break

Source B_i	**BC_{ic}** Outgoing nodes	**Nodes to Destination Buildings B_j**						
		1	**2**	**3**	**4**	**5**	**6**	**7**
1	**47**	7	7	5	7	7	7	7
2	**10**	3	0	1	1	2	2	1
3	**425**	121	91	30	30	31	30	91
4	**272**	6	99	12	25	25	12	93
5	**800**	52	77	52	52	26	103	103
6	**30**	3	10	1	1	1	3	11
7	**1196**	299	239	120	179	60	60	239

The same random distribution applies to all other buildings considered in the study. For each scenario the random distribution is repeated many times with the computation of traffic intensities (T_{ij}), for all routes. Table 4.2 indicates the corresponding traffic intensity from both directions calculated from the values in Table 4.1 where for example traffic from buildings 1 to 2 and 2 to 1 equals respectively to 1 and 0. The total number of scenarios is given by the product of the number of lecture venues in each building, for example if there were 4 buildings with respectively 3, 5, 7 and 4 lecture venues, there would be 3*5*7*4 = 420 scenarios.

Table 4.2 Corresponding traffic intensities Tij from i to j building (i, j =1 to 7)

	1	**2**	**3**	**4**	**5**	**6**	**7**
1	**0**	1	0	2	0	0	0
2	0	**0**	2	1	0	0	0
3	0	2	**0**	2	2	2	3
4	3	0	1	**0**	3	1	4
5	0	0	3	6	**0**	9	5
6	0	0	0	0	0	**0**	1
7	1	0	4	8	3	6	**0**

The random distribution of nodes has two constraints: (i) the sum of incoming nodes to buildings including the originating building must be equal to the total number of outgoing nodes from the originating building, including looping or stationary nodes; (ii) the total number of nodes reaching a building or remaining stationary at that building must not exceed the total capacity of (lecture venues in that) the building; otherwise any excess would represent students not waiting for any next lectures. These constraints impose the use of the maximum space of lecture venues in each building, ensuring the highest possible mobility. At the end of a given scenario accumulative traffic intensities (RT_{ji}=RT_{ij}) (Table 4.3) for individual rounds calculated as the sum of traffic in both directions for each route are compared and the highest value is retained as the simulation result of that route for the scenario at hand.

Table 4.3 Accumulative Route traffic intensities, RTij =RTji

	1	2	3	4	5	6	7
1	**0**	1	0	5	0	0	1
2	1	**0**	4	0	0	0	0
3	0	4	**0**	3	5	2	7
4	5	0	3	**0**	9	1	12
5	0	0	5	9	**0**	9	8
6	0	0	2	1	9	**0**	7
7	1	0	7	12	8	7	**0**

Finally, all route traffics of all possible scenarios are compared and for each route only the scenario offering the highest traffic is considered in Table 4.4. These are Combin (7,2) = ($^{7}{}_{2}$) = Permut (7,2) = [(7!)/ 2! * (7-2)!] such possible number of results (group of 2 regardless of their internal order) for seven (7) items because RT_{ji}=RT_{ij} this traffic is made up of movement in both directions. When these scenarios with high traffics happen during the same inter-lecture break and involve adjacent routes, the possibility of aggregating routes to have extended distance are considered. Individual route mobility can then be analysed regarding their internal movement and directions and an investigation of routing protocols for optimal connectivity can be done.

Table 4. 4 Average Inter-building highest mobility of students

	1	2	3	4	5	6	7
1	**0**	1	2	1	2	6	0
2	1	**0**	0	4	1	3	1
3	2	0	**0**	7	5	6	2
4	1	4	7	**0**	14	5	12
5	2	1	5	14	**0**	6	2
6	6	3	6	5	6	**0**	8
7	0	1	2	12	2	8	**0**

4.3 Performance Evaluation of Routing Protocols

We compared DSR, AODV, OLSR and DSDV protocols by applying group mobility models Random Waypoint Model (RWM), Reference Point Group Mobility (RPGM) and Gauss Markov Mobility Model (GMMM). Following the general ideas of evaluating P2P networks (i.e. end to end delay, routing overhead, packet delivery ratio) as of previous study of simulation from the likes of Deshmukh and Ambhaikar (2010) and Kumar (2009), in this simulation, we generated four scenarios from the Group Mobility analysis done at the NUST campus. We simulated highest, moderate (most repeating traffic before average was calculated), lowest and average traffic generated during inter-breaks of lecture classes during the semester period, with distance and speed being the main factor. Table 4.5 values were used to give a graphical view of the average inter-building mobility of students as indicated in Fig 4.1; from where the following average mobility for four selected scenarios/cases were simulated:

Scenario 1: HighestTraffic intensity of 14 nodes/minute, distance between building 4 and 5 is 40m, speed being covered at 4metres/minute

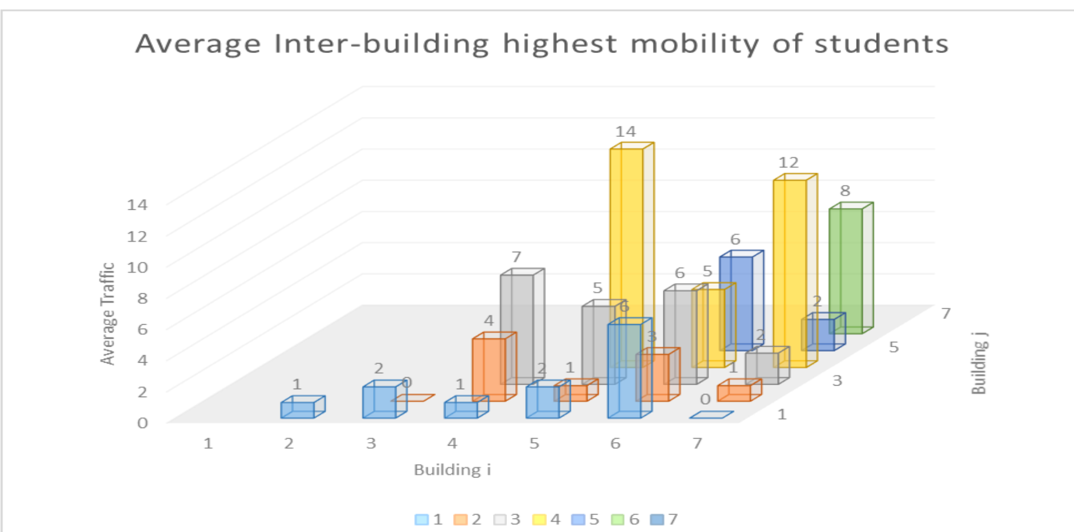
Scenario 2: ModerateTraffic intensity of 8 nodes/minute, distance between building 3 and 6 is 170m, speed being covered at 17metres/minute

Scenario 3: LowestTraffic intensity of 2 nodes/minute, distance between building 1 and 3 is 340m, speed being covered at 34metres/minute

Scenario 4: Traffic intensity of 12 nodes/minute, distance between building 2 and 7 is 620, speed being covered at 62metres/minute

Table 4. 5 Average Inter-building highest mobility of students

	1	2	3	4	5	6	7
1	0	1	2	1	2	6	0
2	1	0	0	4	1	3	1
3	2	0	0	7	5	6	2
4	1	4	7	0	14	5	12
5	2	1	5	14	0	6	2
6	6	3	6	5	6	0	8
7	0	1	2	12	2	8	0



1 - Office building 2 - Lecture building 3 - Library 4 - Auditorium 5 - Engineering building 6 - SciTech 7 - SHAS

Fig 4. 1 Average Inter-building mobility of students

Each scenario produced a CSV file and trace files which were further processed to understand the performance of the network. The repetition of the simulation helped to come up with an average performance of each scenario. Fig 6 shows an animated scenario running in NetAnim of NS3. See Appendix 7 for further information.

4.4 Summary

Although lowest, highest, moderate and average moving nodes per minute were investigated, the main aim was to find out scenarios of mobile nodes that offer the highest traffic intensity over the highest distance route (worst scenario) between lecture buildings. Considering all the buildings' cumulative capacities and that no specific time table was considered; it is assumed that at the break each building would release some random groups of students who attended lectures in particular lecture venues. For each scenario the random distribution is repeated many times with the computation of traffic intensities for all possible routes. The total number of scenarios was given by the product of the number of lecture venues in each building. Four scenarios were generated to compare DSR, AODV, OLSR and DSDV protocols by applying the analytical simulation method using NS 3.24.1 on group mobility models RWMM, RPGMM and GMMM, and each scenario produced a CSV file and trace files.

CHAPTER 5: RESEARCH FINDINGS/ RESULTS

5.1 Introduction

In this chapter data collected is presented in a more meaningful way. It is presented following objectives 3 and 5 in section 1.7, which were set and the procedures of the instruments that were used. Data analyses and findings are core for the study as this will enable the implementation and recommendations of a free non-fixed infrastructure network model utilizing mobile phones that suit the NUST campus setting, and which is fairly affordable and effective for students and staff to communicate locally.

5.2 Findings of Students' Mobility at NUST Campus

Group Mobility Pattern and Connectivity of Nodes

Predictability of node movement was determined by a semester timetable and campus infrastructure. This determined the pattern of how the NUST students would normally attend lectures. The initial sample only focused on the movement of the first year students identified earlier. Mobility prediction of a node is estimated by the locations of the next lectures. The main benefit of location prediction will be to allocate, in advance, the nearest access point before the node leaves its current one in order to reduce the disruption time in communication between mobile nodes. For example there can be a student tasked by the lecturer to distribute information to others at the end of the lecture, and that student acts as a central access point (Kaaniche & Kamoun, 2010).

For the small sample of 1st year students from ICT used to understand the predictability determined by lectures time table, the least number of classes held in a day was four lectures and the highest was six on Wednesday, giving an average of five classes per day over a week. Each day of the week showed the movement of students between Office building = 1, Lecture building = 2, Auditorium = 4 and SHAS = 7, with most of the lectures done in Office building where the majority of computer labs are situated. Because of the closeness of labs, students are always close to each other during lecture breaks with almost zero distance apart and they will be having more time to share information.

However considering the time interval of 10 minutes from one lecture to another, it gives a different scenario when they move from Office building to Lecture building; walking speed and inter building distance affect the closeness of students and this impacts on the sharing of information as some students are faster and others are slower. A long distance of about 620 meters from Office building or Lecture building to the Library (vice versa) will increase node speed. Mobility behaviour, such as unexpected acceleration, unexpected stop, and sharp turn, may frequently occur. This gives limited (if not none) time for nodes to connect and more distance apart among nodes. This brings the challenge of exploring routing protocols which can suit such cases. Considering the infrastructure of the NUST campus, three mobility patterns suited well;

1. **Deterministic Mobility Pattern:** Most simplistic and predictable type of motion of all mobility models. For example within a campus building computer labs scheduled in the timetable for the sample group are next to each other; and mobile nodes are forced to move in the same direction because of the short time interval of changing lecture venues and having no other option of getting to the next lab. Thus the direction that nodes can take is already predefined, that is, in straight- line. An example is the case of mobility within the Office building for the sample group.

2. **Semi-Deterministic Pattern:** In this scenario we take students/nodes' movement from one lecture building to another. The path followed by each node or group of nodes is not specified, but they move in a general direction towards another building. Even though the individual nodes do not have a specified direction, there is a general pattern of nodes leaving the building. Though they can use different corridors within the building to the exit point; they follow a similar pattern.

3. **Random Pattern:** If one considers a random pattern, the movement is totally stateless; that is the nodes' next movement is completely unknown and hence there are no boundaries imposed on which the nodes can take up for their next movement. This uncertainty in choosing the next direction for the node makes this type of pattern entirely unpredictable. If students/nodes are moving from either an upper campus building to down campus (e.g. Auditorium, Engineering, SHAS, SciTech or Library and vice-versa) there is no predefined path one must follow, thus other nodes can use the side of the main gate, Hotel School or small gate, hence making the movement unpredictably random. This kind of randomness contributes to routing challenges as nodes will be changing positions unexpectedly.

