POWER CONSERVATION AND PERFORMANCE ANALYSIS OF MOBILE AD HOC WIRELESS NETWORKS

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requirements of the University of Greenwich
for the Degree of Doctor of Philosophy

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DECLARATION

I certify that this work has not been accepted in substance for any degree, and is not concurrently being submitted for any degree other than that of Doctor of Philosophy (PhD) being studied at the University of Greenwich. I also declare that this work is the result of my own investigations except where otherwise identified by references and that I have not plagiarised the work of others.

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ABSTRACT

Mobile ad-hoc network (MANET) have emerged as a new systems and the most promising fields for research and development of wireless network. As the popularity of mobile device and wireless networks significantly increased over the past years, MANET has now become one of the most vibrant and active field of communication and networks. Due to severe challenges such as the open medium, unpredicted mobility of mobile nodes, distributed and cooperative communication and inherently constrained capabilities, which manifest exhaustible sources of power. Due to the increasing demand for high-speed data services, the limited and high cost of licensed, and the future MANETs are expected to be operating at frequencies greater than 2 GHz and most of the research work in the area has been done in the frequency range of 1-2 GHz.

In this thesis, a power conservation model is proposed. The proposed model is based on the conventional on-demand ad hoc routing protocols with the addition of a power model without incurring additional complexity on the existing MANET characteristics. The mobile nodes are able to computes their power their power status adaptively to decide if they are fit for packet forwarding and reception. The research illustrates the power conserving behaviour of the new technique using an analytical approach and also by computer simulations. The results have shown that power savings of more than 15% were achieved with not much delay in the network. The performance of the routing protocols in the presence of ambient noise in the network was analyzed as well as the sensitivity of MAANETs at a carrier frequencies above 2 GHz using the free space and two slope path loss model. Results show that at carrier frequency greater than 2 GHz the break point distance affects the throughput performance of the network, whilst at frequency less than 2 GHz, the throughput performance for the free space and two slope model was the same.

LIST OF ABBREVIATIONS

AODV	Ad Hoc On-demand Distance Vector
DSR	Dynamic Source Routing
DSDV	Destination-Sequenced Distance-Vector
CBR	Constant Bit Rate
TCP	Transmission Control Protocol
VBR	Variable Bit Rate
RREQ	Route Request
RREP	Route Reply
PRNET	Packet Radio Networks
DARPA	Defence Advanced Research Projects
ALOHA	Area Locations of Hazardous Atmospheres
CSMA	Carrier Sense Medium Access
SURAN	Survivable Adaptive Radio Networks
GloMo	Global Mobile Information Systems project
NTDR	Near term Digital Radio Systems
MSC	Mobile Switching Centers
BSC	Base Stations Centers
MANETs	Mobile Ad Hoc Wireless Network

LIST OF NOTATION SYMBOLS

A_n	Ambient Noise
RW	Receiving Bandwidth
K	Constant Ambient Noise Level
P_L	Path Loss
D_m	Propagation Distance
S_r	Mean Received Signal Power
KS_t	Constant Path loss Factor
r^{n_1}	Distance between the transmitting and the receiving mobile node
n_1	Basic path loss exponent
n_2	Additional path loss exponent
r_{brk} [m]	Breakpoint distance
P_d [W]	Mean Received Signal Power
P_t [W]	Transmitted Signal Power
h_m	Node antenna height
r_{brk}	Breakpoint distance
f_c	Carrier frequency
P_c [W]	Power Consumed
SPL_w	Sustainable Power Level

G_{Tx}	Transmitter antenna gain
G_{Rx}	Receiver antenna gain
P_{Rx}	Received signal power
Min_{tx}	Minimum transmit power
Min_{rx}	Minimum receive power
$beta_0$	Signal to Noise Ratio
eta_0	Ambient Noise level Strength
n_1	Path loss exponent

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LIST OF PUBLICATIONS RELATED TO PhD THESIS

List of publications during the PhD research programme:

Conference Publications

1. Lawal Bello, Panos Bakalis, Samuel John Manam, Titus Eneh and Kwashie A. Anang, *"Power Control and Performance Comparison of AODV and DSR Ad Hoc Routing Protocols"*, IEEE 13th International Conference on Modelling and Simulation (UKSIM 2011). Cambridge University, United Kingdom. ISBN: 978-0-7695-4376-5/11, Pp 457- 460, IEEE Computer Society Press, Sept., 2011.

2. Lawal Bello, Panos Bakalis, Predrag B. Rapajic, and Kwashie A. Anang, *"Sensitivity of DSR Protocol Performance to Propagation Loss Models at Higher Microwave Frequencies"*, 14th. IEEE International Conference on Modelling and Simulation. ISBN:978-0-7695-4682-7/12, Pp 561 - 565, Cambridge University, United Kingdom.

3. Panos Bakalis, Lawal Bello, *"Performance Evaluation of CBR and TCP Traffic models on MANET using DSR Routing Protocol"*, CMC 2010, Shenzhen, China. Volume III pp 318 - 322, IEEE Computer Society Press 2010.

4. Kwashie A. Anang, Lawal Bello, Titus. I. Eneh, Panos Bakalis and Predrag B. Rapajic, *"The Performance of Dynamic Source Routing Protocol to Path Loss Models At Carrier Frequencies Above 2 GHz"*, ICCT2011, ISBN: 978-1-61284-307-0/11, IEEE, 2011, China.

5. Lawal Bello, Panos Bakalis, Phaniteja Chintalapudi ,Kwashie A. Anang ,Titus I. Eneh, *"Impact of Topology Control and Traffic Models Performance on Mobile Ad Hoc Wireless Routing Protocol"* In Proc. of 2011 Future of Instrumentation International Workshop. November 7-8, 2011 Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA.

6. Panos Bakalis, Lawal Bello, Olamide Jagun, Kwashie Anang, Titus Eneh and Aminu Muhammad, *"Performance Evaluation of Constant Bit Rate and Variable Bit Rate Traffic Models on Vehicular Ad Hoc Network Using Dynamic Source Routing Protocol"*, In the Proc. Of 3rd IEEE International Conference on Adaptive Science and Technology.ISBN:978-1-4673-0759-8/11, IEEE, 2011, Abuja, Nigeria.

7. K. A. Anang, P.B. Rapajic, T.I.Eneh and Lawal Bello, *"Sensitivity of Information Capacity of Land Mobile Cellular System to Propagation Loss Parameters at Higher Microwave Frequencies."* 7th International Wireless Communications and Mobile Computing Conference (IEEE-IWCMC 2011). July 5th - 8th, 2011. Istanbul, Turkey.

8. Kwashie A. Anang, Predrag Rapajic, Titus I. Eneh, Lawal Bello and Grace Oletu, *"Impact of Vehicular Traffic on Information Capacity of Cellular Wireless Network at Carrier Frequencies Greater Than 3 GHz."* 5th European Symposium on Computer Modeling and Simulation (EMS '2011). ISBN: 978-0-7695-4619-3.

Journal Publications

1. Lawal Bello, Panos Bakalis, Predrag Rapajic, Kwashie A. Anang and Titus Eneh, *"Adaptive Receiver Power Routing Protocol for Mobile Ad Hoc Wireless Network"*.Special Issue on Advances in Wireless Communications and Networks: ISSN: 1796-2021 vol. 6, No. 7 Journal of Communications,Pp 571-580, 2011.

2. Lawal Bello, Panos Bakalis, Samuel John Manam and Titus Eneh, *"Performance Optimization of Mobile Ad Hoc Reactive Routing protocols"*. Advanced Materials Research Journal vol. 367,Pp 249-254. Trans Tech Publications, Switzerland. 2012.

Book Chapter

1. Lawal Bello, Panos Bakalis. *”Performance Analysis of Traffic Mobility Models on Mobile Ad Hoc and Vehicular Ad Hoc Wireless Network”.* Integrated Models for Information Communication Systems and Networks. Release Date: October, 2012. Copyright © 2013. 462 pages.

Submitted Journal Publications Accepted Subject to Minor Revision

1. Lawal Bello, Panos Bakalis, Predrag B. Rapajic. *”An Optimized Adaptive Power On-demand Routing Protocol for Mobile Ad Hoc Wireless Network”* IET Networks.
2. Lawal Bello, Panos Bakalis, Predrag B. Rapajic *”Computational Power Conservation Technique Using Mobility Adaptation Method in MANET”.* Journal of Communications and Networks (JCN)

Chapter 1

INTRODUCTION

1.1 Background

The term ad-hoc means ’for this purpose only’. So, it comes out that ad hoc networking is a network for a specific purpose. From historical perspectives ad hoc networking came into existence in different categories as first, the second, and the third generation as reported by Humayun in [1]. In the present days ad hoc networking systems are referred to as the third generation.

1.1.1 First Generation of Ad Hoc Networking

Humayun has reported in [1] that the year 1972 showed the emergence of the first generation ad hoc networking. The Defense Advanced Research Projects Agency (DARPA) initiated a network called Packet Radio Networks (PRNET) as shown in Figure.

It was used in combination with ALOHAnet. ALOHAnet was a pioneering computer networking system developed at the University of Hawaii. It is a protocol for satellite and terrestrial radio transmissions and Carrier Sense Medium Access (CSMA). It is also used as a prototype approach to provide medium access control. PRNET was to provide an efficient means of sharing broadcast radio communication channel within a network among many radios. Because of that,the first generation was however not entirely on an infrastructure-less network. The packet radios implementation package provided support for Omni-directional, spread spectrum, half-duplex transmission with a reception rate of up to 400kbit/s. In the PRNET the physical, the data link and the network layers of the OSI reference model were implemented.

1.1.2 Second Generation of Ad Hoc Networking

The birth of the second generation of ad hoc networking began after the approval of the transmission of American Standard Code for Information Interchange (ASCII) for Armature Radios in 1980. This was a further improvement to the First Generation as a part of the Survivable Adaptive Radio Networks Program (SURAN). This provided a packet switched network as a modification to the original commercial X.25 protocol called Armature X.25 (AX.25) [2], [1]. The deployment was in the mobile battlefield, an environment where the deployment of network infrastructure becomes very difficult, if not at all. The program improved the radio performances size reduction, cost reduction and power economy. The algorithms were scalable, and the entire suite was robust and more tolerant to electronic attacks. Therefore, what differentiates second generation ad hoc networking from the first generation one are:

- Global Mobile Information Systems project (GloMo), an initiative to make the wireless and mobile environment the first choice for military applications as well as Defense information infrastructure [3].
- Near term Digital Radio Systems (NTDR), a Defense Academy directed mobile Research project that aimed to interlink strategic operations using packet data radio networks in the Brigade area [4].

1.1.3 Third Generation of Ad Hoc Networking

This is the upgrade of second generation of Ad Hoc networks, which is the commercial form of ad hoc networking introduced in mid 1990 with the proliferation of notebook computers and other sustainable networking equipment [5]. Developments in the Bellman Ford (Distance-Vector) type of routing algorithm [6] led to the proposition of congregating mobile nodes in research conferences. With it came the rebirth of Mobile ad-hoc networks as a promising technology of choice which evolves in standard commercial applications [2] [5].This modern communications day generation of mobile ad hoc networking has produced two major landmarks in the history of computing:

- Bluetooth technology, and
- Mobile ad hoc sensors.

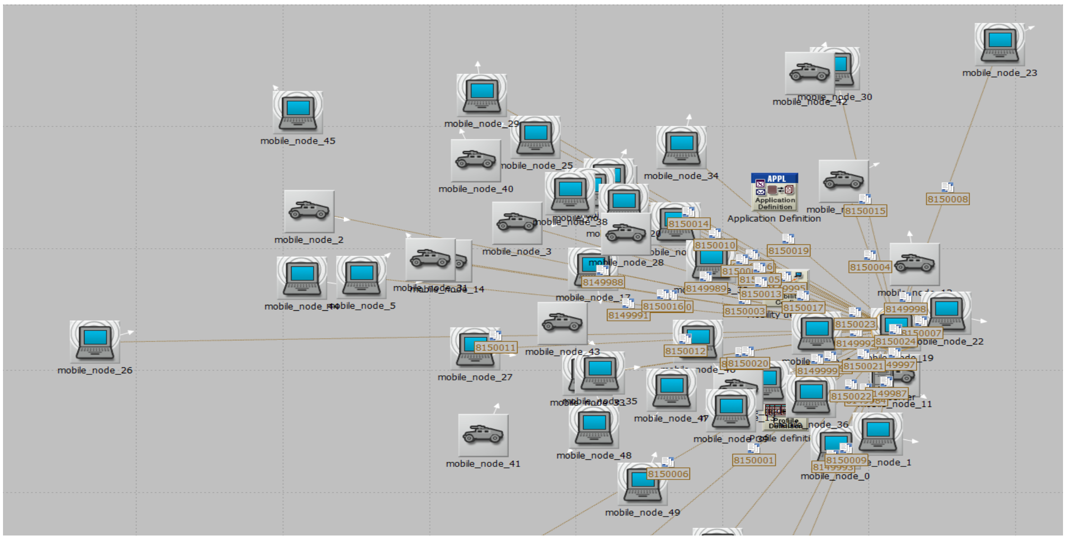

Figure 1.1: Mobile Ad Hoc Wireless Network Communications

- The figure shows the multi hop connections, whereby intermediate mobile nodes send the packets towards their destination.

1.2 Mobile Ad Hoc Wireless Network

Wireless communication is undergoing rapid advancements to meet the demands of current and future trends of communications. Unlike wired networks that require a fixed network infrastructure consisting of wires, base-stations and routers to communicate. Mobile ad-hoc networks are self configuring, thus self organizing mobile nodes participate to form a wireless network without any network cabling infrastructure. However, it should not be completely assumed that MANET cannot have network infrastructure. According to Goldsmith et al., and Haarsten in [7] [8] reported that some inter-mediate mobile nodes may be chosen to act as a base station for neighboring mobile nodes. The application of these networks is highly needed in areas like battlefields, emergency rescue services, lecture theatres conference halls and other places where deployment of network infrastructures becomes very difficult. Recently, most of the communications between mobile devices is achieved through fixed cabling network infrastructure such as cellular networks with base stations (BSC) and mobile switching centers (MSC).

Other mobile devices are connected to the Internet via a wireless access point which is apparently very high cost as well as time consuming to set up the network services.

In MANET, each mobile node acts as a router as well as a base station to discover and maintain the routes to other mobile nodes to communicate over the network as shown in Figure 1.1. MANETs are subject to rapid changes due to their unpredictable mobility and the performance of these networks largely depends on the type of routing protocol used for communication and the routing protocol has to be dynamic and should adapt to the frequent link changes.