Different schools have different learning groups with different time table schedules, therefore the mobility of students at the NUST campus is very broad, and this affects their mobility pattern. Considering the sample which was used which shows the movement of nodes mainly from four different buildings namely, Office building, Lecture building, Auditorium 1 and SHAS, the mobility patterns presented in this scenario are totally different compared to the sample of the same first year students from another school like Engineering or Health and Applied sciences. Students from these two schools have a limited mobility because most of their lecture rooms are under the same building and this completely gives another or a different movement pattern. Therefore, building infrastructure and scheduled timetables have an influence on mobility patterns.

This applies to other students who are non-first year students, as some use almost all buildings because of some courses which are part of their studies but being given by other departments. For example, students from Engineering do pre-Engineering Mathematics which is offered by the department of Mathematics from a different building. These types of setups give a different picture of mobility as students from different schools can still interact and share information when changing lecture rooms; for example Information Technology students use lecture rooms at the SHAS, meaning that they interact with SHAS students. It will be necessary to study the mobility patterns of all scenarios and identify those simultaneous scenarios with summative effects in terms of traffic density, and flow direction to design routing models that allow high ad hoc network performance on campus.

5.3 Analysis and Discussion of Simulation Results of Routing Performance under RWM, RPGM and GMMM Mobility

We analysed results from the simulation of 4 routing protocols, namely DSDV, OLSR, DSR and AODV under 3 mobility patterns RWM, RPGM and GMMM. The routing protocols fall under two categories, which are proactive and reactive protocols, while all the mobility models are synthetic because they presented movements of mobile nodes in a realistic manner. We evaluated these protocols because of their constant use from most P2P studies done before and their ability to allow moving nodes to act as routers, and use the information they store to discover routes, flood packets on the network and deliver packets to the destination even when nodes are not in the same range. This worked well in a campus setup where nodes might be far from each other but need to communicate. In the following section we give a detailed analysis of metrics Routing Overhead, Packet Delivery Ratio and End-to-End Delay which were used to evaluate the routing protocols performance based on the 3 mobility models;

a) Routing Overhead

For RWM, it is evident from Fig 5.1 that among proactive protocols, OLSR and DSDV performed equally better. This is because when nodes are less, there is less information to update on routing tables. RWM can be used to simulate the realistic pattern of movement, for example: the classroom setup, which suits well for the NUST setup if students are not moving to the next lecture or if the next class is close by. OLSR takes advantage of the Hello messages to disseminate the link state, which makes routes immediately available. Figs 5.1, 5.2 and 5.3 show that when there are few nodes in a network the communication overhead is reduced for reactive protocols (DSR and AODV) at the expense of delay due to a route search as compared to proactive protocols (OLSR and DSDV).

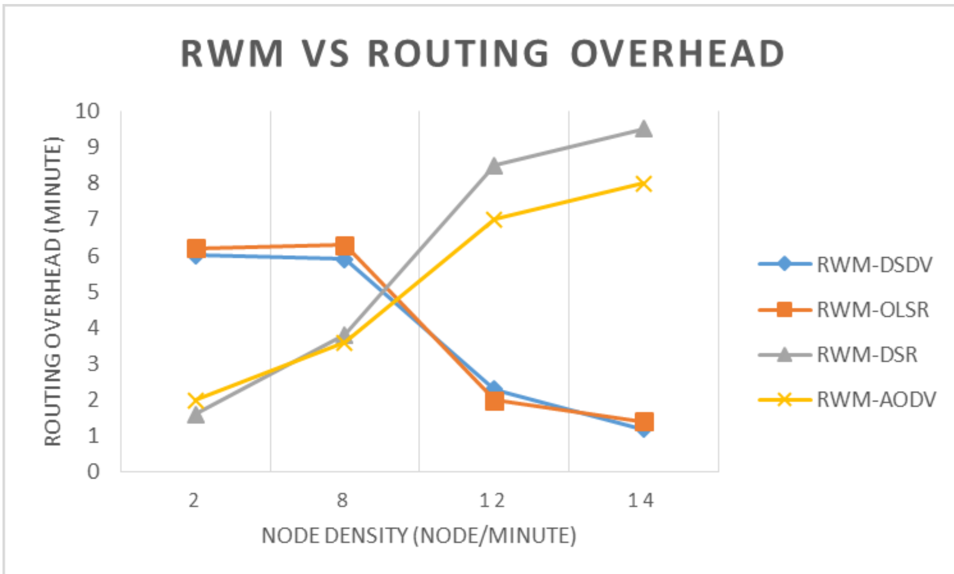


Fig 5.1 Routing overhead in Random Waypoint Mobility Model

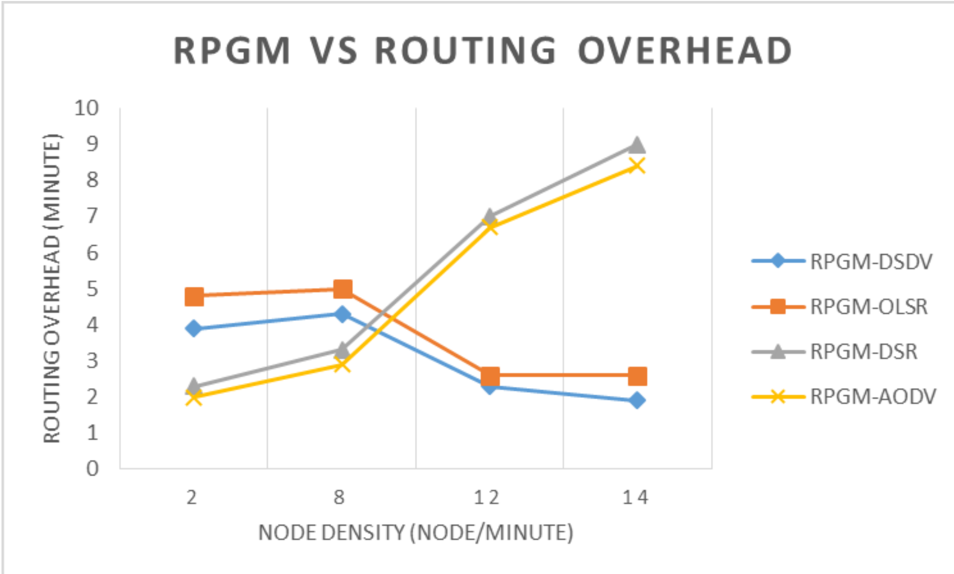


Fig 5.2 Routing overhead in Reference Point Group Mobility Model

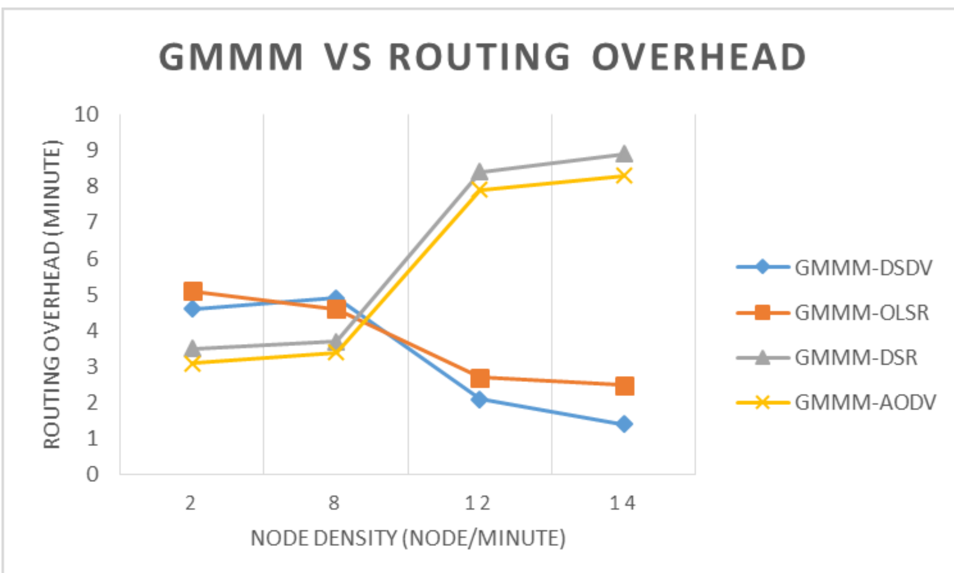


Fig 5.3 Routing overhead in Gauss Markov Mobility Model

As nodes increase (Fig 5.2 and 5.3), each update is broadcasted in the network and this leads to a heavy network load for both DSDV and OLSR, although OLSR minimizes the flooding of update information using Multipoint Relays. This also applies to both RPGM and GMMM in Fig 5.2 and 5.3. When there is a high concentration of nodes, it deteriorates the network performance as nodes cause broken links. However, it is different to how reactive protocols behave. Both DSR and AODV struggle when nodes are few in RWP and not that much in RPGM. This is because the distance between nodes plays a crucial role as they use on-demand mechanisms. When students are moving from one building to another as in Fig 5.2, they follow a group leader who determines the group's behaviour and how they communicate. When there are less group members, proactive protocols behave as compared to reactive protocols because of less information to update on routing tables but things change dramatically when there is a high concentration of nodes.

DSR and AODV worked well on all mobility models when there is an increase in the number of nodes, using a flooding algorithm where a node broadcasts a packet to all its neighbours and intermediary nodes forward that packet to their neighbours, thereby minimizing broken links. In Fig 5.3, the value of the next node's location is calculated based on its current location, which causes the next movement not to be based on the prior angle, but on an angle that brings the nodes back onto the field. It makes DSR have less routing overhead across all mobility models compared to AODV. This happens because DSR uses caching hence there is a high probability of finding a route in cache and perform the route discovery regularly than in AODV. For example if we consider lecture buildings at the NUST campus which are far apart like 1 to 7 vice versa. Frequent topology changes makes AODV protocol to struggle. In that case AODV produces more routing messages compared to DSR. Overall RPGM and GMMM have better performance for the NUST campus setup when there is more movement and a high number of communicating nodes compared to RWM which suit well when students are in a classroom setup with less movement.

Summary

a) OLSR and DSDV perform:
   a. better with few nodes under RWM than RPGM and GMMM,
   b. fairly better with more nodes under all RWM, RPGM and GMMM
b) DSR and AODV are:
   a. worse with few nodes under RWM and RPGM than GMMM,
   b. equally good with more nodes under all RWM, RPGM and GMMM
c) OLSR and DSDV behave:
   a. better than DSR and AODV with few nodes under all RWM, RPGM and GMMM,
   b. worse than DSR and AODV with more nodes under all RWM, RPGM and GMMM

b) Packet Delivery Ratio

An end of Time to Live (TTL) makes packet to drop during communication. By taking much time to decide the destination path, more likely packets have a short life time, thus they might be victims to dropping. To reduce the rate of packet dropping, efficient routing protocols can wisely find out routing direction. RWM model in Fig 5.4 performs better for small networks, due to higher prospects of generating correct routes and sustaining them since there are no space constraints and it even improves as indicated in the Fig 5.5 model. In all cases, the worst results are obtained when nodes density improves across all models. Due to severe restrictions of the node mobility, this happens at the NUST campus setup, regardless of the network size. Additionally, when two nodes diverge, the probability of traffic signal breaking up increases.