Minimal convergence time of the routing protocol and its efficiency in using limited power and bandwidths as well as meeting the demands of dynamic topological changes is regarded as an efficient ad hoc routing protocol. There are many Routing protocols that have been developed for supporting MANETs but each of them has its merits and demerits [9]. Research conducted by Toumpis and Goldsmith in [10] and Gupta and Kumar in [11] showed that multihop network routing significantly increases the network capacity,and consequently increases the rate of power consumption in the network. Therefore, conservation is the key challenge area in the design of Mobile Ad hoc Wireless Network. This thesis addresses the issue of power management in mobile ad hoc wireless network by incorporation of a power conservation technique at the network layer of the protocol stack using the cross layer technique.

1.3 Routing in Mobile Ad Hoc Wireless Networks

Ad Hoc Routing Protocols are responsible for routing packets from the source to destination and between mobile nodes. It also verifies if the packets are coming from the upper layer or lower layer of the network protocol stack and makes a decision as to where to forward the packet. In ad-hoc networks, mobile nodes are not familiar with the topology of their networks. Instead, they have to discover it. The basic idea is that a new node may announce its presence and should listen for announcements broadcasted by its neighbors. Each node learns about nodes nearby and how to reach them. To find and maintain an optimal route between mobile nodes in a dynamic topology area, the routing protocol should be:

- Simple and efficient

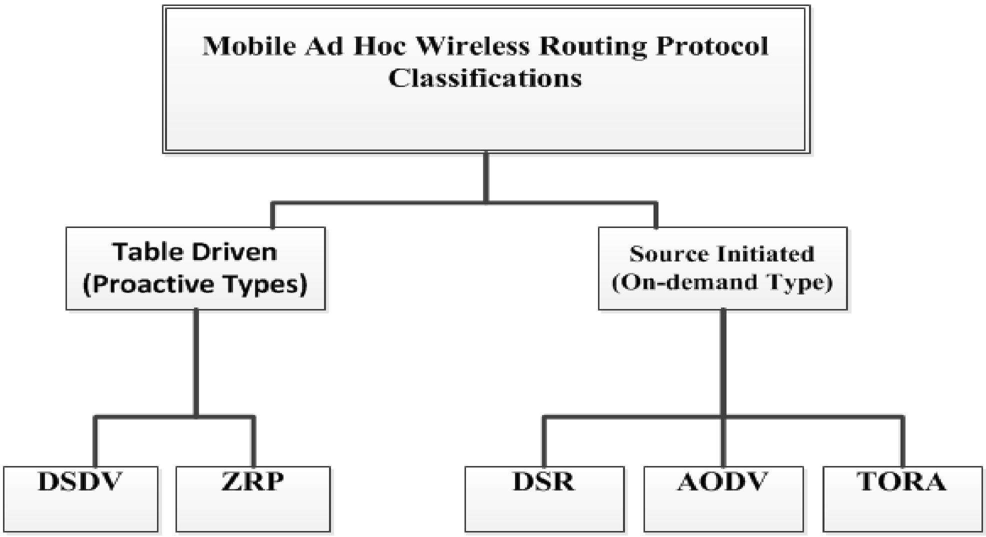

Figure 1.2: Mobile Ad Hoc Routing Protocols Classification.

- Distributed but light weight in nature to avoid computational level cost
- Quick adaptation to unpredicted topology changes and should result in minimal control overhead packets and
- Efficient power utilization

The network routing involves two major activities: first, determining optimal routing paths and second, transferring the data packets. Routing protocols use several metrics to find the best route for routing the data packets to their destination. These metrics are a standard measurement that could be number of hops, which is used by the routing algorithm to determine the optimal path for the packet to its destination. The process of path determination is that routing algorithms initialize route discovery process and maintain routing tables, which contain the total route information for the packet forwarding. This route information varies from one routing algorithm to another. The routing protocols are classified as proactive and reactive types as shown in Figure 1.2. The Table drive type which are proactive and are constant, continuously evaluation of the routes. When the network topology changes, the protocol responds by propagating the updates throughout the network in order to maintain a consistent view of the routes. Meanwhile, the reactive types known as sources initiated type. These protocols mainly create route only when it is needed by the source node. The protocol has two processes. The first one is route discovery which invokes a route discovery procedure and terminated when a route has been found or no route is found after all the route permutations are completed. The second process is route maintenance. The routes are maintained by a route maintenance procedure until no longer needed. The disadvantage of these protocols is longer delay. In other words, a route may not be ready for use immediately when the data packets are ready to send.

1.3.1 Overview of On-demand Mobile Ad Hoc Routing Protocols

Dynamic Source Routing (DSR) protocol is a simple, efficient and an On-demand routing protocol designed specifically for use in multi-hop wireless ad hoc networks. It uses source routing rather than the hop-by-hop routing approach [12]. Each packet to be routed carries in its header a complete ordered list of nodes through which the packet has passed. The advantage of this protocol is that intermediate nodes do not need to maintain up-to-date routing information in order to route the packets. Due to the on-demand characteristics of DSR, periodic route updates and neighbor detection are eliminated to minimize bandwidth consumption [13, 14].

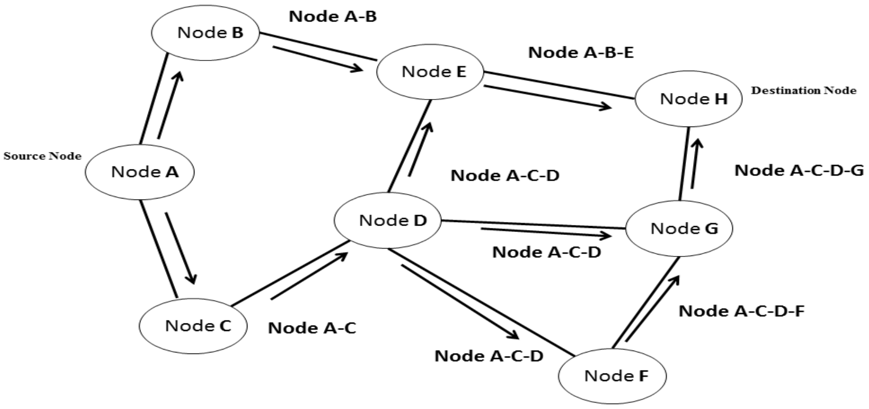

Figure 1.3: Overview of Dynamic Source Routing Protocol:Route request process.

DSR has two basic mechanisms of operations: (1) The Route Discovery process

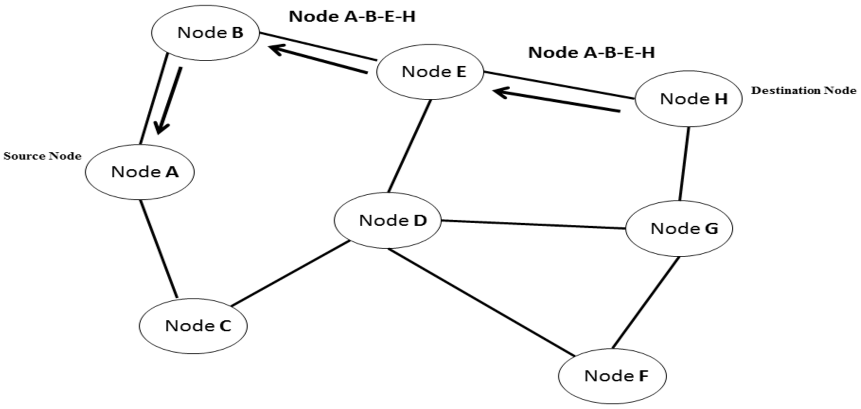

Figure 1.4: Overview of Dynamic Source Routing Protocol:Route reply process.

which floods the network with route request (RREQ) packets to all its neighboring nodes. The header of the packet contains IP addresses of both sender and receiver, as shown in Figure. 1.3. The Route Reply process which returns the route reply messages (RREP). The header of the Route Reply contains a list of the best routes from the source to the target destination, as shown in Figure 1.4.

Ad Hoc On-Demand Distance Vector (AODV) is an on-demand routing protocol that combines the capabilities of both Dynamic Source Routing (DSR) and Destination-Sequenced Distance-Vector (DSDV). It uses the on-demand mechanisms of Route Discovery and Route Maintenance from DSR using forward and reverse path setup, as shown in Figure 1.5, in addition to the hop-by-hop routing sequence numbers and periodic beacons from DSDV as described by [15]. Mobile nodes requesting to forward packets to other mobile nodes will broadcast the route request (RREQ) packet to its neighbours which then forward the request to their neighbours until either the destination or an intermediate mobile node(s) with route(s) to the destination is located. AODV uses destination sequence numbers and broadcast IDs on each node to ensure all routes are loop-free and contain the most recent route information. However, performance evaluation conducted on both AODV and DSR protocols in [12, 16–19], showed that AODV performs better than DSR and other proactive protocols in terms of throughput, end-to-end delay, and packets drop. The DSR performance is attributed to its characteristics of having multiple

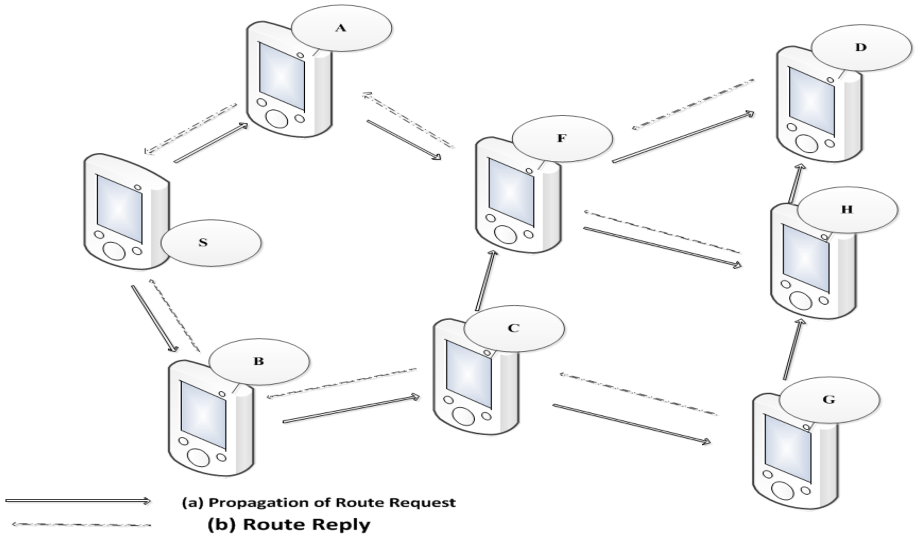

Figure 1.5: Overview of Ad Hoc On-Demand Distance Vector: (a) Propagation of Route request process (b) Route reply process.

routes to other destinations. In case of link failure, it does not require a new route discovery process. For this reason end-to-end delay is reduced; less packet dropping and less energy consumption. Reference [20–23] showed that, in a high complex network where mobility is very high, the DSR has high energy consumption in the entire network compared to its counterpart AODV, which loses energy due to broadcasting hello messages to update its routes.

1.3.2 Mobile Ad Hoc Wireless Network Design Challenges

MANET is vulnerable due to its fundamental characteristics such as open medium, constantly changing network topology, distributed and cooperative communication and inherently constrained capabilities, which manifest themselves in the exhaustible sources of power as Feeney and Nilsson reported in [24]. The research describe some of these technical challenges that affect the MANET's performance and proposed techniques to solving them, with a special emphasis on power management. Some of these technical challenges include the following:

- In conventional wireless communications, wireless devices do communicates with each other using either a base station or a router, but with the emerged of a new technologies such as MANET. Unpredicted mobile nodes movements pose network design challenges especially under power constraints resulting in link failure and possibly packets drop.

- Another challenge is variation in wireless link. Different mobile nodes are configured with one or more network interfaces that have different transmission and reception capabilities and operate at different carrier frequencies and consequently lead to unidirectional links between communication mobile nodes. Therefore, designing ad hoc routing protocols can be a complex case; the design solution requires dynamic adaptation to the traffic load, network traffic congestion as well as power and channel conditions as reported by [25].
- Power constraint is another challenging issue. The mobile devices in ad hoc networks can either be stationary or mobile and some of them are attached to a power source such as vehicles that can provide power to them for a long time. However, the majority of the mobile devices used in mobile ad hoc networks are powered by batteries with limited life span. Some of these batteries are rechargeable and some cannot be recharged, such as sensor nodes that are embedded in walls, or dropped into a remote region. Therefore, power needs to be conserved to maximize the quality of service in terms of successful data delivery and delay reduction.

Jones et al., in [26] has identified the reasons why so much attention is given to the issue of power conservation and control. He has analyzed the sources of power consumption in MANET and classified these sources into two categories as follows:

1. Communication consumption level and
2. Computational consumption level

The communication consumption level involves usage of transceiver at the source mobile node, intermediary mobile nodes as well as the destination mobile node. The transmitter is used for sending control and data packets, while the receiver is used to receive control and data packets as shown in figure 1.6. Good understanding of the power characteristics of the mobile nodes is very important for the design of the mobile communication

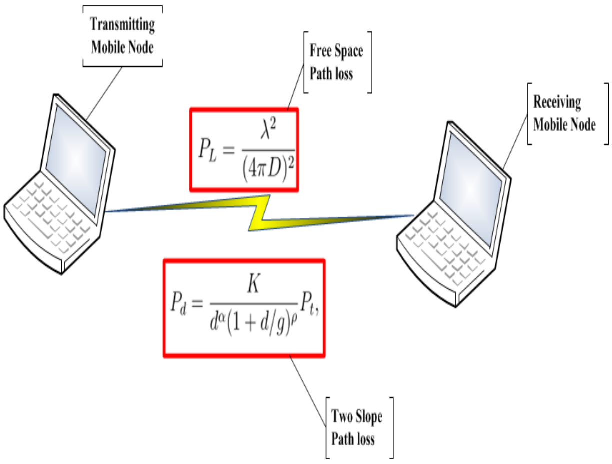

Figure 1.6: Overview of the wireless channel.

channel. Meanwhile, computational consumption level involves the total energy spent at a source and destination mobile nodes through intermediate mobile nodes. Also energy is spent for packet transmission and acknowledgement and energy is spent in packet reception and acknowledgment at the destination mobile node, as well as energy spent at idle state. The design solution for MANET must be self configured to adjust to network environment as well as traffic where they run and this motivated our research focus on power management in the mobile ad hoc wireless network. Therefore, the proposed power model strikes a balance between the two costs.

1.4 Motivation of the research thesis as well as technical issues

The growth of wireless communication technologies has been exceptionally large in the last decade and it is predicted that the demand for these technologies will increase dramatically in the coming years.

Therefore, it is required to broaden the vision of wireless technologies by developing advance techniques at an appropriate layer of the wireless networking, particularly at the network layer of mobile ad hoc wireless networks, where accurate and correct routing algorithms must be used. A little improvement in performance at the network layer has dramatically improved overall output of the wireless networks. To meet increasing demand, many efforts have been made in past research literature by using various power techniques to reduce the power consumption in MANET [27], [28], [29], [30], [31]. The aim of all the schemes is to reduce the routing power consumption rate, so that quality of service and performance throughput can be fully achieved during the communication. The computational complexity is a also very important factor in designing algorithms for routing processing. The complexity further increases in MANETs, particularly when network size grows and feasibility of implementation becomes very difficult. Most of the proposed power reduction schemes presented in past literature [32], [33], [34], [35], [23], [36],[37] are too complex to implement in MANETs. Therefore, it is required to present an adaptive power routing that is not only effective in all conditions of a communication channel but also computationally simple.

Moreover, most of the research work done by the previous researchers was carried out in the frequency range of 1-2 GHZ, whereas in reality, emerging wireless network system (MANET) will operate at a carrier frequency greater than 2 GHz.Therefore, it is required to analyze the performance of MANET at a frequency greater than 2 GHz.

Another important problem in MANET is mobility in the network which also contributes to power consumption. At the network layer, mobility has major implications for the performance of the network. During the detailed literature review [38], [39], [40] it is observed that this problem is never addressed properly and overlooked. Particularly an explanation of what causes the packets losses in MANETs has not fully been given. Which mobile ad hoc routing protocol from the reactive categories is the best to respond to the link failure and packet loss is also unknown. Therefore, it is also required to evaluate and compare different traffic models.

1.5 Key Contribution of the Thesis

In this research, a number of innovative contributions are presented. Some of the important contributions of this thesis are as follows:

- In this research, an adaptive power conservation technique for MANET is proposed. The presented technique is computationally simple mathematical algorithm for MANETs which reduces the computation complexity, whereas previous versions proposed by other researchers are computationally complex and not feasible for practical implementation in MANETs. Two reactive routing protocols of MANETs are used (i) Ad hoc on demand distance vector (AODV) (ii) Dynamic Source Routing (DSR). The performance analysis was studied at real time for the entire network. The proposed technique is incorporated into the network layer of the network. The results showed that power savings of more than 15% were achieved with not much delay in the network and increase throughput by 60% as compared to the network configured with traditional AODV and DSR routing protocols.The research has also dealt with a realistic scenario to include the effects of environmental conditions such as noise, whereas most of the previous research work was carried out in the area uses free space path loss model to represent the network environment. The analysis and results were published as a peer reviewed journal paper [41].

- The second contribution of this research thesis is the sensitivity of MANETs performance to wireless channel at microwave carrier frequencies greater than 2 GHz as well as the impact of wireless channel on the performance of the network. It was shown that at carrier frequencies greater than 2 GHz the break point distance affects the performance network. It is also shown that as the path loss exponent of the propagation model increases, the received signal power at individual mobile nodes also increases. The path loss exponent has no effect on the throughput performance of the networks. It is expected that this research result will be used to provide ultra high speed communication facilities in the 3G, 4G and 5G wireless devices. The research results were published as a peer reviewed conference paper [42], [43].
- The third contribution is the performance analysis of the routing protocols. Statistical results and simulation results presented illustrate the performance of an ad hoc network protocols in the presence of ambient noise in the network. The simulation result for the network with DSR and AODV protocol showed 86.8% decrease in end-to-end delay, while the network with AODV protocol also showed 68.5% drop in end-to-end delay. The network load simulation result revealed that DSR protocol maintained a constant load while there was a 75% drop in routing load for AODV

protocol. The research work was also published as peer reviewed conference papers [44], [45], [46].

1.6 Thesis Outline

This thesis consists of the following parts: Chapter-1 describes a brief introduction with some of the fundamental design challenges of MANETs, an overview of mobile ad hoc on demand routing protocols, a problem statement, as well as a thesis contribution.Chapter 2 gives the literature review of the current state of the related work. Chapter-3 represents the impact of mobility and traffic models in mobile ad hoc wireless network. Chapter-4 presents performance analysis of mobile ad hoc wireless network. The sensitivity of MANETs to propagation loss models at higher carrier frequency is also presented in Chapter-5. Chapter-6 presents an adaptive power on demand routing protocol for MANETs. Chapter-7 presents computational power conservation technique in MANETs. Chapter-8 presents the conclusions and points to the areas for possible future research.

The brief outline of the thesis chapters are as follows:

- Chapter one gives a brief introduction of Mobile Ad Hoc Wireless Network, the emergence of the network from first generation up to the present generation of the network (MANET) as well as the classification of the routing protocols that facilitates the communications between the mobile devices. Also the most recent technical challenges as well as problem statement that motivated the research work were presented and finally the key contribution of the research thesis.

- Chapter 2 gives the literature review of the current state of the related work. The reviewed researched work are categorized based on their most prevailing methodology or technological principles. The categories are as follows:

    1. The impact of mobility and traffic models, performance analysis as well as sensitivity of MANET’s to propagation loss models a frequency greater than 2 GHz.

    2. Power conservation in MANETs

- Chapter 3 analyzes the impact of mobility and traffic models in MANETs. It compares the two traffic models i.e. CBR and TCP using different topology size while maintaining the same simulation parameters. Simulation analysis is used for the comparison. The impact of the topology size on the networks performance for the two traffic models is also studied.

- Based on the performance analysis results from chapter 3. The research work chooses CBR as a traffic model to be used for the rest of the research. Therefore, Chapter 4 analyzes the performance of the network in the presence of environmental factors such as ambient noise. The performance of the network is studied using two different routing protocols (AODV and DSR). The choice of the two reactive protocols was also justified in the chapter.

- Chapter 5 present the studies of the sensitivity of MANETs to propagation loss models at higher frequencies. As MANET's applications in the future will operates at a higher frequency greater than 2 GHz.

- Chapter 6 proposes an adaptive power on demand routing protocol for MANET. Mathematical analysis and computer simulation are used to validate the proposed model. The performance is studied by comparing that of the conventional model to the proposed power model.

- Chapter 7 proposes the mathematical computational power conservation model using mobility adaptation method for calculating the actual power dissipated by a mobile node, power below which mobile nodes will decline in packet transmission, also the sustainable power level that can sustain the transmission. Mathematical analysis and computer simulation are used to validate the proposed model and compared it with the conventional model.

- Chapter 8 summarizes conclusions drawn from the preceding chapters and point to future direction of the thesis.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The chapter one was developed in a unique manner to give the reader a summary as well as understanding of what the research work will accomplish. With the historical background and the brief explanation of the current state-of-the-art elucidated, a novice in the field will have a grasp of the design area and have a better idea of the things to follow.

Therefore, this chapter will go further to review some of the related works. In trying to develop and fine-tune the research findings of power conservation model in MANETs, a lot depended on the current state of the art. For this reason, an intensive research was carried out to review the works of many researchers who have done their research in the area. Analogies were developed for the positive contributions of these papers and from these analogies, the research project idea constantly shifted in approaches and steps, but the goal remained the same. However, the research papers presented a lot of opportunities for improvement based on their weaknesses and shortcomings, which offered the tremendous gaps upon which to base the research idea. Some of the literatures that show strong analogy to the research work have been carefully selected, analyzed and acknowledged to help give background knowledge of this work. The reviewed research papers are categorized based on their most prevailing methodology or technological principles. The categories are as follows:

1. The impact of mobility and traffic models, performance analysis as well as sensitivity of MANET's to propagation loss models at a frequency greater than 2 GHz.
2. Power conservation in MANETs

2.2 The impact of mobility, traffic models and sensitivity of MANET's to propagation loss models at a frequency greater than 2 GHz

With the advances in wireless communication technology and the proliferation of mobile devices (e.g. cell phones and handheld devices), mobile devices have the capability of communicating with other devices even when they are mobile. This type of communication paradigm has fuelled the need for sharing information among mobile devices even in areas with no pre-existing communication infrastructure like wiring, servers and routers. In a domain which lacks communication infrastructure or where the existing wired infrastructure is inconvenient to use, mobile users can communicate through the formation of a temporary wireless Mobile Ad hoc Wireless Network (MANETs). Due to the fact that their topology/location changes rapidly and unpredictably these networks need routing protocols that can respond to these topological changes immediately. These protocols are categorized into pro-active, reactive and hybrid routing protocols [47]. The identification of the most appropriate routing protocol to be used depends on different factors, namely: a) quality of service, b)scalability, and c) traffic and mobility models.

Most of the reactive, proactive and hybrid ad hoc routing protocols have been studied analytically by [48], [49] using Transmission Control Protocol (TCP), Constant Bit Rate (CBR) and Variable Bit Rate (VBR) traffic models. Analysis has revealed that TCP traffic models performed poorly by misinterpretation of packet losses, link failure, and late acknowledgement as a sign of network congestion. Since the TCP protocol was designed for static node networks, MANETs using TCP traffic models are congested due to the frequent topology changes. Explanations of what causes the packet losses in MANET have not fully been given. Which routing protocol from all categories is the best to respond to the link failure and packet loss before the TCP invokes its control congestion algorithm, is also unknown. According to [50] random mobility, high bit error rate, variability and congestion are the main factors affecting the performance of TCP traffic models in MANET. Researches conducted by [51], [52], [53], [9], [54] uses CBR traffic models due to the premature assumption and criticism that the TCP's exhibit weaknesses in MANET. Despite the fact that considerable simulation work has been done, still more investigation is needed into the performance of the traffic and mobility models using a variety of protocols. In [48] evaluates the performance of TCP traffic model using only AODV routing protocol and does not consider the performance of a network using DSR or other protocols at all. The TCP and the CBR are traffic and mobility models. These models play an important role for evaluating the performance of networks. However, due to the increasing demand for high-speed data services, the limited and high cost of licensed spectrum and the statement by Li et al. [55], MANET are deployed during responses to disasters. With the current spate of disasters around the world such as hurricanes, tsunamis and earthquakes, it means that future MANET may best be accommodated above 2 GHz, preferably the unlicensed band of 2.4 and 5.3 GHz. At higher frequency the physical layer needs to be modelled accurately and the best model is the two ray propagation model as Hernandez-Valedez et al., reported in [56]. In previous papers, two ray propagation models have been used [9, 52], for the performance evaluation of MANETs using AODV routing protocol. However, none of these papers studied the impact of path loss exponent on the performance of MANETs using DSR protocol. This omission motivated this work.

2.3 Power Conservation in MANETs

The detailed literature review analysis of the power conservation in MANETs are based on the following categories:

1. Power Experiment models
2. IEEE 802.11 MAC Layer Power Schemes
3. Best Energy Efficient Route Schemes
4. Quality of Service (QoS)
5. Survey and Quorum.
6. Routing Protocols Analysis

2.4 Power Experiment Models

In [57], aimed to retrieve power consumption characteristics of IEEE 802.11 on a PDA at different networking conditions. The authors measured the PDA's power consumption in continuous active mode(CAM) and power save mode (PSM) while varying traffic scenarios, taking internal and external factors such as Beacon period and background traffic into consideration. The impact of these factors was also examined. Also measured the total power of the device instead of the wireless part of the total power, because of the constraints associated with oscilloscope such as lack of flexibility and high cost. However, an IBM T43 laptop was used as a sniffer to monitor the channel. They kept the configuration of the PDA unchanged throughout the experiments so that, other parts of the device such as LCD and CPU stay in a relatively constant state.

Other research works show immense effort in creating some basic and essential steps in directing future research towards the power hungry electronic components and providing a better understanding of the system behaviour. Hamady F., Chehab et al., in [31], have demonstrated results in their work showing variation in energy saving of various components at different workloads. The authors did not follow the conventional method of other authors who measured few components and estimated the others. But used an Intel Platform featuring the duo core second generation Intel (R) Core i5 Processor that supports hyper threading technology. Intel 160 GB SSD drive and 4GB of 1333MHz Micron memory were also used. Fluke 2680 Series data acquisition system was used as the apparatus for measuring the voltage and current of components at various loads of interest. Traces of these measurements were used to calculate the average energy consumption of the components. Some of the different workloads include: Video Streaming, Local Video Playback, 3DMark06 and 3DMark Vantage. Eventually, provided a scalable solution as a contribution to estimating the average power dissipation in mobile systems.

Feeney, L., and Nilsson, M., in [24] believe that energy-aware design and evaluation of network protocols for the ad hoc networking environment requires a practical knowledge of the energy consumption behaviour of the actual wireless devices. In addition, they insist that it is important to present this information in a form that is useful to protocol developers. Such information includes the total energy cost associated with a packet containing some number of bytes of data. A description of series of experiments with detailed measurements of the energy consumption was made. The test host was an IBM ThinkPad 560, running FreeBSD 4.0. The measurement monitored the Lucent WaveLAN IEEE 802.11 wireless network interface test cards (Bronze and Silver) operating in ad hoc mode. The data was presented as a collection of linear equations for calculating the energy consumed in sending, receiving and discarding broadcast and point-to-point data packets of various sizes. While not intended to account for all IEEE 802.11-based products or for all possible factors affecting energy consumption at the wireless interface, the results provided a solid experimental basis for energy-aware design and evaluation of network-layer protocols operating in the IEEE 802.11 environment and suggest new perspectives on design of ad hoc networking protocols.

2.4.1 Weaknesses of Power Experiment Models

While the experimental results presented a solid platform for further research pursuits, they failed to isolate and measure the transmit power in ad hoc mode which is the actual power concern for transmissions and other telecommunication transactions. Also, other complex issues like transmission speed, range and effective node density were not explicitly catered for in the performance experiments.

2.5 IEEE 802.11 MAC Layer Scheme

IEEE802.11 standard's power management support power utilization in two modes:

1. Continuous Aware Mode and
2. Power Save Polling Mode.

It has been shown that IEEE 802.11b in an idle network interface has a power consumption of 800mW. This is comparable to the energy consumed while receiving or transmitting (l000mW-1300mW respectively). However, in the sleeping mode, the power consumption is (66mW-30mW). These values can vary depending on manufacturer and model, so they are only representative. Researchers have explored this doze mode in order to extend the lifetime of networks. Among the literatures that used this mechanism as a basis for their research are: [58], [59], [60], [61] and [62].