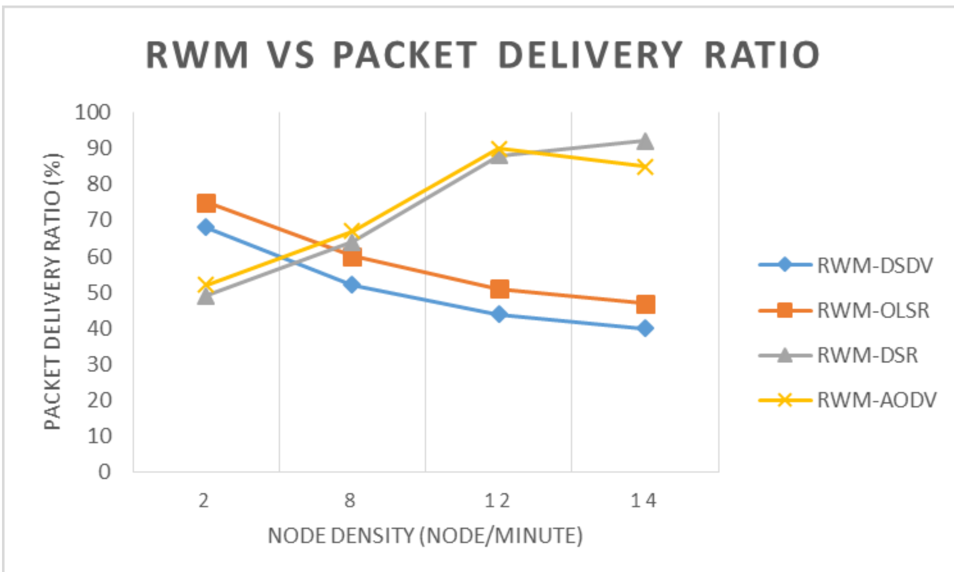


Fig 5.4 Packet Delivery Ratio in Random Waypoint Mobility Model

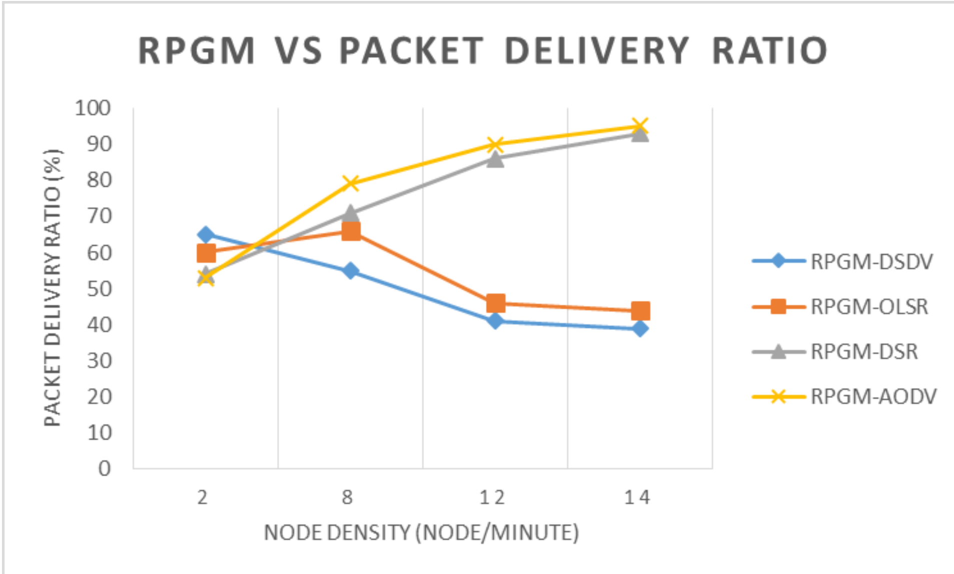


Fig 5.5 Packet Delivery Ratio in Reference Point Group Mobility Model

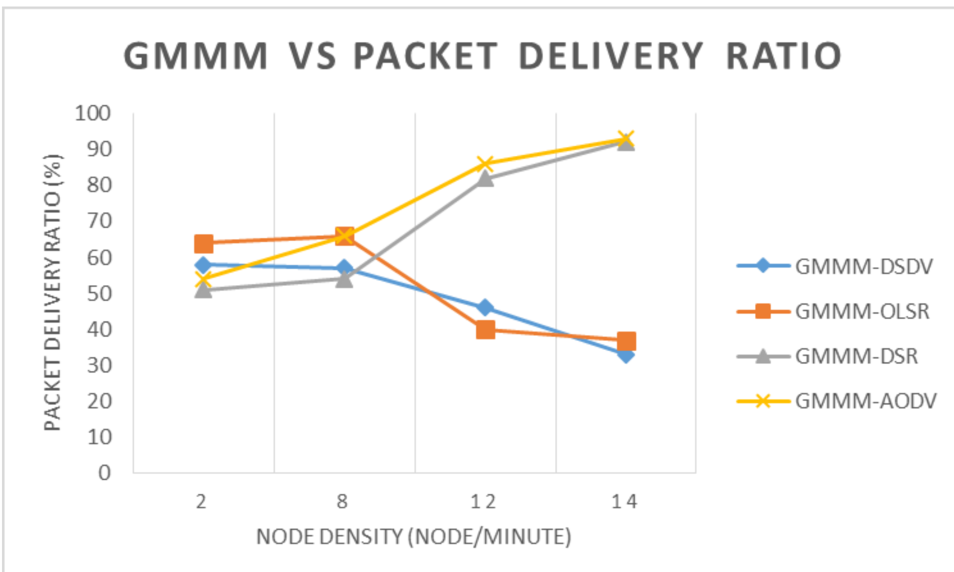


Fig 5.6 Packet Delivery Ratio in Gauss Markov Mobility Model

As witnessed in Fig 5.4, 5.5 and 5.6, DSDV is most affected compared to the other three and this only occurs when the nodes increase. In RPGM and GMMM, the packet drop ratio for DSR is less because of the close proximity of the group leader (acting as access point) to other nodes. In Fig 5.5, there is higher possibility that sources and destinations are located in different clusters, with the possibility of greater distances among them. Packet delivery ratio increases when there are more nodes and groups on the path between source and destination. The high availability of intermediate nodes between the sender and receiver increases in the packet delivery ratio (many routes to use) as there is a continuous connection without much interruption. Considering for example that the distance between Office building and Scitech building is 620m with a node density of 14 nodes/minute, DSDV and OLSR are the most affected because they have to update their routing table with changes of all their neighbours and with almost every node trying to communicate, the congestion becomes increased, thereby affecting some of the nodes which are supposed to relay the packets along the way.

Generally, OLSR performed better than DSDV for all mobility models. As network density increases, random motion greatly varies and the packet drop rate is high in DSDV and less in OLSR. Packet drop rate is less for AODV in GMMM, even though the drop rate remained constant as the network density increased. In Fig 5.6, DSR shows that more packets are delivered when nodes are less compared to Fig 5.5 where more packets are delivered. This is because in Fig 5.5, group leaders determine the group's behaviour even when nodes are less in their respective groups. For example at the NUST campus, for students moving from Lecture building 1 to 2, there is a shorter distance and there are not many options reach the destination. Using a fixed simulation time, the packet received was calculated by changing the nodes number at different levels. Between DSDV and OLSR, DSR and AODV can ensure a high successful transfer rate than the DSDV and OLSR. Overall the success rate of the packet received for AODV is far much better than the DSDV, OLSR and fairly better than DSR.

Summary

a) OLSR and DSDV perform:
   a. good with few nodes under RPGM than RWM and GMMM,
   b. fairly better with more nodes under all RWM, RPGM and GMMM

b) DSR and AODV are:
   a. better with few nodes under RWM and RPGM than GMMM,
   b. very good with more nodes under all RWM, RPGM and GMMM

c) OLSR and DSDV behave:
   a. fairly better than DSR and AODV with few nodes under RWM than RPGM and GMMM,
   b. worse than DSR and AODV with more nodes under RPGM and GMMM than RWM

c) End-to-end data delay

It is evident from the results in Fig 5.7 that the delay is higher in DSDV and less in OLSR among proactive protocols, and among reactive protocols the delay is less in AODV compared to DSR. This happens because the AODV exchange of HELLO messages and cache is not used to store the required routes. With the rise of speed and distance, the routes change more regularly and there is a strong need for finding new routes including in DSR. In that case the presence of cache becomes inadequate and it can potentially become invalid in DSR although it still performs better than proactive protocols in such situations.

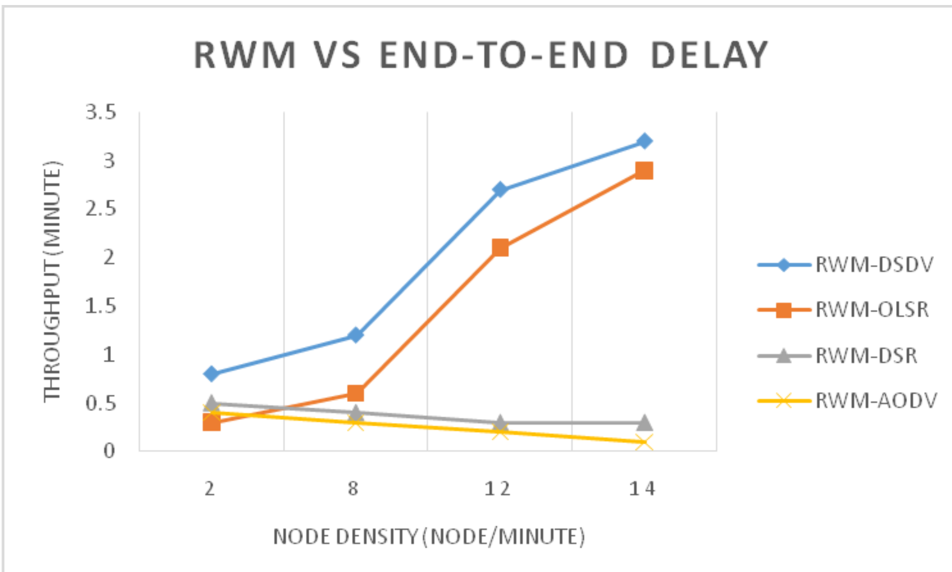


Fig 5.7 Transmitting Delay in Random Waypoint Mobility Model

Simulation results, considering nodes density of 14 nodes/minute as presented in Fig. 5.8, with the group model, RPGM, show that end-to-end delay improves with an increase of network size. The network with approximately 140 mobile nodes is more scarce and the entire communication done among groups, for example if we consider them moving from lecture building to the library, they might move in small groups depending on their social relationships and naturally there tends to be a group leader. The performance delay suffers from temporary node connections that exist in a sparse network. With an increase in the number of mobile nodes, RPGM (using DSR and AODV) becomes the most recommendable mobility model.