Cano, J.C., and Manzoni, P in [58], present an Intra-cluster data dissemination protocol (Icdp) which is used to group nodes around a special node called the Cluster Leader (CL). The CL centralists the power management mechanism and also acts as proxy for data transmission between the cluster and other nodes in the region. When the cluster leader initiates the power saving mode, it goes to sleep mode to minimize power consumption. The cluster leader also buffers data frames for the stations, and the role of the

CL is periodically distributed among nodes inside the cluster to avoid overloading a single node. The authors went further to give example of the MAC power scheme, stating that the ORINOCO/IEEE Turbo 11Mb PC Card has the following characteristics:

1. Doze mode: 15mA
2. Receive and idle mode: 240mA
3. Transmit mode: 280mA

The authors used the Network Simulator 2 (NS-2) to model the performance of their scheme. The preliminary result showed that energy was saved, but they hoped to adopt a more optimized version of the scheme as the application proved to be a bandwidth eater. However, Corbett, D.J., Everitt, D. in [59], proposed a power and location aware Medium Access Control (MAC) protocol called LAMP. LAMP uses the concept of cellular geographical network division to build distributed Time Division Multiple Access (TDMA) based schedule to switch into transmission, reception and sleep mode. LAMP converts the increase in latency to energy conservation; thus, rather than a host overhearing the network, it goes to sleep and conserves power.

This is a theoretical scheme that aims to model the possibility of power saving protocol based on MAC layer power control conditions. Just like a cellular network, the proposed MAC protocol uses location information to partition the network into cells. Once a host knows its cell, it can synchronize its clock and build TDMA based communication schedule. This protocol intelligently minimizes power consumption and also avoids interference. While in [60], proposes a probabilistic wake-up based power management scheme in which every wireless device probabilistically switch between active and sleep state to save energy, which also works for malicious node detection. The paper proposed neighbour monitoring as a way to manage power usage at MAC layer which differentiated it from previous works. The simulation result and analysis was conducted using GlomoSim 2.03 version, and they were able to detect Loss rate, Threshold Achievement Rate and Energy gain.

Liu et al., in [61], proposed a Device-Energy-Load Aware Relaying Framework (DELAR) which utilizes powerful nodes (P-nodes) to conserve energy for other common nodes (B-nodes). This is aimed at prolonging the lifetime of nodes as well as the network. The authors adopted an Asymmetric MAC (A-MAC) to support communications on unidirectional links caused by asymmetric transmission power between the participating transmitter and receiver. The research extends the DELAR framework which emphasizes the interaction between the MAC layer and the network layer to incorporate the physical layer, consequently, proposes a multiple-packet transmission scheme which is jointly operated with hierarchical modulation to further improve the energy efficiency and shorten the packet delay. The basic idea is to enable such P-nodes to transmit multiple packets towards different receivers in one transmission, and this transmission is implemented with hierarchical modulation to ensure sufficient signal to noise ratio (SNR) at all the receivers.

Zabian, A. in [62], showed that transmission power required by transmitting packets between any two mobile nodes increases exponentially with distance, and less energy is consumed in transmitting through the intermediate nodes as compared with when the transmission is done directly between two nodes. Furthermore, the research demonstrates that measurements for the power consumption in IEEE 802.11b that, an idle network interface consumes over 800mW. Therefore nodes not involved in any active packet transmission can go to sleep. This research also shows that power consumption in a tree like structure is related to the height of the tree and slightly related to the size of the packet. Thus, aim to reduce the height of the tree and increase the width. However, the idea is to reduce power whenever possible, by adjusting the transmission distance in such a manner that will enable power saving in the entire network. This work is a theoretical system which they intend to implement using NS2 simulator.

2.5.1 Weaknesses of IEEE 802.11 MAC Layer Scheme

Every research faces shortcomings in one way or another, either in the form of a technical flaw or as some basic assumptions which are not always guaranteed. In literature [58], an increase in Network size and the network traffic will affect the efficiency of the protocol, and there is no indication as to the metrics to be used in transferring the cluster leader's (CL) role among the nodes as the power management mode is initiated. As the work in [59] is not conclusive and appears like a theoretical declaration, the authors in [60] made the following assumptions:

1. Transmission radius is constant
2. Nodes are equipped with omnidirectional antenna.
3. Network nodes are time-synchronized so that, time slots of nodes are aligned.

It is obvious that, multiple assumptions could undermine the fundamental existence of MANET, and should all the assumptions be put in place for the researches to go forward, the cost may be enormous leading to a more expensive implementation. However, in [61], the researcher only considered asymmetric transmission power as the primary cause of losses in power for unidirectional links while others such as collision, noise and interference were omitted at various nodes. Also in the constant bit rate data session, only the power used to transmit information is considered. But in [62], the basic assumption is that power consumption is the same for all nodes - homogeneity. However, the general issues with the MAC protocol sleep-wake power management schemes is that, energy expended in bootstrapping the device is high. And if the device did not sleep long enough, the wake up energy may be greater than the energy saved which will make the scheme counter-productive. Then again, for nodes to sleep too long, it means that the basic aim of networks which is to get devices interconnected is at risk.

2.6 Best Energy Efficient Route Schemes

It has been found, in the entire wireless networks and MANET in particular that, transmission collision is a major source of energy loss. In the work of Huang, Y. C., Chuang, S.Y., and Wang, S.D in [30], they argued that a successful reduction in the number of transmission collision will increase energy saving. They used the Relative Neighbour Graph (RNG) approach to adjust the transmission range according to the degree of the node which is based on local information. They found that using the transmission range determined by RNG may result in asymmetric links. The asymmetric link problem can be solved by two approaches.

1. Each node only accepts messages from one node which is its RNG neighbour.

2. Whenever a node receives a broadcast message from its neighbour, it checks its information to ensure that it includes this neighbour.

The authors used the GlomoSim simulator to evaluate the routing protocol performances of collision and energy consumption with and without their algorithm. Also suggest appropriate transmission power ranges to some routing protocols such as AODV, DSR and BELLMAN-FORD. Gallina, L. et al., in [63], evaluate and compare both throughput and energy efficiency of mobile ad hoc networks based on the probabilistic, energy-aware calculus for mobile and ad hoc networks. This mathematical model is used to demonstrate the ability of a node to control its transmission power by the modification of the transmission radius among the communicating nodes in the network. This protocol was developed as an application to evaluate and compare two well-known automatic repeat request-based (ARQ-based) error control protocols: stop-and-wait (SW) and go-back-N (GBN). The authors believe that their mathematical model is applicable and realistic because of its cost functions which:

1. Are flexible and adaptable to the specific applications;
2. Are composed of different independently-configurable metrics, e.g., energy cost delivery time, interference level, which can be extended, cancelled or augmented;
3. Have weights which allow for modelling different importance level for each factor of interest.

Mahimkar, A, Shyamasundar, R.K in their work [64], proposed a Minimum Energy Cost Routing Algorithm (MECRA) which will select the routes and the corresponding power levels; thus maximizing the battery life of individual nodes. To achieve this, the traffic will be routed such that all consumption is balanced among the nodes in proportion to their energy reserves. It does not however emphasize on the absolute energy consumption. MECRA is also extended to develop Secure MECRA (S-MECRA) which considers a node's reputation while making routing decisions. Nodes selection is based on higher reputation number and higher residual energy. When nodes with lower residual energy are exempted from the data transmission, they can conserve their energy. The researchers modified the DSR route request packet to suit their need and also the MECRA algorithm makes use of the route cache in a similar fashion as that in DSR.

Adaptation to local conditions in ad hoc networks is proving more and more effective in recent times, and more efforts are required towards developing protocols with this approach. In [65], proposed a method to reduce the overall power consumption per broadcast. Every node attempts to adjust its transmission power level based on local (two-hop neighbourhood) information. Their method can reduce the energy consumption and eliminate redundant transmissions as that of a scheme in which every node uses the default maximum power level for transmissions. The authors developed a simulation tool to simulate their algorithm in the ad hoc network environment. The simulation tool was also able to implement the channel model and the medium access control. But Tang, C., Raghavendra, C.S., Prasanna, V in [66], proposed an energy-efficient adaptation based on clustering scheme. A node is assigned to be a head node in each cluster. The head node acts as a forwarding agent that forwards all data for its cluster members, and also decides the best route through which to forward the data. All head nodes form a super-node-backbone. They deployed a multicast data transmission method with three steps:

1. A sender node transmits data to its head node;
2. The data travels along the super node backbone;
3. Receivers finally obtain the multicast data from the cluster head node within their clusters.

For the sake of balancing power consumption, cluster nodes take turn to be a cluster head-node by using some strategies. To demonstrate the benefits of their adaptation techniques, the researchers modified and enhanced the GloMoSim package by implementing a multi-power level for transmissions. Codes from their protocol were added to determine the appropriate power level to use for various transmission destinations. GloMoSim was also enhanced to calculate the energy costs with power levels for various communication activities.

Li, et al., in literature [67], have used the mobile node energy level and different message forwarding tactics to present Energy Level Based Routing Protocol (ELBRP).

They argue that this protocol makes the system energy consumption low, and also prolongs the system lifetime thereby reducing delay characteristic. They used Network Simulator version 2 (NS-2) to model their parameters. However, a comparison is made via simulation between ELBRP and other protocols such as AODV and RDRP which apparently yielded better results for ELBRP in terms of energy management. From the simulating results, ELBRP not only made the system energy consumption low, it also prolonged the system lifetime and reduced the delay characteristic.

We now look at how a network can cope with situations where the battery power of nodes may get completely drained. Vaithiyanathan et al., in [68], intended a self-management scheme where there is an automated energy consumption management by the nodes which results in nodes saving up their battery capacity until recharge. This is to be done by continuous unstable node tracking method at an optimum threshold battery capacity value. The literature also uses two methods to rectify drawbacks due to network blockages. The two methods are:

1. Self-recovery of nodes and;
2. Intelligent adaptation to the safest routing point in order to conserve energy until recharge.

The novel ’unstable node’ tracking method is devised exclusively for Node Transition Probability (NTP) based routing environment and the same technique can be adapted to any protocol by manipulating the corresponding control packets according to the propositions of this work. Simulation and analysis were done at real time scenarios using GloMoSim simulator. Taking the total battery capacity of each node to be equal to the battery capacity of an actual laptop node. They however, indicated that this model has been extended to universal usage and performance had been carried out in using AODV protocol.

To simultaneously minimize the energy of the node and reduce transmit power, this been a hard nut to crack for researchers over the years. However, Gomathi, S.S., Krishnamurthi, in [69], review the existing Minimum Drain Rate (MDR) which aims to predict the lifetime of nodes according to the current traffic conditions. It however found that MDR does not guarantee the minimization of total transmission power over a particular route chosen. Therefore, the authors provided a modified version of this algorithm called

Extended Optimal Energy Drain Rate (EOEDR) which is able to extend the battery life and duration of the path, and also minimize the total transmission power consumed per packet. The ultimate aim of this model is to prolong the lifetime of each node while extending the lifetime of the connection. NS-2 simulator was used to study how satisfactory the performance of their scheme can be in comparison with current MANET standards. It has the intelligence to detect and determine which node becomes a part of a route. The flexibility of the protocol adapts it as a route establishment facility in any other routing protocol of MANET, but Dynamic Source Routing (DSR) routing protocol was taken to be the protocol platform for their model.

Toh, C.K., in [70], shows that in order to maximize the lifetime of MANETs, the power consumption rate of each node must be evenly distributed, and the overall transmission power for each connection request must be minimized. These two objectives according to the author could not be satisfied simultaneously by the previous routing algorithms; therefore, this work presents a new power-aware routing protocol to satisfy these two constraints simultaneously. A trade-off between them is needed. This made a proposition of a conditional maximum-minimum battery capacity routing (CMMBCR) scheme which chooses a shortest path if all nodes in all possible routes have sufficient battery capacity. When the battery capacity for some nodes goes below a predefined threshold, routes going through these nodes will be avoided, and therefore the time for the first node to power down is extended. Adjustments to the value of the battery capacity threshold showed that, the time for the first node to power down and the lifetime of most nodes in the network can be maximized. Zhu, J., et al., in [71], proposed a new link cost for reliable transmission that includes the energy consumption for data packets as well as that for signalling packets in MAC layer. The authors after proposing a more comprehensive energy consumption models that first considered the energy consumption for data packets, they also considered control packets. Based on these models, the minimum energy routing scheme was proposed. To obtain the energy consumed during transmission from source to destination.

However,to eliminate the impact of finding the route on energy consumption, they used static routing. The simulation results confirmed that, the scheme performed better than the existing minimum energy routing schemes in terms of energy consumption and throughput. Once a new link cost was derived, the DSR algorithm proposed by Garcia, J.E., et al., in [72] can be modified with the new link cost. In the modification, a proposal for a novel routing mechanism called Energy Dependent that tries to avoid the use of weak nodes with low battery supply was proposed. In order to achieve this goal, EDDSR uses information related to the residual energy in the route discovery procedure. Network Simulator, NS-2 was used to evaluate and compare the performance of EDDSR mechanism against the conventional DSR protocol, Minimum Drain-Rate (MDR) and Least-Energy Aware Routing (LEAR) in a dense network scenario and a sparse network scenario. EDDSR has been implemented using DSR as the base protocol since it was proved to be one of the efficient reactive routing protocols in bounded networks. However, there are some problems with such straightforward modification:

1. The routing overhead for the route discovery is very high, which consumes a lot of energy.
2. The route setup time is very long.
3. The route maintenance scheme is not suitable for dynamic situations, such as in mobile ad hoc environments.

Alsalih, W., et al., in [73], introduced a cooperative computing scheme over MANETs through the use of remote execution platforms. In such a scenario, the computational duties of resource-limited devices are distributed amongst in-network devices in such a manner that energy is eventually conserved and overall performance is improved. With exact illustration, this distributed environment can be a set of consumers, such as, mobile applications, and a set of resources such as energy and processing power and then the authors proposed a heuristic-based scheduler that shows by experiment. The potential to come out with execution plans that are efficient in terms of energy saving and processing performance. They conducted several experiments to investigate the performance of their algorithm. To help bring their experiment to view, they used Task Graphs For Free (TGFF) to generate series of random values which they used to obtain their results. The unique contribution of this work can be summarized as follows:

- The authors formulated a novel energy-aware scheduling problem that is suitable for recent and future computing environments, such as MANET and pervasive computing in which energy is the most valuable resources.

- They also proposed a heuristic-based scheduler that maintains an equilibrium between energy saving and performance, and provides the system with the ability to set different importance levels for each of them.

Subbarao, M.W, in [66], conducted an initial investigation on the possible benefits of energy-efficient wireless routing in MANETs. They developed an initial dynamic power-conscious routing scheme known as Minimum Power Routing (MPR) that integrates physical and link layers' statistics to conserve power. This scheme also tends to compensate for the propagation path loss, shadowing and fading effects, and interference environment at the intended receiver while carrying out the MPR processes. The main idea of MPR is to select the optimal path between a given source and a given destination that will require the least amount of total power resources expended, while still maintaining an acceptable SNR at each receiver. A cost function is assigned to every link to determine the transmitter power required to reliably communicate on that link. The distributed Bellman-Ford algorithm can be used as an initial approach to perform the shortest path selection with the route cost functions as the link distances. The Network Simulator 2 (NS-2) was used to simulate the results of various test scenarios, and data transmission and reception between nodes was modelled by constant bit rate (CBR) traffic over UDP.

2.6.1 Weaknesses of Best Energy Efficient Route Schemes

In summarizing the intricacies of the literatures analyzed under the Best Energy Efficient Route Scheme, some works show some complexities in that. The fundamental characteristics of MANET might affect the models during application. For instance, in [30] has asymmetric link problem because accepting data from only one node might not be feasible in a MANET environment. The authors in [31] required that, both sender and receiver must be located at the same place. This cannot be guaranteed given the random movement that characterizes MANET. The basic assumptions in [62] that, each node is aware of its geographical location and that each node is equipped with an omnidirectional radio transceiver tend to increase the design complexity of devices and the operating complexity of accompanying protocols. In [65], the protocol results in a larger number of low power rebroadcasts and a slight increase in the fraction of colliding packets. This complexity can affect the network performance, and I think the performance of the network is paramount. In [74], also, the strategy of selecting the super node is not well defined. Queuing delay may be inevitable in the works of literature [75] due to different data rates among the communicating nodes. More delay will be counterproductive in terms of energy saving. Literature [76] intended the battery capacity of all nodes to be the same, which assumes MANET devices to be homogeneous and high node mobility will affect the efficiency of this protocol. Literature [77], did not put into account the energy expended by nodes in overhearing their neighbours in the network which might accumulate to a damaging level. The protocol in [2] tends to select longer path of communication which could increase the average relaying load for most nodes. The effect is that the lifetime of the nodes will be reduced.

The accuracy of the link cost is the determinant of the efficiency of performance of literature [78], and the busy channel problem of their scheme is complicated. The work in [79] proves to incur some complexities especially when deployed with Local Energy Aware Protocol (LEAR). In this Protocol, when there is high node density and high mobility, performance will suffer. However, it is assumed in [73] that the task is already efficiently partitioned and therefore, the task partitioning problem is assumed to have already been solved before this scheme can work. Literature [66], shows a trade-off between the utilization of current routing information and the communication overhead generated, and there is guess work here that the optimum update interval is the same as the slow fading duration.

2.7 Quality of Service (QoS)

Baboo, S.S., and Narasimhan, B. in [80], considered interference and fading of transmitted packet due to shared wireless channel and dynamic topology. They discovered that in a route of links with heterogeneous data rates, there is a chance of congestion if a high data rate node passes more traffic to a low data rate node. This results to queuing delay in such routes. Therefore, the operations of this scheme are based on data rate, queuing delay, link quality, residual energy and MAC overhead. Hence, the authors proposed to develop an energy efficient congestion-aware routing protocol, which uses a combined weight value as a routing metric, based on the node weight of the in-network nodes. They used the NS-2 and also used the Distributed Co-ordination Function (DCF) of the IEEE 802.11 as the MAC protocol to discover multiple routes from source to destination, they used a multiple path on-demand routing protocol as their basis. Among the discovered routes, the route with lowest cost index is selected. A research is carried out in [81] to secure the Ad Hoc On-demand routing protocol against one particular attack - the Black Hole attack. In this attack, the forwarded packets are purposely consumed by the malicious node. The researchers proposed a solution to this problem by making the source node to accept route reply (RREP) only from the destination nodes.

2.7.1 Weaknesses Quality of Service (QoS)

However, the shortcomings of the research [81] include the route delay is increased, and the assumption that the suspected attacking node is not the legitimate destination node whose energy/power level has depleted below a participating level. This literature though not much related to the work at hand and was included especially to highlight the extent of confusions that exist in MANET protocol development attempts. It generalized some bad network symptoms as malicious and failed to acknowledge that some symptoms of security threats interweaves with that of power issues. The weaknesses and assumptions of paper [67] is that all nodes move independently and with the same average speed.

2.8 Survey and Quorum

Paper [68] of Anand, D.K., Prakash, S, is a survey based literature. It surveys and classifies the energy aware routing protocols proposed for MANETs as well as different parameters responsible for power optimization. They went through the various layers of internet protocol to provide an intensive understanding of the existing protocols in order to get the basic knowledge of MANET protocols. The essence is to enhance an energy-efficient protocol design. They however presented the taxonomy of the energy efficient routing protocols, their properties and design features. The authors aim to aid those MANET researchers and application developers in selecting the appropriate energy efficient routing protocol for their work.

Quorum based literature [69] as presented by Wu, S.H., Chen, C.M., and Chen, M.S. showed that quorum-based power saving (QPS) protocol proves very challenging in MANET applications. The reason is due to the fact that node timers are asynchronous, incurred delay is adaptive, and network topology is asymmetrical. In their paper, they propose an Asynchronous, Adaptive and Asymmetric (AAA) power management protocol that fulfils the unique requirements of MANET. This paper makes a presentation of the asymmetric grid quorum system which is a generalization of traditional grid-based quorum system. A theoretical analysis was conducted to demonstrate the advantages of this AAA over the previous art. AAA employs the asymmetric grid quorum system to ensure the overlap of wake beacon intervals between stations.

2.8.1 Weaknesses Quorum

This survey article [68] has a big challenge in comparing the protocols directly because each method has different goal with different assumptions, and also employs different methods to achieve the goal. For example, node density or traffic density is not uniform; so, a load distribution approach must be employed to alleviate the energy imbalance. The problem with quorum based protocols [69] is that they perform well at small quorum sizes and tend to prove inefficient as the quorum sizes increase. Also their performances are mostly affected by clustering algorithm.

2.9 Routing Protocols Analysis

Studies in the area of MANET routing protocols have shown that some protocols perform better than others in a varied network evaluation conditions. Some perform better in terms of security; others do so in terms of bandwidth utilization, while some others work excellently in terms of power efficiency; and so on. Analysis of [71], aimed to compare the routing protocols in selected mobile network scenarios. Four different mobility models were proposed for simulating the scenarios in a mobile ad hoc networks environment. Also a method was introduced based on byte energy consumption to evaluation and assess the protocol. In order to construct the four categories of mobility model, they used the NS-2 simulator to model their specific ideas. Four classical routing protocols, AODV, DSDV, DSR and TORA, were chosen and their performances analysed. While TORA was found to be fit for networks with low node mobility, AODV, DSR and DSDV were better suited for networks with high node mobility.

The work Ismail, Z. and Hassan, R in Ismail2010, singled out the AODV routing protocol to analyze and evaluate its most vital characteristics as a possible choice for ad hoc communications. Network Description (NED) file, written in C++ was used to store the relationship between modules and communication links and also represent the scenario behaviour. This was also able to be modelled graphically. They however found the AODV as a routing protocol for MANET and proposed an optimal enhancement for the protocol in future. A detailed simulation analysis was carried out in [82] to determine the relative performance advantages of the routing protocols in MANET: Ad Hoc On-Demand Distance Vector (AODV), and Dynamic MANET On-demand (DYMO) routing protocol (reactive), Optimized Link State Routing protocol (OLSR) (proactive) and Zone Routing Protocol (ZRP) (hybrid). The simulation was done using QualNet version 4.5 (a software that provides scalable simulations of Ad hoc Networks) and a commercial version of GloMoSim. Constant bit rate (CBR) traffic was used for all the simulation, and the protocols showed results of one performing better than the other depending on the metrics being evaluated.

2.9.1 Assumptions

All nodes are homogenous and operate with the same energy and speed. This may not be obtainable in a real time scenario.

2.10 Review Summary

From the review, there is considerable effort in reducing power consumption in MANETs, but there is need for clear requirement solutions to the unresolved issues like:

1. Complex issues like mathematical computational model seem a challenging task, particularly when network size grows and feasibility of implementation becomes very difficult.
2. The route delay is increased, and the assumption that the suspected attacking node is not the legitimate destination node whose energy/power level has depleted below a participating level.

Chapter 3

IMPACT OF MOBILITY AND TRAFFIC MODELS IN MOBILE AD HOC WIRELESS NETWORK

3.1 Introduction

The traffic and mobility model is designed to describe the movement pattern of mobile devices, and how their positions, speed change over time. Since traffic and mobility patterns play an important and significant role in determining the protocol performance, it is necessary for traffic and mobility models to emulate the movement pattern of real life scenario of MANETs in a reasonable way. Otherwise, the observations made and the conclusions drawn from the simulation studies may be misleading. Thus, when evaluating MANET protocols, it is necessary to choose the proper underlying traffic model. In random-based mobility models, the mobile nodes move randomly and freely without restrictions as shown in figure 3.1. To be more specific, the destination, speed and direction are all chosen randomly and independently of other mobile nodes.

3.2 Impact of Topology Control, Traffic and Mobility Models on Mobile Ad Hoc Network

The present research is looking into the impact of topology control and traffic models performance on MANET. Unlike wired networks which require a fixed infrastructure consisting of wireless base stations and routers to communicate, the temporary physical topology of the network is determined by the random distribution of the mobile nodes and their own transmission power as reported in [83]. Also, Hu in his research [84] reports that mobile nodes in dense regions have high nodal degree, and more traffic per unit area is generated and delivered in these regions than in sparse regions. This causes performance degradation in terms of throughput and congestion in the network. However, the authors do not consider the impact of any of the traffic mobility models while evaluating the energy efficiency in the network. Another important issue analyzed by [84] is how to adopt the unpredicted dynamics movement of mobile nodes. Their main research results provide fully distributed algorithm for topology control that provide reliability, throughput and distributedness under topological changes. Achieving Optimal Quality of Service (QoS) depends on the routing protocol, scalability, traffic and mobility models employed in the network which the author did not consider while evaluating and analyzing network perfor-

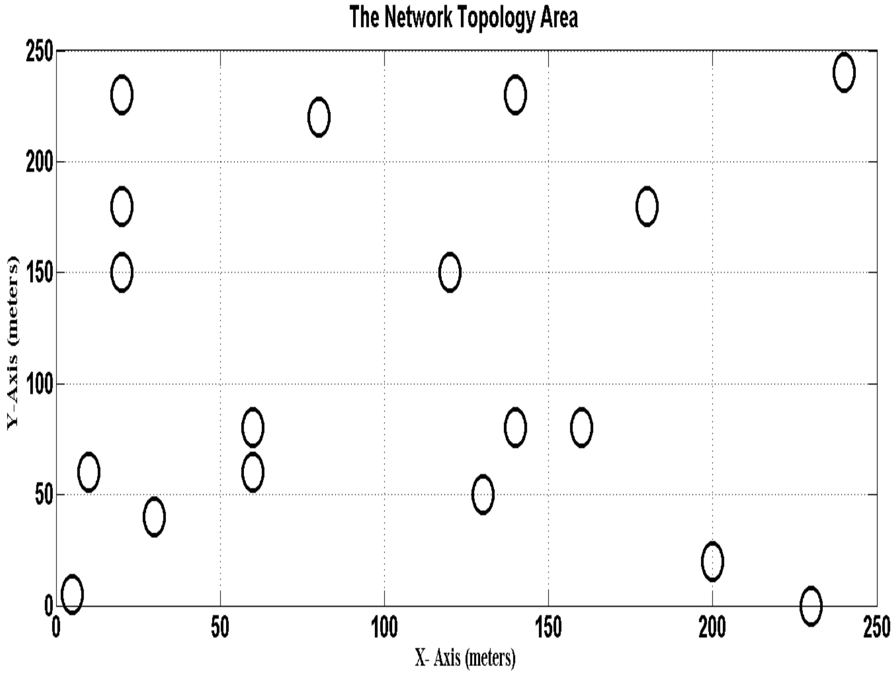

Figure 3.1: Network Topology area consists of mobile nodes moving around using random way point mobility model

mances. However, the majority of the research on topology control of MANETs use localized approaches to find a small transmission range and most of these approaches assume static networks without considering the impact of mobility and traffic models [85–90]. In a typical approach, mobile nodes move arbitrarily independent of each other and hence dynamic changes in topologies with fluctuating link capacities exist and the parameters can change unpredictably with time. The scope of this chapter is to analyze the impact of topology control and traffic models on MANETs networking.

3.3 Methodology

In order to evaluate the impact of mobility and different traffic model's performance on MANET, simulation were carried out using NS-2.34 [91]. Ns-2 is a discrete event simulator targeted at networking research. It provides substantial support for simulation of TCP, unicast and multicast routing protocols over wired and wireless networks. The topology area consists of 100m X 100m and 500m X 500m grid with 50 mobile nodes moving around using random way point model with speed randomly and uniformly selected between 0 - 20m/s while varying pause time. This parameter was used as a measure of nodes mobility. The low pause time means nodes will wait for less time thus giving rise to high mobility. The basic simulation parameters are summarized in table 3.1. The common parameters are left unaltered so as to provide linearity between all scenarios. Energy and power models in NS-2 were not changed and the default values of 281.8mW power for transmission and reception. Various performance metrics were considered to justify the performance evaluation of the network.

3.3.1 Traffic and Mobility generation for MANET

When simulating a large scenario, implementing the methodology as described in section 2.3 for every mobile node in the network may not prove an ideal way of defining traffic and is highly time consuming. Hence, the NS-2.34 simulator provides traffic generation scripts that can dynamically set up traffic between mobile nodes by defining all parameters required. It groups the nodes available into Agent nodes and Sink nodes and generates either TCP or CBR traffic between them.

3.3.2 Random - traffic pattern generators for MANET

Traffic-scenario generation script can define random traffic patterns for mobile nodes in the NS-2.34 simulator. To create traffic generation files, there is a need to define the type of traffic connection (CBR/TCP), the number of mobile nodes involved, and the maximum number of connections between the mobile nodes. In defining CBR/TCP traffics, the rate of traffic generation's inverse value is used to compute the interval between the CBR/TCP packets. The default packet size is 512 bits, but this can be altered as per requirement inside the configuration file cbrgen.tcl. Start times for CBR and TCP are generated and there is no guarantee as to how many sources and sinks can be deployed.

Table 3.1: General simulation parameters

Parameters	Values
Simulation time	300 seconds
Topology area	100 × 100 m , 500 × 500 m
Traffic Models	CBR, TCP
Number of nodes	50 nodes
Simulator	NS-2.34
Node Mobility Model	Random Way point
Propagation Model	Free Space path loss model
Physical Characteristics	802.11g
Data rate (bits)	5.5 Mbps
Transmission and reception power	281.8 mW
Bandwidth	22,000 KHz
Carrier frequency, f_c	2.4 GHz
Packet size	512 bits
Packet inter-arrival time	0.25 seconds
Routing protocol	DSR
Speed (m/s)	Uniform (0-20) m/s
Number of trial	six (6)

3.4 Simulation Results

This section presents simulation results comparing the performance of CBR over TCP on the MANET network using DSR protocol. The simulation was run at different pause times.Pause time can be defined as time for which nodes waits on a destination before moving to other destination. This parameter was used as it is a measure of mobility of nodes. The low pause time means nodes will waits for less time thus giving rise to high mobility scenario. Therefore, each node waits for a pause time, and then moves towards a destination with a speed lying between 0 and 20 meter per seconds. On reaching the destination it pauses again and repeats the above procedure till the end of the simulation time.