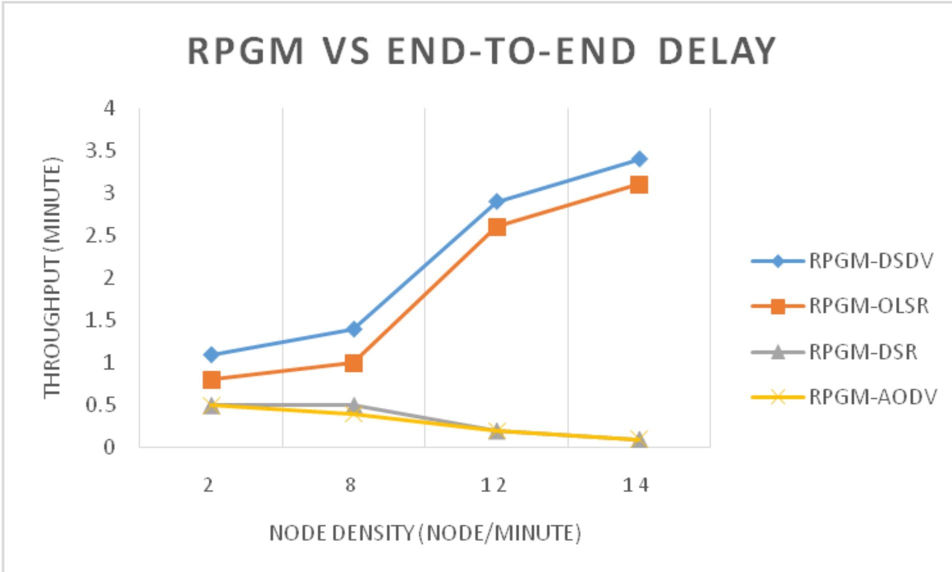


Fig 5.8 Transmitting Delay in Reference Point Group Mobility Model

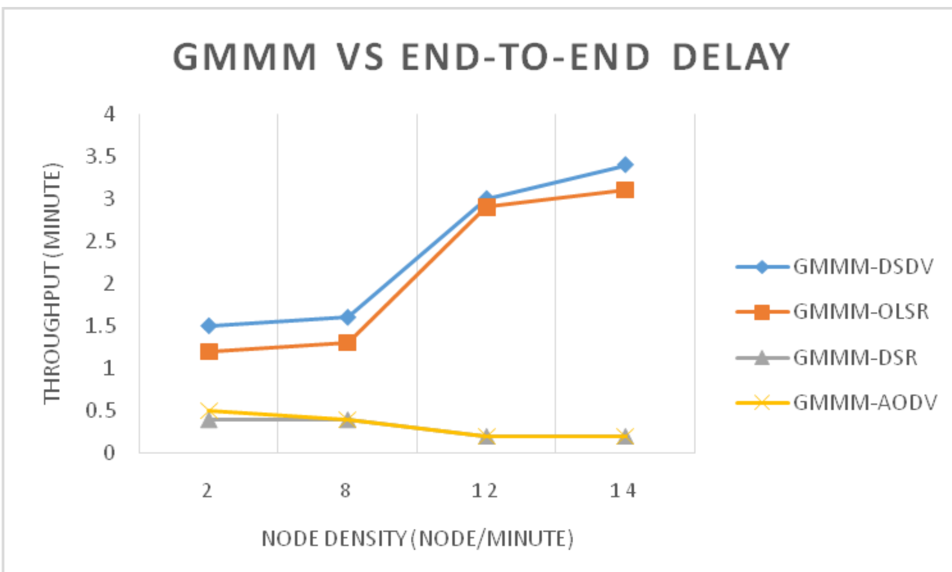


Fig 5.9 Transmitting Delay in Gauss Markov Mobility Model

But with the increase of nodes as shown in Fig 5.8 and 5.9, when all the four are compared AODV has got a higher efficiency in delay. It has been observed that with GMMM and RPGM, the highest throughput is achieved by DSR and AODV protocol as compared to the RWP mobility model, due to a similar relative speed. The high number of nodes (more intermediate nodes involved) for RPGM means a higher link and path duration, which in turn will result in higher throughput.

In GMMM, end to end delay is lesser for DSR and AODV because of the flooding mechanism applied and throughput always improves as nodes increase, whereby for DSDV and OLSR the network deteriorates drastically. Consequently, with less frequent topology changes, less routing messages are sent through AODV. Greater network density comprises more nodes on the paths, which results in higher frequency and less delay of finding new routes.

Summary

a) OLSR and DSDV perform:
    a. worse with few nodes under RWM and GMMM than RPGM,
    b. better with more nodes under RPGM

b) DSR and AODV are:
    a. better with few nodes under RWM and RPGM than GMMM,
    b. very good with more nodes under all RWM, RPGM and GMMM

c) OLSR and DSDV behave:
    a. worse than DSR and AODV with few/more nodes under all RWM, RPGM and GMMM

5.4 Analytical Comparison of Results of Group Mobility Model based on Routing Protocols

In Table 5.1 we give a summarised comparison of the four routings which were tested based on the three mobility models, RWM, RPGM and GMMM. The comparison results were drawn from the results of the analytical simulation done using NS3.24.1 running on Ubuntu operating system.

Table 5. 1 Analytical Comparison of results of Group Mobility Model based on Routing Protocols

Metrics	DSDV	OLSR	DSR	AODV	DSDV	OLSR	DSR	AODV	DSDV	OLSR	DSR	AODV
	Random Waypoint Model				Reference Point Group Mobility				Gauss Markov Mobility Model			
Routing Overhead	Higher routing load than the AODV and DSR	Less routing load than the DSDV	Better than the AODV when nodes remain less	Consistent and worse when the number of nodes does not increase.	Higher routing load as OLSR	Higher routing load as OLSR	Consistent and a bit stable when nodes increase and less route discovery processes	Consistent and a bit unstable when nodes increase with high route discovery processes	Higher routing load as OLSR	Higher routing load as DSDV	Best and stable when nodes increase	Good and stable when nodes increase
Packet Delivery Ratio	Least number of packets are delivered	Best when nodes are less but performance degrades with the increase of nodes	Best when nodes are less but it declines drastically when nodes are increased	Best as more packets are delivered compared to DSDV, OLSR and DSR	More packets are delivered when nodes are few	Best when nodes are less but it declines drastically when nodes are increased	Best when nodes are less but performance degrades with the increase of nodes	Best as more packets are delivered even when nodes increase	Least number of packets are delivered because of distance apart	Least number of packets is delivered because of distance apart	Best when nodes are more because less nodes are affected by distance	Best as more packets are delivered even when nodes increase
End-to-end delay	Higher delay as increase in the networks	Higher delay but improves as nodes increase in the networks compared to DSDV	Less delay time and performance improves as nodes increase	Less delay time and performance improves as nodes increase compared to DSR	Performance degrade because of more delay time before a packet is transmitted	Higher waiting time before a packet is transmitted but better throughput	Less delay before a packet is transmitted but better throughput	Less delay before a packet is transmitted but high throughput compared to DSR	Higher latency when nodes increase	Higher waiting time before a packet is transmitted but less throughput	Less delay before a packet is transmitted but high throughput.	Less delay before a packet is transmitted but higher throughput as nodes increases compared to DSR

5.5 Summary

Three mobility models namely RWM, RPGM and GMMM were identified and analysed to model the mobility or movements on a university setup using a semester timetable. We found that performance differs in different network sizes; and it is a challenge to apply results from one scenario to another. Simulations and analysing the effects of routing protocols namely DSDV, OLSR, DSR and AODV as indicated by the available literature were conducted based on the three mobility models RWM, RPGM and GMMM. These were used to evaluate the performance of opportunistic networks that can emerge at a university campus. Simulation work showed that AODV performs better in a network with a larger number of nodes, whereas DSR performed equally better when the number of nodes was moderate, while OLSR and DSDV worked fairly better with fewer nodes. Overall, results show that Reactive protocols worked quite well with both RPGM and GMMM than RWM mobility models with the scenarios identified for NUST campus considering that the number of students always increases each year. RPGM was the most suited for the NUST campus setup considering that students normally move in groups and we suggest AODV routing protocol because of its on-demand capability, and the fair results it showed on the metrics investigated.

CHAPTER 6: SUMMARY AND CONCLUSION

6.1 Introduction

This chapter presents a summary of the research design and the achieved objectives, as well as the challenges and limitations faced throughout the study. Future work, recommendations and potential value of the study are discussed. Graphs, tables and pictures which were referred to in the main body of the thesis are presented in the appendix section.

6.2 Summary of the Research Design

The researcher wished to recommend a free non-fixed infrastructure network model utilizing mobile phones that suits NUST's Windhoek campus setting, which is fairly affordable and effective for students and staff to communicate locally without paying for the services to mobile service providers. The research involved a case study of students' movement, which is referred to as node mobility done at NUST and a semester lectures timetable was used to model students' movement. Visual basic programming was used to design interfaces and compute all possible scenarios for different cumulative lecture building capacities. Four scenarios were generated from the Group Mobility analysis done at NUST' Windhoek campus and we simulated the highest, moderate, lowest and average traffic generated during inter-breaks of lecture classes during the semester period. Using experimental methodology which gave greater control over the research environment, variables were simulated in a controlled environment. To evaluate the performance of opportunistic network, a quantitative research method was used with the primary aim to collect, count, measure, and assess the meaning behind specific variables. NS-3.24.1 with NetAnim 3.106 was used to create the artificial environment on the communication (routing protocols based on the mobility models) of mobile phones, thus simulating events such as receiving, sending, dropping and forwarding packets. Microsoft Access and Excel were used to analyse the data generated both by the mobility of learners and the effects of routing protocols on these models.

6.3 Achievement of the Objectives

The main objective of the research was to evaluate the performance of mobile device opportunistic networks (P2P) in an uncontrolled university campus environment and we used simulation to achieve this. The main objective was achieved through the following (sub) objectives:

1. **Investigate how the mobility of learners during inter lecture time slots can be modelled;**

   A semester timetable that determined the lecture schedule of a group of students was used to analyse their mobility pattern as they change lectures. Three synthetic models; RWM, RPGM and GMMM identified in section 2.4 were used to model the movements of students in section 3.4.1. Of these three models, the RPGM model was adapted to characterise the group mobility of students moving between building lectures at NUST's Windhoek campus, as reported in section 4.2. Students tend to move in groups according to social or class related relationships and most of these groups tend to have a leader(s).

2. **Investigate capabilities of existing ad-hoc routing protocols based on selected mobility models;**

   The importance of opportunistic routing protocols is to optimally deliver data packets among nodes without a pre-set topology or centralized control. After modelling the students' movements, four routing protocols were identified: Proactive (DSDV and OLSR) and Reactive (DSR and AODV), depending on their functionalities. We investigated these two categories under RWM, RPGM and GMMM group mobilities because of their constant use from most of the P2P studies done. Their ability to dynamically discover routes, ability to work with nodes moving in groups and flood packets on the network, allowing moving nodes to act as routers, and how they use the information they store to deliver packets to the destination even when nodes are not in the same range as mentioned in section 2.5 was analysed. All the four routing protocols are capable of delivering packets depending on the network density and mobility of nodes. For example AODV is more effective when there is a high number of nodes moving in groups, which is the scenario found at a university campus. Therefore, each routing protocol has got its own capabilities depending on the environment being used.

3. **Determine network performance measures;**

   In section 3.4.1.3, three quantitative properties (metrics) Routing Overhead, Packet Delivery Ratio and End-to-end data delay were used to evaluate the performance of the protocols based on the mobility models identified. With these metrics one can measure the quality of service of "free" communication in an opportunistic mobile phone network that students can be using on a campus setting. It was found that AODV and DSR perform better under RPGM and GMMM compared to OSLR, DSDV and RWM mobility model.

4. **Identify a relevant routing protocol for NUST campus setting based on student mobility models;**

   We discovered in section 5.2, that reactive routing protocol AODV is a viable choice for an opportunistic network considering that it supports the connection of thousands of nodes which suit well for a university setup, with DSR also equally important depending on the scenario being investigated, for example if focusing on classrooms and conferences. AODV worked well with both RPGM and GMMM mobility models with the scenarios identified for NUST's Windhoek campus, considering that the number of students always increases each year.

5. **Apply network performance metrics to evaluate the proposed opportunistic traffic model;**

   Using simulation in section 4.3, we generated four scenarios from the Group Mobility analysis done at NUST's Windhoek campus. We simulated highest, moderate, lowest and average traffic generated during inter-breaks of lecture classes during semester period, with distance and speed being the main factor. To apply metrics on these scenarios, NS-3.24.1 with NetAnim 3.106 was used to create the artificial environment on the communication of mobile phones thus simulating events such as receiving, sending, dropping and forwarding packets using parameters described in section 3.4.1.3. Microsoft Access and Excel were used to analyse the data generated both by the mobility of learners and the effects of routing protocols on these models. To achieve results in section 5.2, each scenario produced a CSV file and trace files which were further processed to understand the performance of the network. Repetition of the simulation helped to come up with an average performance of each scenario.