Figure 3.2 shows the Average End-to-End delay curves for CBR and TCP traffic models at different network topology sizes. The figure 3.2 shows that, as the pause time increases, the network delay decreases (See line 3 and 4), but line 4 remains constant throughout the simulation time and this is because, there is no much link failure in the network and the routing protocol has alternative routes to send the packets in case of link

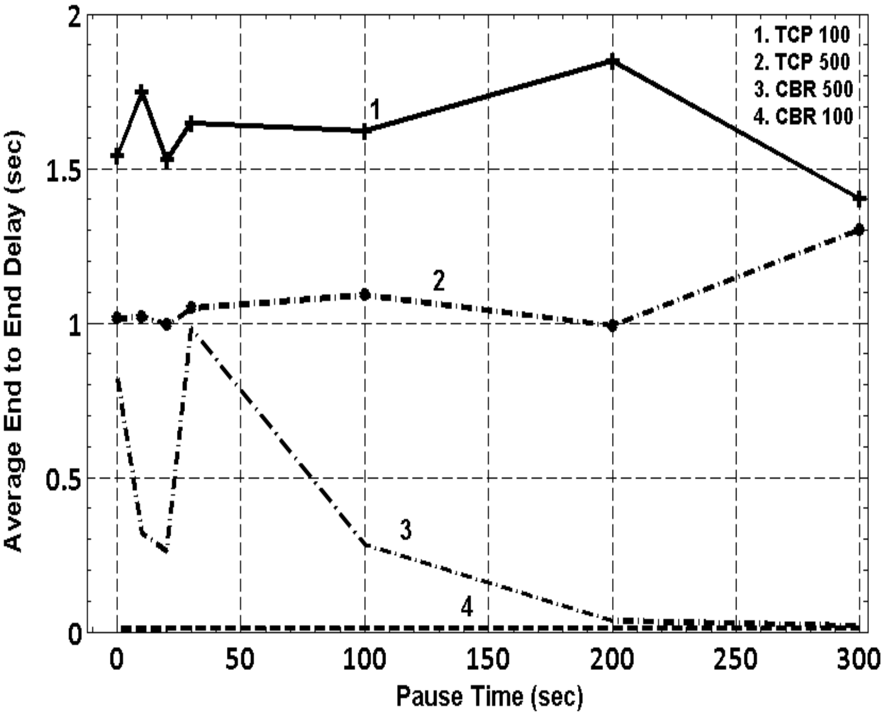

Figure 3.2: Average End to End delay versus pause time showing the network delay at different network topology size (100m X 100m and 500m X 500m)

1. Average End to End delay of TCP at 100 X 100 network topology size
2. Average End to End delay of TCP at 500 X 500 network topology size
3. Average End to End delay of CBR at 500 X 500 network topology size
4. Average End to End delay of CBR at 100 X 100 network topology size

breakage.

Also, as the routing pause time increases, mobility decreases and thus, link breakage becomes rare which in turn decreases the number of route request and hence decreasing the End to End delay in the network. But, If a retransmitted packet is lost, the TCP sender node waits for a time called Recovery Time Objective (RTO) and then retransmits. The RTO is doubled every time a transmission attempt is made. The extended waiting time can cause spurious delays (see line 1 and 2) and degrade the network's performance. These shows the effect of increasing the network topology size without considering the increase in number of communicating mobile nodes. Therefore, according to the simula-

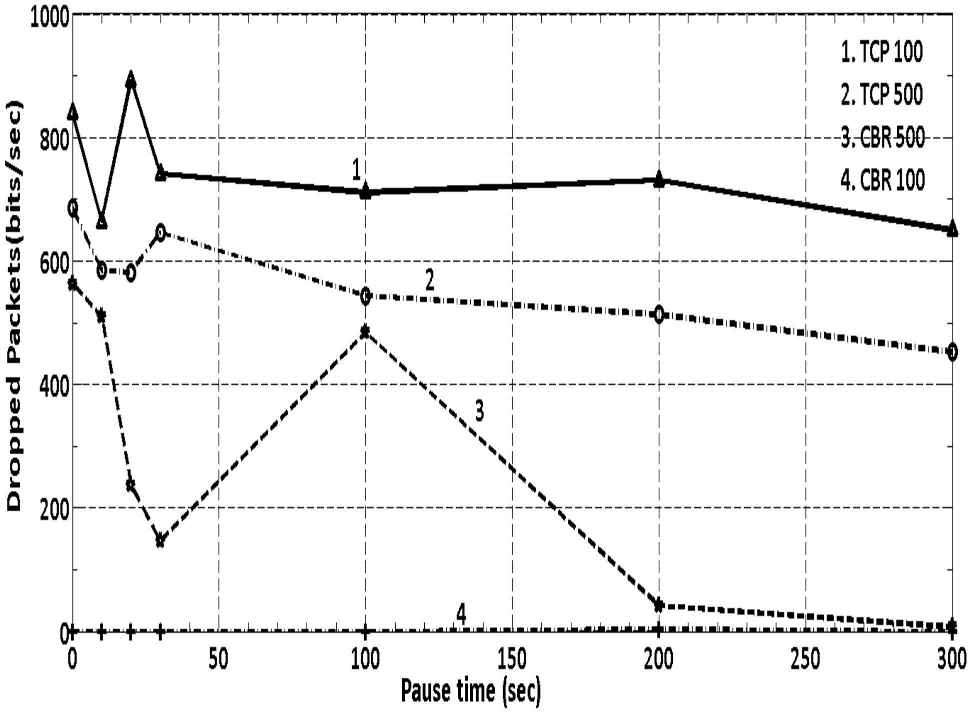

Figure 3.3: Dropped Packets versus pause time showing the dropped packets at different network topology size (100m X 100m and 500m X 500m)

1. Dropped Packets of TCP at 100 X 100 network topology size
2. Dropped Packets of TCP at 500 X 500 network topology size
3. Dropped Packets of CBR at 500 X 500 network topology size
4. Dropped Packets of CBR at 100 X 100 network topology size

tion results, for TCP traffic model to be use in less and high dense MANETs, the number of communicating mobile nodes need to be increase as well. This is to reduce the frequent link failure due to the unpredicted movement of the mobile nodes and to allow the routing protocol to initiate and discover alternative route(s) in case of link failure before the TCP invoke its congestion control algorithm, which can cause high delay and consequently packet drops in the network.

The delay caused in the network as a result of link breakage, this caused TCP traffic model to reduce its packets sending rate, consequently resulted into packets drops as a result of time to live (TTL) expiration of the routing protocol as shown in figure 3.3.

TTL is the time given to a mobile node(s) by a routing protocol to reach all the nodes in the network to ensure successful route discovery as well as packet delivery in one round of flooding. If the time allocated to a mobile node(s) elapsed before its reaches the final destination then, the packets will be drop. When ever TCP invokes its congestion control algorithm by reducing the sending rates of the packets, this can slow the sending rates of the packets, which can leads to expiration of the time allocated to the mobile nodes. For that packets will be drop.

Therefore, as the pause time increases, the nodes will waits more time before moving to another point, TCP traffic model drops more packets than the CBR traffic model shown in figure 3.3.It can be observed the effect of increase of network topology size without increasing the number of communicating node as shown in figure 3.3 as well.

Figure 3.4, shows that CBR traffic model being a connectionless protocol does guarantee successful delivery of packets as opposed to TCP which is not reliable in providing this metric in a high mobility environment, where delays are expected. As the pause time increases, CBR delivered almost 100 % packet delivery (See line 1) and this is due to the mobile nodes not too far from each other. However, as the network sizes increase, the mobile nodes being too far from each other this caused link breakage and hence, leads to decrease in packet delivery. In comparison with TCP model, TCP was able to deliver a reasonable amount of packets successfully despite its delays transmission. As the pause time increases while the routing protocol tries to find the valid route to destination, the TCP traffic model was unable to withstand the stress of the waiting. Therefore, it considers the waiting to be a sign of network congestion and consequently applies the congestion control mechanism, which increases the End-to-End delay exponentially leading to packet drops and consequently decreasing the packet delivery (See line 3 and 4). Therefore, an increase in pause time decreases the percentage of the packets being delivered, despite the DSR routing protocol's effort in justifying equal opportunities amongst the traffic models.

In general, at low and high mobility (low pause time and high pause time), the End-to-End delay and dropped packets fall drastically, but in the TCP traffic model this is not the case in high pause times. But there is considerable good response of DSR routing protocol to link failure at both low and high mobility before the TCP's congestion mechanism responds, and packets were successfully delivered while the packets dropped is due

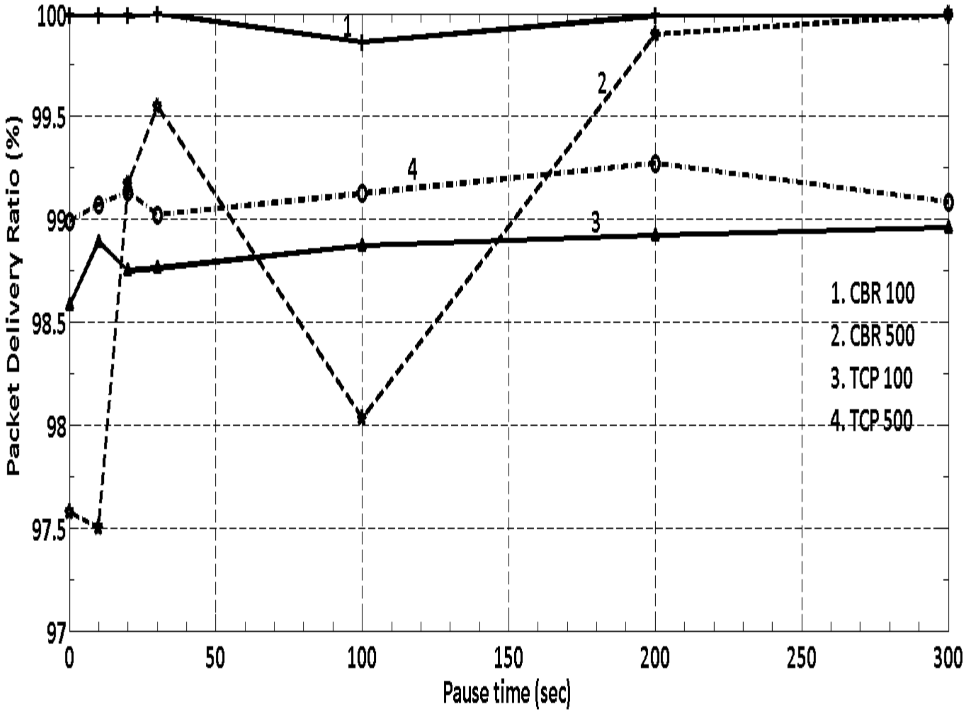

Figure 3.4: Packet Delivery Ratio (PDR) versus pause time showing the PDR at different network topology size (100m X 100m and 500m X 500m)

1. Packet Delivery Ratio of CBR at 100 X 100 network topology size
2. Packet Delivery Ratio of CBR at 500 X 500 network topology size
3. Packet Delivery Ratio of TCP at 100 X 100 network topology size
4. Packet Delivery Ratio of TCP at 500 X 500 network topology size

to increased in End-to-End delay, time-to-live (TTL) expiration of the routing protocol and end of simulation time. In all network sizes area, CBR showed peak performance results in all metrics chosen, whereas in a large topological area, TCP traffic perform well in terms of packet delivery. However, it can be justified that quality of service with CBR in MANETs is higher than that of TCP traffic due to its low overall end-to-end delay. TCP traffic experienced more delay than CBR traffic, the mobile nodes being too far from each other, the network is subjected to partition and delay is increased. The impact of traffic type in MANETs can be clearly justified with this analysis.

3.5 Chapter Summary

In this chapter, traffic and mobility models play an important role in evaluating the performance of MANETs, despite criticism and assumption from various research on TCP's weaknesses on MANET. The research analyzed the impact of mobility and traffic models on MANET's. Although CBR and TCP have significantly different manufacture behaviour, these differences lead to significant performance of CBR over TCP with better packet delivery and less delay. The DSR protocol used was able to respond to link failure at low pause time, and this led to TCP's performance in packets delivery. Simulation results show that CBR outperformed TCP in all metrics chosen, except for TCP which was able to handle packet delivery in larger topologies than CBR, but at the cost of increase in overall delay in the network. From the simulation results it is summarized that, the increase in spurious packet drops in TCP is due to its slow start which invokes its congestion control algorithm.

Based on this analysis, TCP traffic model can be used for small networks where frequent topology changes are limited and could be controlled by DSR routing protocol. It is believed that most packets dropped are due to high delay, time-to-live (TTL) of the routing protocol and end of simulation time. This behavior justifies the limitations of the routing protocols described in IETF documentation on DSR [92]. TCP could provide more reliable delivery of data packets in large environments during high mobility, despite spurious degradation in performance, increasing overall delay in the network. Hence, CBR traffic model is chosen and will be used for the next analysis and the next chapter will focus on the performance comparison of mobile ad hoc reactive routing protocols of MANETs in a hostile environment. As the research work chose to work on reactive routing protocols only, and this is due to their advantages over proactive types.

Chapter 4

PERFORMANCE COMPARISON OF MOBILE AD HOC REACTIVE ROUTING PROTOCOLS

4.1 Introduction

In MANET, the goal is to establish the best path to route packets to its destination while considering the limited resources available in the network which includes bandwidth and energy [93, 94]. However, due to frequent topology changes associated with mobile nodes movements, the amount of control traffic generated by the routing protocols must be minimized to achieve optimal performance [54]. In this chapter, the performance analysis of MANET's reactive routing protocol (AODV, DSR) in a hostile environment has been achieved as well as the effect of power model on the received packets. This performance analysis aims to maximize throughput in a large capacity network while minimizing end-to-end delay in the presence of ambient noise. Performance evaluation conducted on both proactive and reactive protocols [95–99] shows high routing overhead, and a considerable amount of dropped packets. In [100], though the author mentioned the effects of salvaging, gratuitous route and promiscuous listening, simulation was not carried out to ascertain the effect of delay on the overall performance of the network. In [54, 101], throughput was optimized but routing overhead obtained was high compared to the proposed method. In terms of power consumption [52, 102] showed that network configured with DSR protocol has less energy consumption in the entire network as compared to its counterpart network with AODV. The network configured with AODV protocol latter loses energy due to hello messages broadcasted at every interval of time in seconds to update its routes. Therefore, in this chapter, performance comparison of network configured with AODV and DSR protocols in the presence of multiple access interference with increased ambient noise level was carried out.

4.2 Materials and Method

Various researches [15], [103], [104], carried out in optimizing the performance of DSR and AODV in MANET are usually carried in a free space environment without reference to multiple interferences on the operating environment and hence, results obtained cannot be used to model a real-time physical MANET environment without considering the effect of various obstacles such as diffractions, reflections and multi-user interferences.

This chapter, have evaluated the effect of path loss on the received power level, while incorporating ambient noise into the simulation environment. Ambient noise can be in different forms depending on the network operating environment. For urban areas, the ambient noise can be in the form of car engine noise, horns, trains, construction machines, and aircraft etc. In rural areas, it can be the sounds of farm animals, wildlife, wind in the trees, and tractors. Ambient noise can be calculated using equation (4.1).

$$A_n = rw * K, \tag{4.1}$$

where An is the ambient Noise, rw is the receiving bandwidth and K is the constant ambient noise level which is given as 1.0E-26 dB and it is measured in decibels (dB) using sound level meter. The radio channel is characterized by first (1) Path loss and second (2) Ambient noise. Signal is transmitted through distortion area to the receiver located at a distance *D*. The path loss model used in this analysis is given by [105] and presented in (4.2);

$$P_L = \frac{\lambda^2}{(4\pi D)^2} \tag{4.2}$$

P_L is the path loss, λ is wavelength and *D* is the propagation distance. In our technique, equations (4.1) and (4.2) are merged to obtain equation (4.3) which can represent a path loss model in an interfering and non-line of sight network environment as shown in appendix [K].

$$P_L = \frac{\lambda^2}{(4\pi D)^2} + A_n \tag{4.3}$$

Three performance metrics are evaluated against pause time. These performance metrics are as follows;

- **Throughput**: This is the total number of successful received bits or packets at the destination nodes for the entire simulation period.
- **Network Load**: The total traffic (bits/sec) received by the network layer from the higher MAC that is accepted and queued for transmission.
- **End-to-End Delay**: This includes all possible delays caused by buffering during route discovery time, queuing at the interface queue, retransmission, and processing time.

4.3 Methodology

Simulations was carried out using the OPNET simulator in a physical topology area of 700m x 500m using a random way point mobility model. At the beginning of the simulation, each node waits for a pause time, and then moves towards a destination with a speed lying between 0 and 36 kilometers per hour uniformly distributed. On reaching the destination it pauses again and repeats the above procedure till the end of the simulation time. Mobility models were created for the simulations using 40 mobile nodes with pause times of 100, 200, 400, 600, 800, and 900 seconds. The CBR agents and packets size of 1000 bytes are used to generate traffic in the network. The general simulation parameters are summarized in Table 4.1. Table 4.2 and Table 4.3 represent the basic simulation parameters for AODV and DSR protocols.

Table 4.1: Simulation Parameters

Parameters	Values
Channel Type	Wireless Channel
Physical Characteristics	Direct Sequence
Mac Type	802.11b
Data Rate	11Mbs
Topology	700 m X 500 m
Routing Protocols	AODV, DSR
Number of Nodes	40
Transmit Power	0.005 W
Packet Size	1000 bytes
Mobility Model	Random Way Point
Simulation Time	900 sec
Traffic model	CBR
Speed	0 - 36 km/h
Ambient noise level	1.0E-26 dB

4.4 Simulation Results and Discussions

Figure 4.1 shows both networks with DSR and AODV throughput in bits per seconds. The network with AODV achieved 4.0E+05 bit/sec at 100 seconds pause time 9.0E05 bit/sec of network with DSR protocol. The initial increase in throughput is attributed to route

Table 4.2: AODV Parameters

Parameters	Values
Hello Interval	Uniform (1, 1.1) sec
Net Diameter	35
Time to live (TTL) Start	1
TTL Incremental	2
TTL Threshold	13
Local Add TTL	4

Table 4.3: DSR Parameters

Parameters	Values
Request Table Size (Node)	64
Maximum Request Re-transmission	32
Initial Request Period	0.5 sec
Maximum Acknowledgement Timer	0.5 sec

discovery processes initiated by both routing protocols. This implies that more control information in the form of RREQ and RREP was forwarded by all nodes in the network which consequently lead to a higher obtained throughput. As the pause time increases and more network routes are discovered, networks with AODV throughput drops to 0.5E+05 bit/sec while its counterpart remains constant at 6.0E+05 bit/sec with an increase in pause time. This shows the effect of variation in pause time in the network. Both protocols deliver a greater percentage of the originated data packet at low node mobility, with AODV routing protocol delivering 99% confidence interval as given in Table 4.4 (AODV simulation statistics) while DSR routing protocol delivers at 98% confidence interval as well as given in Table 4.5 (DSR simulation statistics). These results also show that both routing protocols were very good at all mobility rates and movement speeds.

Figure 4.2 shows the overall end-to-end delay for both networks. It can be observed that at the beginning of the simulation, the network with DSR protocol experienced a higher end-to-end delay, and packets were held in the cache memory for a much longer period of time before being forwarded to the routing layer for queuing at the MAC layer. This delay of 0.1522 seconds is illustrated by the network with DSR routing protocol at a pause time of 100 seconds, while the network with AODV stands at 0.034 seconds for

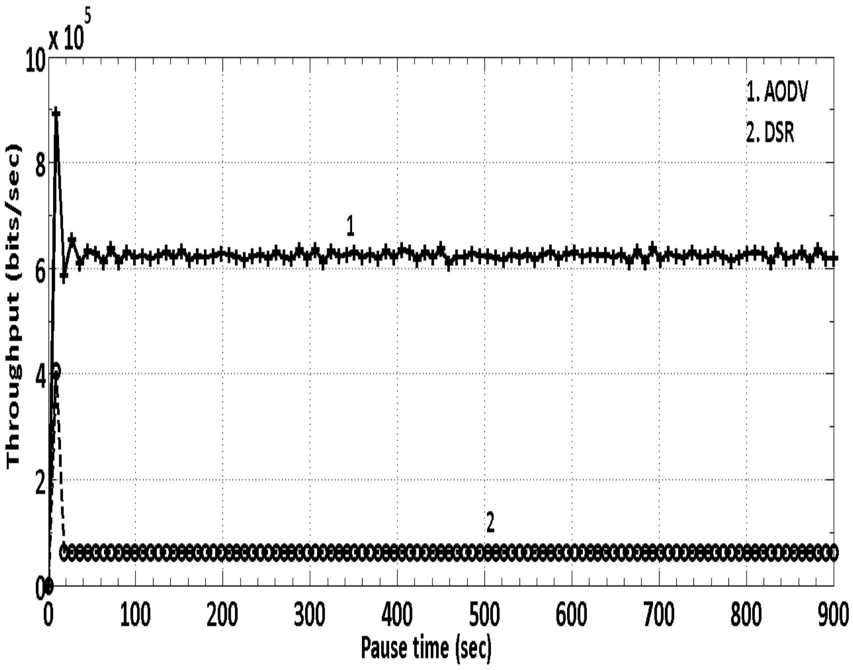

Figure 4.1: Throughput Performance Comparison of AODV and DSR

Table 4.4: AODV-Network without power model-Throughput

Parameter	Value
Initial value	0.0
Final value	2,680,344
Expected value	2,873,951.25333333
Sample mean	2,873,951.25333333
Variance	9,863,777,098,925.4
Standard deviation	3,140,665.07270759
98% conf interval	2,061,155.80882608, 3,686,746.69784058

Table 4.5: DSR Simulation Statistics-Throughput (bits/sec)

Parameter	Value
Initial value	0.0
Final value	99,286.2222222
Expected value	103,309.466666667
Sample mean	103,309.466666667
Variance	1,924,126,941.52494
Standard deviation	43,864.8713839
98% conf interval	93,052.0108996, 113,566.922433714

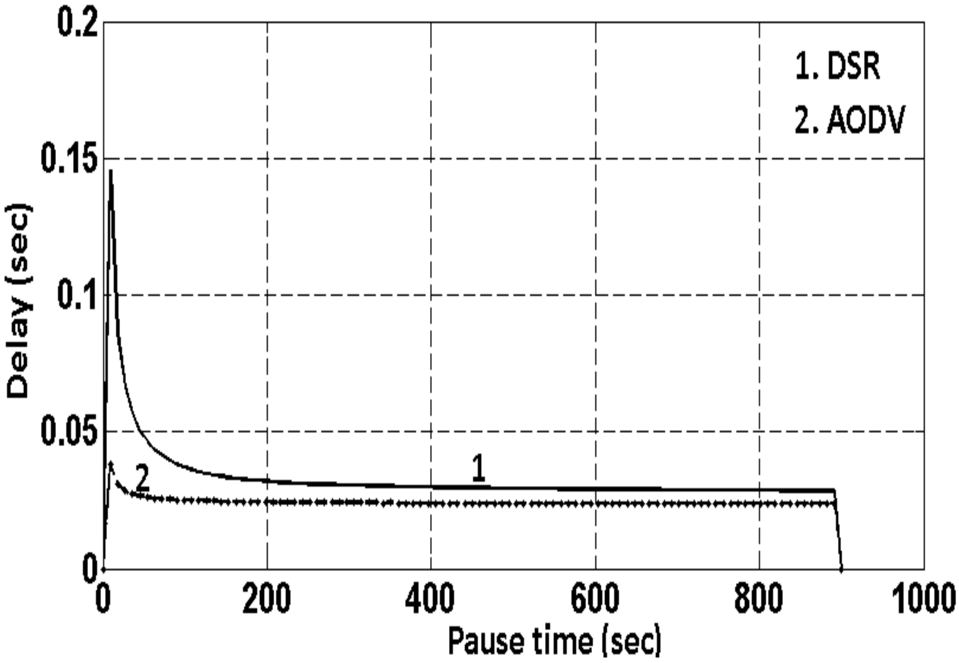

Figure 4.2: End-to-End Delay Comparison between DSR and AODV

the same pause time. As mobility increases, the network with DSR protocol experiences a huge drop in end-to-end delay from 0.152 seconds to 0.02 seconds while its counterparts experienced a slight drop from 0.054 seconds to 0.017 seconds respectively. Both the two network scenarios (AODV and DSR) maintain steady flow in their end-to-end delay while maintaining route and link consistency throughout the simulation period. The initial increase in end-to-end delays was a result of route discovery processes initiated by both routing protocols, while the steady drop in delay is a result of route stability as the network converges.

When comparing the network load sent by each routing protocol, Figure 4.3, showed that the network with DSR routing protocol has the highest network load of 13.0E+04 bit/sec compared to the network with AODV routing protocol network load of 8.0E+04 bit/sec. As mobility increases, the network load of DSR falls drastically to about 6.0E+04 bit/sec while AODV network load remains constant with about 7.5E+04 bits/sec throughout the simulation time. The rise and falling of network load packets of AODV protocol was attributed to the constant hello messages generated. These messages are used by AODV protocol to maintain link consistency in the network based on the proposed power

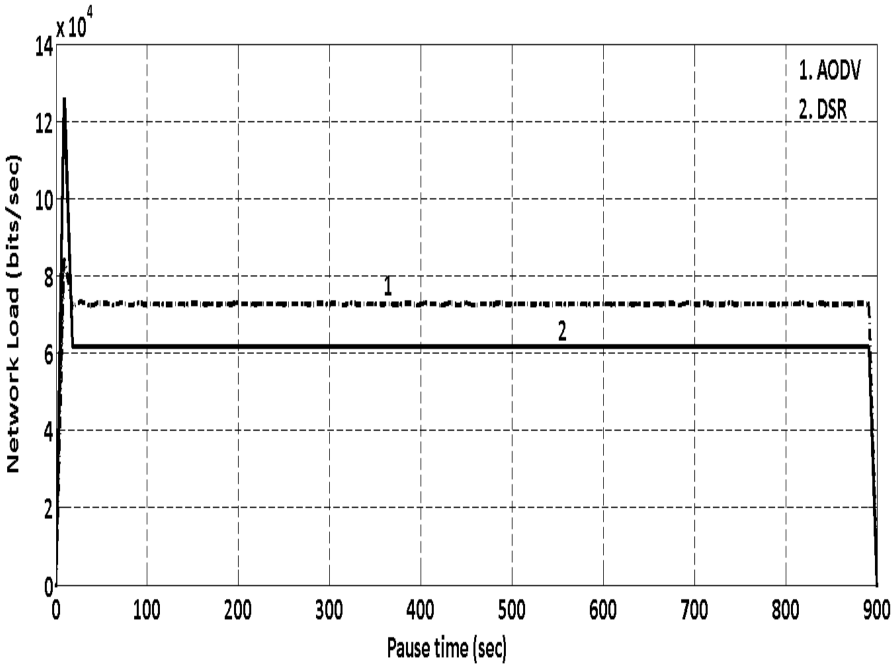

Figure 4.3: Network Load Comparison between DSR and AODV

model; DSR protocol on the other hand has multiple routes to various destinations and as such does not require constant hello messages to maintain the links between mobile nodes on the network.

4.5 Effect of Power Model on Received Packets

Routing of packets in DSR and AODV routing protocols are controlled by the power model embedded in a mobile node. Mobile nodes broadcast RREQ with transmission power inserted in the header field of the packet format; the receiving node measures the received signal strength (P_r) and passes the packet to the routing layer for queuing at the MAC layer if the received signal of the packet is equal to or greater than the packet reception power-threshold at the receiver node. Figures 4.1 shows that 98% of the packets transmitted were successfully received by the receiving nodes during the simulation and hence, the implemented power model can serve as a reference model for future evaluation and optimization mobile ad hoc networks using DSR and AODV in a very high density and high mobility network.

4.6 Chapter Summary

Various ad hoc routing protocols have been developed but minimal performance has been achieved as must of the research work was carried out without reference to multiple interferences on the operating environment and hence, results obtained cannot be used to model a real-time physical MANET environment without considering the effect of various obstacles such as diffractions, reflections and multi-user interferences.

Based on the model, coupled with mathematical analysis supported by computer simulation. The performance of the routing protocols was analyzed. Statistical results and simulation results presented illustrate the performance of an ad hoc network protocols in the presence of ambient noise in the network. The simulation result for the network with DSR and AODV protocol showed 86.8% decrease in end-to-end delay, while the network with AODV protocol also showed 68.5% drop in end-to-end delay. The network load simulation result revealed that DSR protocol maintained a constant load while there was a 75% drop in routing load for AODV protocol. The simulation results of AODV and DSR routing protocols showed 99% and 98% confidence intervals respectively. Interference, high mobility, and high noise level degrades the performance of MANET but this effects was overcome by adaptively setting the received signal threshold from range of levels in accordance with speed of nodes and topology of its operating environment.