   The simulation results observed indicated that AODV has got higher performance in throughput compared to DSR and it gives less packet loss rate and delay across all mobility models. Lowest routing protocol overhead was experienced in DSR at the expense of average delays with the three mobility models, RWM, RPGM and GMMM compared to AODV and proactive protocols. AODV performance was the best considering its ability to maintain connection by frequently using Hello messages. As far as latency is concerned, both AODV and DSR protocols perform better than proactive DSDV and OLSR, even when the network has a large number of nodes on all three mobility models. DSR is designed mainly to support mobile opportunistic networks of up to about two hundred (200) nodes and it can work well in varying mobility patterns. It performed better both in RPGM and GMMM. Average End-to-End Delay is the least for DSDV compared to OLSR in the RWM model when there is less movement but it increases drastically if the number of nodes is increased in RPGM and GMMM.

6.4 Challenges and Limitations

The biggest challenge was being able to test the same simulated effects of node mobility on the opportunistic routing protocols and opportunistic applications on real world conditions because of the technical and programming challenges on implementing a middleware approach (between phone kernel and application level). In opportunistic networks, creating a real working implementation is non-trivial and more challenging than developing a simulation. It needs to interoperate with a large and complex system which includes components such as the operating system, sockets, and network interfaces. Outdoor field tests of mobile opportunistic networks reveal realistic use case scenarios and can validate anticipated results under real-world conditions. However these tests can be restrictively costly and distant for a typical researcher or developer. Significantly it takes more determination and time to create real implementation than a simulation.

Additional implementation problems surfaced because current mobile phone operating systems are not built to support opportunistic routing protocols, whilst those supporting them need additional components. A number of required settings are restricted or blocked and support for these settings must be added, for example to change components on the kernel. Moreover, installing patches, updating software, configuring individual nodes, log monitoring, and debugging releases of experimental software distributions on a modest size opportunistic network can be time-consuming. Recreating realistic environmental settings and signal transmission features using off-the-shelf computing nodes and wireless cards in a lab environment is also challenging. Therefore, for this study we were limited to a simulation environment and all the results are based on simulation.

6.5 Suggestions for Future Work

The testing of opportunistic networking protocols in a simulated environment allows researchers a chance to validate theories in practice, to test simulation assumptions, and to discover and highlight practical problems facing opportunistic network users and developers. To date, the majority of opportunistic network research has been done using simulation only. There is a need in the future for some proof of the concept by applying Middleware Approach using mobile phones whose operating systems will be programmed to implement the AODV routing protocol (under RPGM) and algorithms which were simulated. Middleware Approach was also implemented to provide the opportunistic networking services for android applications. It maintains a clean networking stack, so the system is more reliable by having no interference with Linux kernel and it reduces the difficulty of maintenance and testing. The middleware can be implemented as a standard Android Service in the user space and it runs in its own process. The service can be installed and uninstalled as a normal Android application and it requires no OS configuration.

There is a need to do a comprehensive study at NUST's Windhoek campus, assessing all active students at a specific period of time as opposed to FCI only which we did in the research. It will be very important to include other NUST faculties and centres as this will bring a new dimension in terms of mobility and how the students communicate through their mobile phones. It will be of much significance to apply the Middleware Approach to the whole NUST campus as this can be used (if successful) as a model for other universities in Namibia. With the benefits of the Middleware Approach more and more researchers and developers now adopt this approach for their implementations, thereby we recommend the application of the Middleware Approach in the future for the NUST campus setting.

6.6 Potential Value of the Study

The study proposes a potential product: a free non-fixed infrastructure network model utilizing mobile phones which is fairly affordable and effective for students and staff to communicate locally. It can be used as an influential tool on whether to fully implement an opportunistic network at the university's campus, to help learners improve communication using a cost effective setup hence also helping improve students' performance by enabling convenient sharing of study materials. The main aim is to help address some of the gaps that currently exist in the network setup of NUST and also help complement the current structures used by the university.

Now that most university learners own personal mobile phones, it presents a unique chance to appreciate how mobile phones can be used for studying purposes, both inside and outside the lecture rooms and also for exploring new possible learning opportunities that can be introduced with the most up-to-date technology. Other researchers have seen mobile devices delivering encouraging results on supporting teaching and learning, showing that students are now more likely to use their mobile phones to learn, and students are more involved and motivated when allowed to use mobile devices.

The study is expected to enlighten researchers and educators on the current abilities of mobile phones at a university setup and help administrators and mentors to understand how the mobility or movement of students plays a crucial role in determining how they communicate to each other. The study is also expected to show the potential uses for mobile learning inside and outside the lecture rooms at a university setting. Further implementation of the outcomes of the study may help universities save costs on the implementation of networks.

6.7 Conclusion

We investigated the cluster mobility of students at NUST as this impacts the performance of mobile Opportunistic network on how to route information using routing algorithm. Mobility and location prediction can improve routing and create consistent connections. In this study, it was observed that the mobility pattern can influence the viability of opportunistic networks in many ways. Most research results demonstrate that the performance of an Opportunistic network differs across different mobility models and henceforth the study outcomes from one model might not be practical to other models.

We presented results from conducting simulations and analysing the effects of routing protocols DSDV, OLSR, DSR and AODV on the mobility models RWM, RPGM and GMMM to evaluate the performance of Opportunistic networks that can emerge at a university campus. RPGM suited NUST's Windhoek campus setup because most students tend to move in groups when changing lectures. The study demonstrated that the comparative status of routing protocols may differ subject to the mobility model applied and they performed differently for the three mobility models RWM, RPGM and GMMM. Overall, our simulation work showed that AODV performed better in a network with a greater number of nodes (it is meant for thousands of mobile nodes like in a campus setting), whereas DSR performed better when the number of nodes is moderate.

Thus, we found that AODV is a viable choice for P2P, considering that it supports the connection of thousands of nodes which suit well for a university setup, with DSR also equally important depending on the scenario being investigated, for example if focusing on classrooms and conferences. In this study, a complete analysis of four Opportunistic routing protocols was done. We established that the Reactive protocols worked well with both RPGM and GMMM mobility models, with the scenarios identified for NUST's Windhoek campus considering that the number of students always increases each year. In conclusion, RPGM is the most recommended mobility model because it can cater for students' mobility patterns as they mostly tend to move in groups depending on their social relationships or as guided by the level of studies they are doing. It can also be concluded from the simulation results that the efficiency of AODV under RPGM and GMMM is far better than those of DSR, DSDV and OLSR, therefore suggesting AODV protocol for NUST's Windhoek campus setup.

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APPENDICES

Appendix 1: NUST Semester Timetable

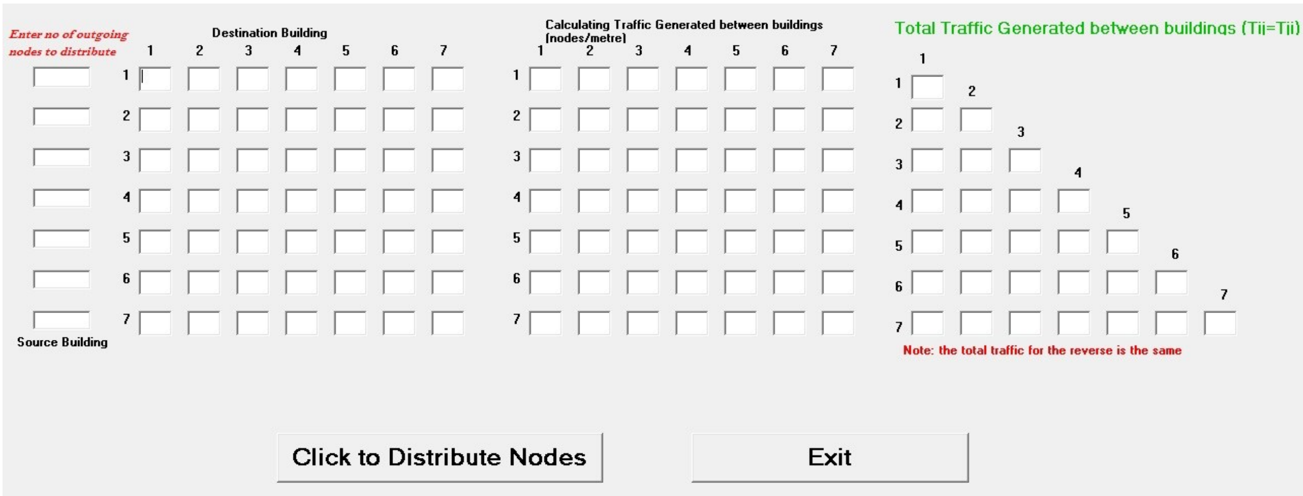
School of Computing & Informatics - Semester 1 - 2016 - v5

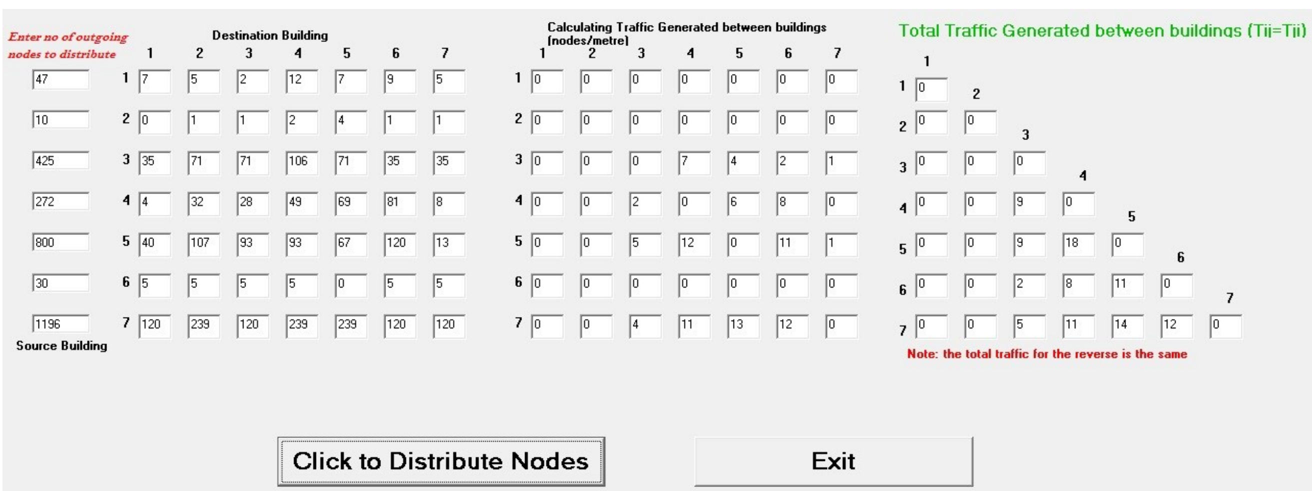
Programme timetable - 07BACS, s1 G3, Bachelor of Computer Science NQF: 7

	07:30AM	08:30AM	09:30AM	10:30AM	11:30AM	12:30PM	02:00PM	03:00PM	04:00PM	05:15PM	06:35PM	08:00PM	09:25PM
Monday	BSC410S E1/G/AUD (Health & Applied Sciences Building)		LIP411S D3/1/Clr 2 (Auditoria); D3/1/Clr 3 (Auditoria)		MIT112S Amunyela, J. 1002955; Nambashu, J; Ndadi, I.D.O. 1004752; Ndinodiva, F.N. 1002317; Shaanika, A.N. 1003390 A15/1/311 (Lecture Block); A15/2/402 (Lecture Block); A15/G/202 (Lecture Block); A15/G/212 (Lecture Block)				COA511S Samuel Jegede computer Lab 10 (Science & Technology Building) *Grp 3 Self study*				
Tuesday	LIP411S D3/1/Clr 2 (Auditoria); D3/1/Clr 3 (Auditoria)		BSC410S E1/G/AUD (Health & Applied Sciences Building)				COA511S Gamundani, A.M. E1/G/AUD (Health & Applied Sciences Building) *Theory ALL*	MNS511S Maravanyika D3/G/AUD 1 (Auditoria)					

Page 11, published 2016/03/07 12:38:25 PM, by cstanley (Polytechnic of Namibia) - CELCAT Timetabling (continued...)

Appendix 2: Interface Screenshots





Appendix 3: VB Source Code

```
Dim i, n, clicks As Integer
Dim found As Boolean

Private Sub cmdExit_Click()
End
End Sub

Private Sub cmdGenerate_Click()
On Error Resume Next
Dim aintRandomN(1 To 49) As Integer
 Dim intX, rm, sum, smallest As Integer
txt1.Text = txtTB_1
txt2.Text = txtTB_2
txt3.Text = txtTB_3
txt4.Text = txtTB_4
txt5.Text = txtTB_5
txt6.Text = txtTB_6
txt7.Text = txtTB_7

sum = 0
smallest = 100
 Randomize
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' Building 1 - Lecture Venue
' Randomize the distribution of  from building 1 to other buildings
rm = Val(txtTB_1)
For intX = 1 To 7
   aintRandomN(intX) = Int(100 * Rnd) + 1
   If aintRandomN(intX) < smallest Then
     smallest = aintRandomN(intX)
   End If
Next

For intX = 1 To 7
   aintRandomN(intX) = aintRandomN(intX) / smallest
   sum = sum + aintRandomN(intX)
Next

For intX = 1 To 7
   aintRandomN(intX) = (aintRandomN(intX) / sum) * rm
Next


' display the contents of the "aintRandomNum" array ...
For intX = 1 To 7
   Form1.txtDistribution(intX) = aintRandomN(intX)
Next

''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' Building 2 - Office Building
' Randomize the distribution of  from building 2 to other buildings
Dim ro, sumo, smallesto As Integer
```

```
sumo = 0
smallesto = 100
ro = Val(txtTB_2)
For intX = 8 To 14
   aintRandomN(intX) = Int(100 * Rnd) + 1
   If aintRandomN(intX) < smallesto Then
     smallesto = aintRandomN(intX)
   End If
Next

For intX = 8 To 14
   aintRandomN(intX) = aintRandomN(intX) / smallesto
   sumo = sumo + aintRandomN(intX)
Next

For intX = 8 To 14
   aintRandomN(intX) = (aintRandomN(intX) / sumo) * ro
Next
' display the contents of the "aintRandomNum" array ...

For intX = 8 To 14
   Form1.txtDistribution(intX) = aintRandomN(intX)
Next
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' Building 3 - Library
' Randomize the distribution of  from building 3 to other buildings
Dim rq, sumq, smallestq As Integer
sumq = 0
smallestq = 100
rq = Val(txtTB_3)
For intX = 15 To 21
   aintRandomN(intX) = Int(100 * Rnd) + 1
   If aintRandomN(intX) < smallestq Then
     smallestq = aintRandomN(intX)
   End If
Next

For intX = 15 To 21
   aintRandomN(intX) = aintRandomN(intX) / smallestq
   sumq = sumq + aintRandomN(intX)
Next

For intX = 15 To 21
   aintRandomN(intX) = (aintRandomN(intX) / sumq) * rq
Next
' display the contents of the "aintRandomNum" array ...

For intX = 15 To 21
   Form1.txtDistribution(intX) = aintRandomN(intX)
Next
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' Building 4 - Auditorium
' Randomize the distribution of  from building 4 to other buildings
```

```
Dim ru, sumu, smallestu As Integer
sumu = 0
smallestu = 100
ru = Val(txtTB_4)
For intX = 22 To 28
   aintRandomN(intX) = Int(100 * Rnd) + 1
   If aintRandomN(intX) < smallestu Then
     smallestu = aintRandomN(intX)
   End If
Next

For intX = 22 To 28
   aintRandomN(intX) = aintRandomN(intX) / smallestu
   sumu = sumu + aintRandomN(intX)
Next

For intX = 22 To 28
   aintRandomN(intX) = (aintRandomN(intX) / sumu) * ru
Next
' display the contents of the "aintRandomNum" array ...

For intX = 22 To 28
   Form1.txtDistribution(intX) = aintRandomN(intX)
Next
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' Building 5 - Engineering Building
' Randomize the distribution of  from building 5 to other buildings
Dim rx, sumx, smallestx As Integer
sumx = 0
smallestx = 100
rx = Val(txtTB_5)
For intX = 29 To 35
   aintRandomN(intX) = Int(100 * Rnd) + 1
   If aintRandomN(intX) < smallest Then
     smallest = aintRandomN(intX)
   End If
Next

For intX = 29 To 35
   aintRandomN(intX) = aintRandomN(intX) / smallest
   sum = sum + aintRandomN(intX)
Next

For intX = 29 To 35
   aintRandomN(intX) = (aintRandomN(intX) / sum) * rx
Next
' display the contents of the "aintRandomNum" array ...

For intX = 29 To 35
   Form1.txtDistribution(intX) = aintRandomN(intX)
Next
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' Building 6 - Scitech Building
```

```
' Randomize the distribution of  from building 6 to other buildings
Dim ra, suma, smallesta As Integer
suma = 0
smallesta = 50
ra = Val(txtTB_6)
For intX = 36 To 42
   aintRandomN(intX) = Int(100 * Rnd) + 1
   If aintRandomN(intX) < smallest Then
     smallesta = aintRandomN(intX)
   End If
Next

For intX = 36 To 42
   aintRandomN(intX) = aintRandomN(intX) / smallesta
   suma = suma + aintRandomN(intX)
Next

For intX = 36 To 42
   aintRandomN(intX) = (aintRandomN(intX) / suma) * ra
Next
' display the contents of the "aintRandomNum" array ...

For intX = 36 To 42
   Form1.txtDistribution(intX) = aintRandomN(intX)
Next
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' Building 7 - SHAS Building
' Randomize the distribution of  from building 7 to other buildings
Dim rc, sumc, smallestc As Integer
sumc = 0
smallestc = 100
rc = Val(txtTB_7)
For intX = 43 To 49
   aintRandomN(intX) = Int(100 * Rnd) + 1
   If aintRandomN(intX) < smallestc Then
     smallestc = aintRandomN(intX)
   End If
Next

For intX = 43 To 49
   aintRandomN(intX) = aintRandomN(intX) / smallestc
   sumc = sumc + aintRandomN(intX)
Next

For intX = 43 To 49
   aintRandomN(intX) = (aintRandomN(intX) / sumc) * rc
Next
' display the contents of the "aintRandomNum" array ...

For intX = 43 To 49
   Form1.txtDistribution(intX) = aintRandomN(intX)
Next
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
Call cmdTraffic_Click
```

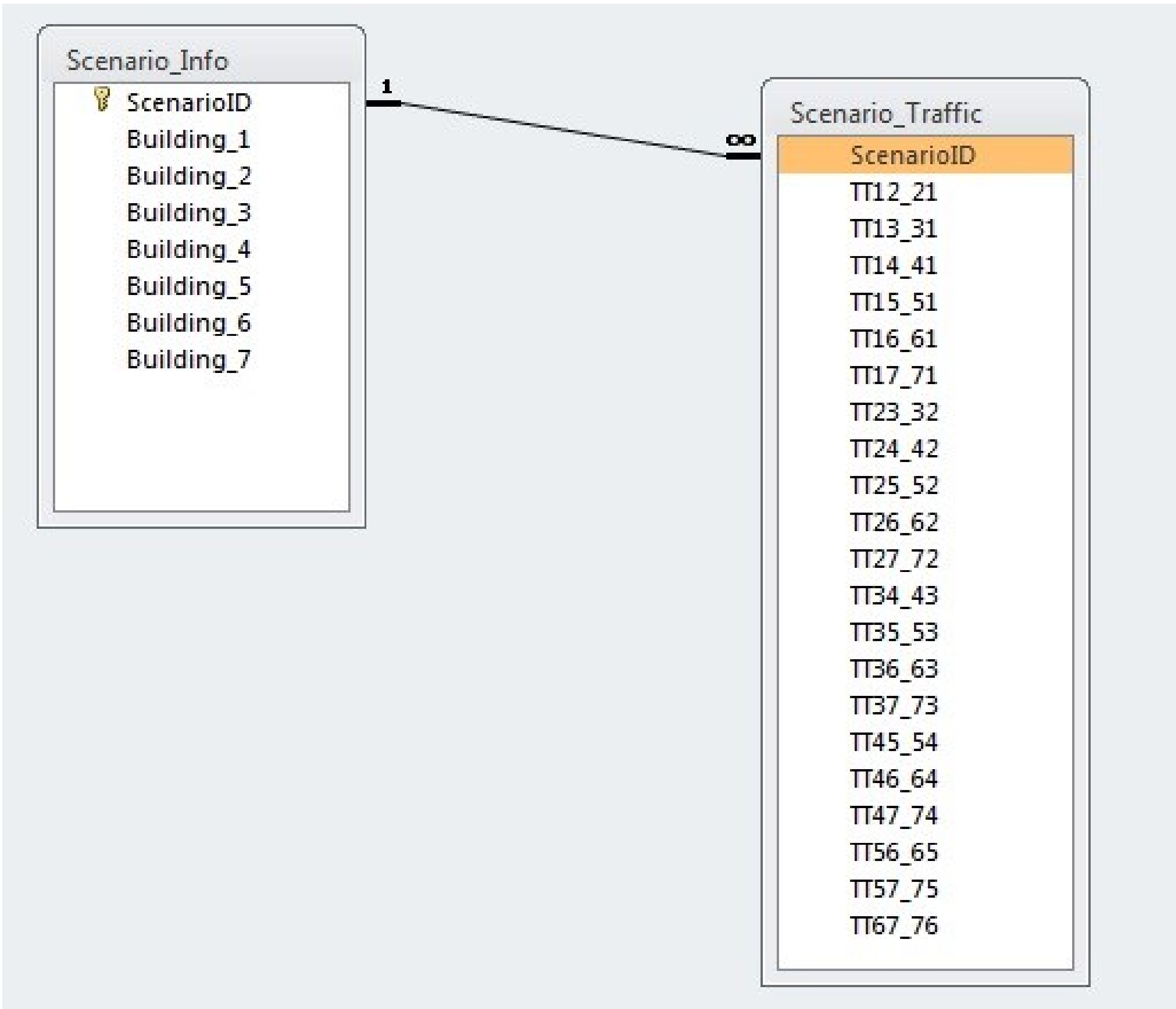
```
Call cmdTT_Click
End Sub
Private Sub cmdRnd_Click()
          'For i = 0 To 10
           'i = i + 1
          ' txtRndID.Text = "Rnd" & i
           'txtScenarioID.Text = "Scenario" & i
           'Next
           'i = Int(Rnd() * 100) + 1
 'txtScenarioID.Text = "Scenario" & i
End Sub

Private Sub cmdSave_Click()
On Error Resume Next
i = Int(Rnd() * 10000) + 1
 txtScenarioID.Text = "Scenario" & i
found = False
dteNodes.rscmdRnd.Open
dteNodes.rscmdRnd.MoveFirst
  Do Until dteNodes.rscmdRnd.EOF
    If dteNodes.rscmdRnd![ScenarioID] = txtScenarioID Then
       found = True
    End If
dteNodes.rscmdRnd.MoveNext
  Loop
dteNodes.rscmdRnd.Close
If found = True Then
i = Int(Rnd() * 10000) + 1
 txtScenarioID.Text = "Scenario" & i
Else
dteNodes.rscmdRnd.Open
  dteNodes.rscmdRnd.AddNew
  dteNodes.rscmdRnd![ScenarioID] = txtScenarioID
  dteNodes.rscmdRnd![Building_1] = txt1
  dteNodes.rscmdRnd![Building_2] = txt2
  dteNodes.rscmdRnd![Building_3] = txt3
  dteNodes.rscmdRnd![Building_4] = txt4
  dteNodes.rscmdRnd![Building_5] = txt5
  dteNodes.rscmdRnd![Building_6] = txt6
  dteNodes.rscmdRnd![Building_7] = txt7
  dteNodes.rscmdRnd.Update
 dteNodes.rscmdRnd.Close

For i = 1 To 5
Call cmdGenerate_Click
dteNodes.rscmdScenario.Open
  dteNodes.rscmdScenario.AddNew
  dteNodes.rscmdScenario![ScenarioID] = txtScenarioID
  dteNodes.rscmdScenario![TT12_21] = txtTT(0)
  dteNodes.rscmdScenario![TT13_31] = txtTT(1)
  dteNodes.rscmdScenario![TT14_41] = txtTT(3)
  dteNodes.rscmdScenario![TT15_51] = txtTT(6)
  dteNodes.rscmdScenario![TT16_61] = txtTT(10)
  dteNodes.rscmdScenario![TT17_71] = txtTT(15)
  dteNodes.rscmdScenario![TT23_32] = txtTT(2)
  dteNodes.rscmdScenario![TT24_42] = txtTT(4)
  dteNodes.rscmdScenario![TT25_52] = txtTT(7)
  dteNodes.rscmdScenario![TT26_62] = txtTT(11)
```

```
  dteNodes.rscmdScenario![TT27_72] = txtTT(16)
  dteNodes.rscmdScenario![TT34_43] = txtTT(5)
  dteNodes.rscmdScenario![TT35_53] = txtTT(8)
  dteNodes.rscmdScenario![TT36_63] = txtTT(12)
  dteNodes.rscmdScenario![TT37_73] = txtTT(17)
  dteNodes.rscmdScenario![TT45_54] = txtTT(9)
  dteNodes.rscmdScenario![TT46_64] = txtTT(13)
  dteNodes.rscmdScenario![TT47_74] = txtTT(18)
  dteNodes.rscmdScenario![TT56_65] = txtTT(14)
  dteNodes.rscmdScenario![TT57_75] = txtTT(19)
  dteNodes.rscmdScenario![TT67_76] = txtTT(20)
  dteNodes.rscmdScenario.Update
 dteNodes.rscmdScenario.Close
Next
End If
End Sub
```

Appendix 4: Database Schema



Appendix 5: Mobility and Routing C++ Source Code

```
#include <fstream>
#include <iostream>
#include "ns3/core-module.h"
#include "ns3/network-module.h"
#include "ns3/internet-module.h"
#include "ns3/mobility-module.h"
#include "ns3/WiFi-module.h"
#include "ns3/aodv-module.h"
#include "ns3/olsr-module.h"
#include "ns3/dsdv-module.h"
#include "ns3/dsr-module.h"
#include "ns3/applications-module.h"
#include "ns3/netanim-module.h"

using namespace ns3;
using namespace dsr;

NS_LOG_COMPONENT_DEFINE ("manet-routing-compare");

class RoutingExperiment
{
public:
  RoutingExperiment ();
  void Run (int nSinks, double txp, std::string CSVfileName);
  static void SetMACParam (ns3::NetDeviceContainer & devices,
                           int slotDistance);
  std::string CommandSetup (int argc, char **argv);

private:
  Ptr<Socket> SetupPacketReceive (Ipv4Address addr, Ptr<Node> node);
  void ReceivePacket (Ptr<Socket> socket);
  void CheckThroughput ();

  uint32_t port;
  uint32_t bytesTotal;
  uint32_t packetsReceived;

  std::string m_CSVfileName;
  int m_nSinks;
  std::string m_protocolName;
  double m_txp;
  bool m_traceMobility;
  uint32_t m_protocol;
};

RoutingExperiment::RoutingExperiment ()
  : port (9),
    bytesTotal (0),
    packetsReceived (0),
    m_CSVfileName ("opportunistic-routing.output.csv"),
    m_traceMobility (false),
```

```
    //m_protocol (1) // OLSR
    m_protocol (2) // AODV
    //m_protocol (3) // DSDV
    //m_protocol (4) // DSR
{
}

static inline std::string
PrintReceivedPacket (Ptr<Socket> socket, Ptr<Packet> packet)
{
  SocketAddressTag tag;
  bool found;
  found = packet->PeekPacketTag (tag);
  std::ostringstream oss;

  oss << Simulator::Now ().GetSeconds () << " " << socket->GetNode ()->GetId ();

  if (found)
    {
      InetSocketAddress addr = InetSocketAddress::ConvertFrom (tag.GetAddress ());
      oss << " received one packet from " << addr.GetIpv4 ();
    }
  else
    {
      oss << " received one packet!";
    }
  return oss.str ();
}

void
RoutingExperiment::ReceivePacket (Ptr<Socket> socket)
{
  Ptr<Packet> packet;
  while ((packet = socket->Recv ()))
    {
      bytesTotal += packet->GetSize ();
      packetsReceived += 1;
      NS_LOG_UNCOND (PrintReceivedPacket (socket, packet));
    }
}

void
RoutingExperiment::CheckThroughput ()
{
  double byte = 64;
  bytesTotal = 0;

  std::ofstream out (m_CSVfileName.c_str (), std::ios::app);

  out << (Simulator::Now ()).GetSeconds () << ","
      << kbs << ","
      << packetsReceived << ","
      << m_nSinks << ","
      << m_protocolName << ","
      << m_txp << ""
```

```
    << std::endl;

  out.close ();
  packetsReceived = 0;
  Simulator::Schedule (Seconds (1.0), &RoutingExperiment::CheckThroughput, this);
}

Ptr<Socket>
RoutingExperiment::SetupPacketReceive (Ipv4Address addr, Ptr<Node> node)
{
  TypeId tid = TypeId::LookupByName ("ns3::UdpSocketFactory");
  Ptr<Socket> sink = Socket::CreateSocket (node, tid);
  InetSocketAddress local = InetSocketAddress (addr, port);
  sink->Bind (local);
  sink->SetRecvCallback (MakeCallback (&RoutingExperiment::ReceivePacket, this));

  return sink;
}

std::string
RoutingExperiment::CommandSetup (int argc, char **argv)
{
  CommandLine cmd;
  cmd.AddValue ("CSVfileName", "The name of the CSV output file name", m_CSVfileName);
  cmd.AddValue ("traceMobility", "Enable mobility tracing", m_traceMobility);
  cmd.AddValue ("protocol", "1=OLSR;2=AODV;3=DSDV;4=DSR", m_protocol);
  cmd.Parse (argc, argv);
  return m_CSVfileName;
}

int
main (int argc, char *argv[])
{
  RoutingExperiment experiment;
  std::string CSVfileName = experiment.CommandSetup (argc,argv);

  //blank out the last output file and write the column headers
  std::ofstream out (CSVfileName.c_str ());
  out << "SimulationSecond," <<
  "ReceiveRate," <<
  "PacketsReceived," <<
  "NumberOfSinks," <<
  "RoutingProtocol," <<
  "TransmissionPower" <<
  std::endl;
  out.close ();

  int nSinks = 11;
  double txp = 8;

  experiment.Run (nSinks, txp, CSVfileName);
}

void
RoutingExperiment::Run (int nSinks, double txp, std::string CSVfileName)
```

```
{
  Packet::EnablePrinting ();
  m_nSinks = nSinks;
  m_txp = txp;
  m_CSVfileName = CSVfileName;

  int nWiFis = 140;

  double TotalTime = 200.0;
  std::string rate ("2048bps");
  std::string phyMode ("DsssRate11Mbps");
  std::string tr_name ("manet-routing-compare");
  int nodeSpeed = 20; //in m/s
  int nodePause = 0; //in s
  m_protocolName = "protocol";

  Config::SetDefault  ("ns3::OnOffApplication::PacketSize",StringValue ("64"));
  Config::SetDefault ("ns3::OnOffApplication::DataRate",  StringValue (rate));

  //Set Non-unicastMode rate to unicast mode
  Config::SetDefault ("ns3::WiFiRemoteStationManager::NonUnicastMode",StringValue (phyMode));

  NodeContainer Ad-hocNodes;
  Ad-hocNodes.Create (nWiFis);

  // setting up WiFi phy and channel using helpers
  WiFiHelper WiFi;
  WiFi.SetStandard (WIFI_PHY_STANDARD_80211b);

  YansWiFiPhyHelper WiFiPhy =  YansWiFiPhyHelper::Default ();
  YansWiFiChannelHelper WiFiChannel;
  WiFiChannel.SetPropagationDelay ("ns3::ConstantSpeedPropagationDelayModel");
  WiFiChannel.AddPropagationLoss ("ns3::FriisPropagationLossModel");
  WiFiPhy.SetChannel (WiFiChannel.Create ());

  // Add a non-QoS upper mac, and disable rate control
  NqosWiFiMacHelper WiFiMac = NqosWiFiMacHelper::Default ();
  WiFi.SetRemoteStationManager ("ns3::ConstantRateWiFiManager",
                        "DataMode",StringValue (phyMode),
                        "ControlMode",StringValue (phyMode));

  WiFiPhy.Set ("TxPowerStart",DoubleValue (txp));
  WiFiPhy.Set ("TxPowerEnd", DoubleValue (txp));

  WiFiMac.SetType ("ns3::Ad-hocWiFiMac");
  NetDeviceContainer Ad-hocDevices = WiFi.Install (WiFiPhy, WiFiMac, Ad-hocNodes);

  MobilityHelper mobilityAd-hoc;
  int64_t streamIndex = 0; // used to get consistent mobility across scenarios

  ObjectFactory pos;
  pos.SetTypeId ("ns3::RandomRectanglePositionAllocator");
  pos.Set ("X", StringValue ("ns3::UniformRandomVariable[Min=0.0|Max=300.0]"));
  pos.Set ("Y", StringValue ("ns3::UniformRandomVariable[Min=0.0|Max=1500.0]"));
```

```
Ptr<PositionAllocator> taPositionAlloc = pos.Create ()->GetObject<PositionAllocator> ();
streamIndex += taPositionAlloc->AssignStreams (streamIndex);

std::stringstream ssSpeed;
ssSpeed << "ns3::UniformRandomVariable[Min=0.0|Max=" << nodeSpeed << "]";
std::stringstream ssPause;
ssPause << "ns3::ConstantRandomVariable[Constant=" << nodePause << "]";
mobilityAd-hoc.SetMobilityModel ("ns3::RandomWaypointMobilityModel",
                                 "Speed", StringValue (ssSpeed.str ()),
                                 "Pause", StringValue (ssPause.str ()),
                                 "PositionAllocator", PointerValue (taPositionAlloc));
mobilityAd-hoc.SetPositionAllocator (taPositionAlloc);
mobilityAd-hoc.Install (Ad-hocNodes);
streamIndex += mobilityAd-hoc.AssignStreams (Ad-hocNodes, streamIndex);

AodvHelper aodv;
OlsrHelper olsr;
DsdvHelper dsdv;
DsrHelper dsr;
DsrMainHelper dsrMain;
Ipv4ListRoutingHelper list;
InternetStackHelper internet;

switch (m_protocol)
  {
  case 1:
    list.Add (olsr, 140);
    m_protocolName = "OLSR";
    break;
  case 2:
    list.Add (aodv, 140);
    m_protocolName = "AODV";
    break;
  case 3:
    list.Add (dsdv, 140);
    m_protocolName = "DSDV";
    break;
  case 4:
    m_protocolName = "DSR";
    break;
  default:
    NS_FATAL_ERROR ("No such protocol:" << m_protocol);
  }

if (m_protocol < 4)
  {
    internet.SetRoutingHelper (list);
    internet.Install (Ad-hocNodes);
  }
else if (m_protocol == 4)
  {
    internet.Install (Ad-hocNodes);
    dsrMain.Install (dsr, Ad-hocNodes);
  }
```

```
  NS_LOG_INFO ("assigning ip address");

  Ipv4AddressHelper addressAd-hoc;
  addressAd-hoc.SetBase ("10.1.1.0", "255.255.0.0");
  Ipv4InterfaceContainer Ad-hocInterfaces;
  Ad-hocInterfaces = addressAd-hoc.Assign (Ad-hocDevices);

  OnOffHelper onoff1 ("ns3::UdpSocketFactory",Address ());
  onoff1.SetAttribute ("OnTime", StringValue ("ns3::ConstantRandomVariable[Constant=1.0]"));
  onoff1.SetAttribute ("OffTime", StringValue ("ns3::ConstantRandomVariable[Constant=0.0]"));

  for (int i = 0; i <= nSinks - 1; i++)
    {
      Ptr<Socket> sink = SetupPacketReceive (Ad-hocInterfaces.GetAddress (i), Ad-hocNodes.Get (i));

      AddressValue remoteAddress (InetSocketAddress (Ad-hocInterfaces.GetAddress (i), port));
      onoff1.SetAttribute ("Remote", remoteAddress);

      Ptr<UniformRandomVariable> var = CreateObject<UniformRandomVariable> ();
      ApplicationContainer temp = onoff1.Install (Ad-hocNodes.Get (i + nSinks));
      temp.Start (Seconds (var->GetValue (100.0,101.0)));
      temp.Stop (Seconds (TotalTime));
    }

  NS_LOG_INFO ("Configure Tracing.");
  tr_name = tr_name + "_" + m_protocolName +"_" + nodes + "nodes_" + sNodeSpeed + "speed_" + sNodePause +
"pause_" + sRate + "rate";

  AsciiTraceHelper ascii;
  Ptr<OutputStreamWrapper> osw = ascii.CreateFileStream ( (tr_name + ".tr").c_str());
  WiFiPhy.EnableAsciiAll (osw);
  //AsciiTraceHelper ascii;
  MobilityHelper::EnableAsciiAll (ascii.CreateFileStream (tr_name + ".mob"));

  //Ptr<FlowMonitor> flowmon;
  //FlowMonitorHelper flowmonHelper;
  //flowmon = flowmonHelper.InstallAll ();

  AnimationInterface anim ("pahla.xml");
  NS_LOG_INFO ("Run Simulation.");

  CheckThroughput ();

  Simulator::Stop (Seconds (TotalTime));
  Simulator::Run ();

  //flowmon->SerializeToXmlFile ((tr_name + ".flowmon").c_str(), false, false);

  Simulator::Destroy ();
}
```

Appendix 6: NUST Lecture Venues

Unique_Name	Name	Default Capacity
B01	Basement Parking Area/Exam Centre	800
AUD, Flr G	Auditorium	285
Aud 1, Flr G	Auditorium 1	272
IT Lab 12	Computer Laboratory	180
207, Flr G	Classroom	170
Aud S, 0.11, Flr G	South Auditorium	152
Aud N, Flr G	North Auditorium	152
LG39	Thermodinamic Laboratory	120
G69	Auditorium Engineering	107
204, Flr G	Classroom	101
Aud 2, Flr G	Auditorium 2	96
210, Flr G	Classroom	90
304, Flr 1	Classroom	84
0.58, Flr G, CLR a	Classroom A	80
1.26, Flr 1, CLR B	Classroom B	80
2.42, Flr 2, CLR C	Classroom C	80
2.45, Flr 2, CLR D	Classroom D	80
2.48, Flr 2, CLR E	Classroom E	80
3.2, Flr 3, CLR F	Classroom F	80
3.24, Flr 3, CLR G	Classroom G	80
3.31, Flr 3, CLR H	Classroom H	80
311, Flr 1	Classroom	70
404, Flr 2	Classroom	70
409, Flr 2	Classroom	70
LECTURE HALL 4, 3678	Lecture Hall	60
302, Flr 1	Classroom	55
312, Flr 1	Classroom	55
402, Flr 2	Classroom	55
410, Flr 2	Classroom	55
202, Flr G	Classroom	54
Aud 3, Flr G	Auditorium 3	54
203, Flr G	Classroom	52
304, Flr 3	Classroom	50
211, Flr G	Classroom	48
303, Flr 1	Classroom	47
313, Flr 1	Classroom	47

403, Flr 2	Classroom	47
411, Flr 2	Classroom	47
G51, Flr G	Classroom	45
212, Flr G	Classroom	44
101, Floor 0	Classroom	42
G09	Mechanics and Science Laboratory	40
G80, Flr G	Skills Laboratory	40
G83, Flr G	Skills Laboratory	40
G85, Flr G	Classroom	40
G86, Flr G	Classroom	40
1.102, Flr 1	Classroom	40
2.159, Flr 2	Classroom	40
2.16, Flr 2	Classroom	40
2.198, Flr 2	Classroom	40
3.24, Flr 3	Classroom	40
3.273, Flr 3	Classroom	40
4.331, Flr 4	Classroom	40
4.338, Flr 4	Classroom	40
4.339, Flr 4	Classroom	40
G37	Classroom	36
G41	Computer Laboratory (Mechanical)	36
G54	SO Computer Laboratory	36
G61	Classroom	36
G60	Classroom	35
1.23, Flr 1	Computer Laboratory C	35
1.33, Flr 1	Computer Laboratory D	35
282, Flr 2, LL 1	Computer Laboratory	35
G57	Classroom	34
F39	Classroom	34
F42	Classroom	34
F46	Computer Laboratory (Electrical)	34
F67	Classroom	34
74, Lower Level, SIT Lab 11	Computer Laboratory	34
75, Lower Level	Seminar Room	34
76, Upper level, CLR 2	Classroom 2	34
79, Upper level, CLR 1	Classroom 1	34
37, Upper level, CLR 6	Classroom 6	34
38, Upper level, CLR 5	Classroom 5	34
41, Upper level, CLR 4	Classroom 4	34
43, Upper level, CLR 3	Classroom 3	34

LG12	Classroom	32
F17	Classroom	32
12, Flr G	Classroom	30
14, Flr G	GIT Computer Lab	30
6	EC Computer Lab	30
14	GIT Computer Lab	30
LG14	Construction Mat. Lab	30
LG23	Classroom	30
LG24	Classroom	30
LG25	Classroom	30
LG26	Hydraulics Laboratory	30
G32	PC Laboratory Civil Engineering	30
G36	Classroom	30
F66	Classroom	30
0.33, Flr G	Medical Laboratory D	30
0.34, Flr G	Medical Laboratory C	30
0.46, Flr G	Medical Laboratory B	30
0.55, Flr G	Medical Laboratory A	30
TRAINING KITCHEN, 3498	Training Kitchen	30
LECTURE HALL 1, 3672	Lecture Hall	30
LECTURE HALL 2, 3673	Lecture Hall	30
LECTURE HALL 3, 3674	Lecture Hall	30
B08, Flr 0	Laboratory	30
1.95, Flr 1	Laboratory	30
1.129, Flr 1	Classroom	30
1.141, Flr 1	Laboratory	30
2.158, Flr 1	Laboratory	30
2.199, Flr 2	Laboratory	30
2.209, Flr 2	Laboratory	30
3.221, Flr 3	Laboratory	30
3.23, Flr 3	Laboratory	30
3.274, Flr 3	Laboratory	30
3.284, Flr 3	Laboratory	30
4.296, Flr 4	Laboratory	30
4.315, Flr 4	Laboratory	30
4.341, Flr 4	Laboratory	30
4.349, Flr 4	Laboratory (Chemistry)	30
4.352, Flr 4	Laboratory	30
PRE-FAB A	Pre-Fab Classrooms	30
PRE-FAB B	Pre-Fab Classrooms	30
PRE-FAB C	Pre-Fab Classrooms	30

PRE-FAB D	Pre-Fab Classrooms	30
PRE-FAB E	Pre-Fab Classrooms	30
PRE-FAB F	Pre-Fab Classrooms	30
163, Flr 1, SIT Lab 2	computer Laboratory 2	30
235, Flr 2	Agriculture Laboratory	30
269, Flr 2	Nat. Conservation Laboratory	30
277, Flr 2, LL 4	Computer Laboratory	30
F63	Classroom	29
205, Flr G	Classroom	28
162, Flr 1, SIT Lab 1	computer Laboratory 1	28
29, Flr G, LM Lab 3	Computer Laboratory	27
G19	Classroom	26
15, Flr G	Classroom	25
33, Flr G	Classroom	25
25	Classroom	25
19, Flr G	Classroom NHRDP Building	25
G39, Flr G	Computer Laboratory	25
42, Flr G	Secretarial Studies Lab 3	25
62, Flr G	Computer Laboratory	25
152, Flr 1, SIT Lab 8	Computer Laboratory 8	25
208, Flr G	Classroom	24
213, Flr G	Classroom	24
306, Flr 1	Classroom	24
307, Flr 1	Classroom	24
308, Flr 1	Classroom	24
13, Flr G	Classroom	23
153, Flr 1, SIT Lab 7	Computer Laboratory	23
155, Flr 1, SIT Lab 6	Computer Laboratory 6	22
F56	Basic Electronic Laboratory	20
F57	Project laboratory	20
3, Flr G	Workshop	20
11, Flr G	Classroom	20
16, Flr G	Classroom NHRDP Building	20
28, Flr G	Classroom	20
COMPUTER CENTER, 3675	Computer Center	20
B06, Flr 0	Laboratory	20
B14, Flr 0	Laboratory	20
G33, Flr G	Laboratory	20
G34, Flr G	Laboratory	20
2, Flr G	Secretarial Studies Lab 3	20
3, Flr G	Acer Laboratory	20

1, Flr 2	Nature Conservation Laboratory	20
283, Flr 2, LL 2	Computer Laboratory	20
1, Flr 3	Compaq Laboratory	20
145, Flr 1, SIT Lab 5	Computer Laboratory 5	16
165, Flr 1, SIT Lab 4	Computer Laboratory 4	16
LG18	Strength Material Lab	15
F06	Basic Power Laboratory	15
F09	Advance Power Laboratory	15
4, Flr G	Workshop	15
14, Flr G	Workshop	15
15, Flr G	Resource Room	15
17, Flr G	Computer Laboratory	15
Room 18, Flr G	Classroom	15
19, Flr G	Classroom	15
22, Flr G	Classroom	15
164, Flr 1, SIT Lab 3	Computer Laboratory 3	15
6, Flr G	EC Computer Lab	13
3.16, Flr 3	Computer Laboratory A	12
3.19, Flr 3	Computer Laboratory B	12
26, Flr G, LM Lab 1	Computer Laporatory 11	12
LG06	Mechanical Workshop	10
1, Flr 1	Cimulation Laboratory	10
G53	Computer Laboratory	9
F59	Electical/Mechanical Workshop	8
73, Flr G, Business Cimulation Lab 2	Computer Laboratory	8
74, Flr G, Business Cimulation Lab 2	Computer Laboratory	8

Appendix 6: NetAnim Screenshot for RWMM