Chapter 5

SENSITIVITY OF MANETs TO PATH LOSS EXPONENT AT HIGHER FREQUENCIES

5.1 Introduction

Mobility in ad hoc wireless networks implies that links between nodes may change rapidly and unpredictably, hence the number of nodes in a network is not constant. The physical size of a MANET is larger than the radio range of the wireless interfaces, thus for any two mobile nodes in the network to be able to communicate, routing is necessary [106]. Therefore MANET needs routing protocols that can respond to the topological changes instantly, hence the performance of MANET depends on its routing protocols which are either proactive or reactive. Most of the routing protocols proposed in [107] addresses the problem of establishing and maintaining the routes in a dynamically changing network topology. However, most of these routing protocols are designed to take into consideration only the network layer with less emphasis on the lower layer. Due to the increasing demand for high-speed data services, the limited and high cost of licensed spectrum and the statement by Li et al. [55], MANET are deployed during responses to disasters. With the current spate of disasters around the world such as hurricanes, tsunamis and earthquakes, it means that future MANET may best be accommodated above 2 GHz, preferably the unlicensed band of 2.4 and 5.3 GHz. At higher frequency the physical layer needs to be modelled accurately and the best model is the two ray propagation model as Hernandez-Valedez et al., reported in [56]. In previous papers, two ray propagation models have been used [9, 52], for the performance evaluation of MANETs using AODV routing protocol. However, none of these papers studied the effect of path loss exponent on the performance of MANETs.

Path loss normally includes propagation losses caused by the natural expansion of the radio wave front in free space (which usually takes the shape of an ever-increasing sphere), absorption losses (sometimes called penetration losses), when the signal passes through media not transparent to electromagnetic waves, diffraction losses when part of the radio wave front is obstructed by an opaque obstacle, and losses caused by other phenomena. Therefore, in the study of wireless communications, path loss can be represented by the path loss exponent, whose value is normally in the range of 2 to 4 (where 2 is for propagation in free space, 4 is for relatively noisy environments. In some environments, such as buildings, stadiums and other indoor environments, the path loss exponent can reach values in the range of 4 to 6. This omission motivated this work.

Therefore, this chapter studies the effect of path loss exponent on end-to-end throughput, and the received signal power of MANETs. It is observed that, as the path loss exponent increases the received signal power at the individual mobile nodes for multi-hop wireless ad hoc networks also increases, whilst the throughput remains the same for different path loss exponent. It was also observed that at microwave carrier frequencies greater than 2 GHz, the network's performance is sensitive to the wireless channel model and the break point distance.

5.2 System and Propagation Model

This section describe the system model used for our computer simulation and outline the basic assumptions that have to be made.

5.2.1 Path Loss

When the electromagnetic signal propagates through the ionosphere, it is diffracted, reflected and scattered. Therefore the radio environment is characterized by: (1) path loss (2) shadowing and (3) multipath fading. In this work, only path loss is considered to simplify the analysis, as it is assumed a scenario where an efficient antenna diversity-combining system is used at the mobile nodes to eliminate the effects of multipath fading.

Path loss is due to the decay of the intensity of a propagating radio-wave, and it requires an accurate estimation for proper determination of the electric field strength, signal-to-noise ratio, carrier-to-interference ratio, etc [108]. In the present analysis and simulations the two-slope path loss model was used to obtain the mean received power as function of distance, which is given by [109] as:

$$S_r = \frac{KS_t}{r^{n_1}(1 + r/r_{brk})^{n_2}}, \tag{5.1}$$

where S_r [W] is the mean received signal power, K is the constant path loss factor, which is the free space path loss at a reference distance, r [m] is the distance between the transmitting mobile node and the receiving mobile node, n_1 is the basic path loss exponent (between 0.5 and 2), n_2 is the additional path loss exponent (between 2 and 8) and r_{brk} [m] is the breakpoint distance, which is proportional to the product of the transmitting node antenna height and the receiving mobile node antenna height and inversely proportional to the wavelength of the transmitter source.

5.2.2 Two-Slope Path Loss

In this analysis and these simulations, the two-slope path loss model was used to obtain the mean received power as function of distance, which is given by [109] as:

$$P_d = \frac{K}{d^{\alpha}(1 + d/g)^{\rho}} P_t, \tag{5.2}$$

where P_d [W] is the mean received signal power, K is the constant path loss factor, d [m] is the distance between the transmitting node and the receiving mobile node, α is the basic path loss exponent (roughly 2), ρ is the additional path loss exponent (between 2-8) and P_t [W] is the transmitted signal power, and g [m] is the break point distance in a line of sight (LoS) micro cellular networks, which is proportional to the product of the transmitting node antenna height and the receiving mobile node antenna height and inversely proportional to the wavelength of the transmitter source. For a Mobile Ad Hoc Wireless Network with carrier frequency, f_c = 900 MHz, and wavelength λ_c. with the transmitting node antenna height h_b and receiving mobile node antenna height h_m. The breakpoint distance $r_{brk} = 4h_b h_m/\lambda_c$.

5.2.3 Relationship between Breakpoint Distance and Carrier Frequency

Fig. 5.1 shows the average received signal power given by Equation (5.2) plotted as a function of distance. The same Figure shows that for the path loss, two regions may be distinguished, which are separated by a break point. Before the break point the path loss is similar to free space path loss (path loss decreases $\propto$ 1/(distance)^2). The path loss after the break point is inversely proportional to the fourth power of distance (path loss decreases $\propto$ 1/(distance)^4). Therefore, using the break point formula the carrier frequency of f_c = 900 MHz the breakpoint distance from the transmitting mobile node is $\approx$ 4800 m. For f_c = 2.4 GHz the breakpoint distance increases to 12800 m and for 5.3 GHz, the breakpoint becomes $\approx$ 28267 m.

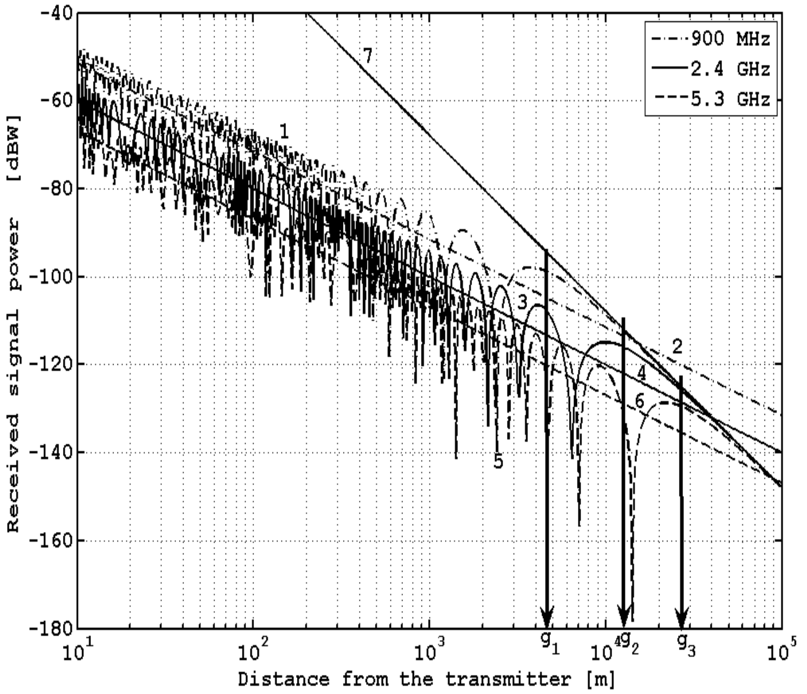

Figure 5.1: Two-slope received signal power P_d, vs distance d, showing the break point distance from the transmitter;g_1, g_2 and g_3 at carrier frequencies f_c; 900 MHz, 2.4 GHz and 5.3 GHz. (Transmit and receive antenna gain; G_{Tx} = G_{Rx} = 0 dB, basic path loss exponent $\alpha = 2$, extra path loss exponent $\rho = 4$.

1. Two Ray Model Received Power P_d at 900 MHz
2. Free Space Model Received Power P_d at 900 MHz
3. Two Ray Model Received Power P_d at 2.4 GHz
4. Free Space Model Received Power P_d at 2.4 GHz
5. Two Ray Model Received Power P_d at 5.3 GHz
6. Free Space Model Received Power P_d at 5.3 GHz)
7. Power falls off $\propto$ 1/(distance)^4

5.3 Simulation Model

OPNET Modeler version 16.0 [110], developed by OPNET Technologies was used for the simulations. Details about the simulation model and environment are presented in the rest of this section.

Table 5.1: General simulation parameters

Parameters	Values
Simulation time	900 seconds
Topology area	500 × 500 m
Traffic Models	CBR
Number of nodes	50 nodes
Simulator	OPNET Modeller 16.0
Node Mobility Model	Random Way point
Propagation Model	Free Space path loss model
Data rate (bits)	5.5 Mbps
Transmission power	0.050 W
Carrier frequency, f_c	900 MHz, 2.4 GHz and 5.3 GHz
Packet size	512 bits
Packet inter-arrival time	0.25 seconds
Routing protocol	DSR
Speed (m/s)	Uniform (0-10) m/s
Number of trial	six (6)

5.3.1 Simulation Parameters

In order to evaluate the impact of propagation loss parameter (path loss exponent) as well as sensitivity of the network's performance using DSR Protocol toward wireless channel with frequencies greater than 2 GHz, simulations were carried out using the OPNET simulator [110]. The topology consists of a 500 m × 500 m grid with 50 mobiles nodes moving around randomly using the way point mobility model. Constant bit rate agents, with packets sizes of 512 bits were used for generating traffic in the network. The simulation time was 900 seconds in real time, which enabled the simulation to converge for accurate results. The basic parameters used for the simulations are summarized in Table 5.1.

5.4 Simulation Results

This section describes three different path loss exponent estimation at different carrier frequencies; each based on a certain network characteristics and provide simulation results. Figure 5.2 shows a plot of received power at 900 MHz as a function of simulation time. At 0.5 path loss exponent, the transmitting mobile node and receiving mobile node have a clear line of sight path between them. No other sources of impairment. As the path loss exponent increases to (n_1 = 1.5 and 2.0), the received power also increases exponentially. However, as the carrier frequency increases 5.3 and 5.4, the received power signal remain the same for the whole path loss exponents (n_1 = 0.5, 1.5 and 2). Whilst the wireless channel had an effect on the received signal power at individual mobile nodes of the network, because in the wireless communication system the wireless environment is being represented by the path loss exponent; which represents the reduction in power density (attenuation) of an electromagnetic wave as it propagates through space.

It is also show that for different path loss exponents n_1 (0.5, 1.5 and 2.0), throughput performance remained the same as shown in figures 5.5, 5.8, and 5.7. It can therefore be concluded that, the wireless channel had no effect on the throughput of mobile ad hoc wireless network. Whilst the wireless channel had an effect on the received signal power at individual mobile nodes of the network. In general, at a carrier frequency of 900 MHz, the curves overlap each other, because at microwave carrier frequencies less than 2 GHz the break point distance, g_1(refer to fig. 5.1) is not far from the transmitting source. Therefore, only few a mobile nodes are in the free space region ($\propto$ 1/(distance)^2), whilst the majority of the nodes are in the region after the break point where path loss is inversely proportional to the fourth power of distance ($\propto$ 1/(distance)^4).

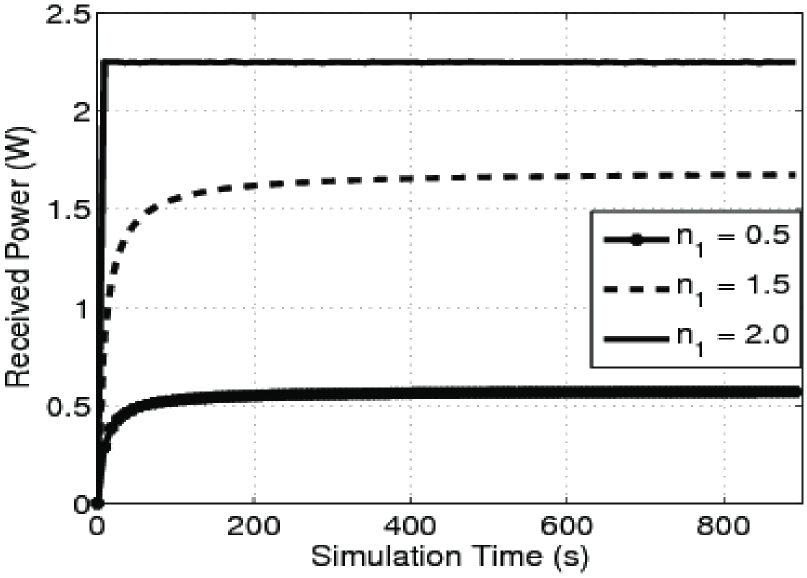

Figure 5.2: Received power at carrier frequency, f_c = 900 MHz and path loss exponent, n_1 = 0.5, 1.5 and 2

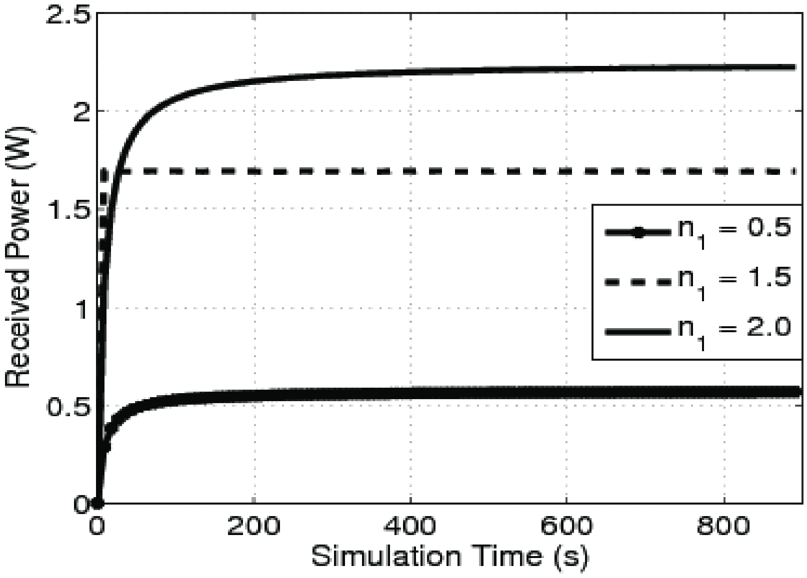

Figure 5.3: Received power at carrier frequency, f_c = 2.4 GHz and path loss exponent, n_1 = 0.5, 1.5 and 2

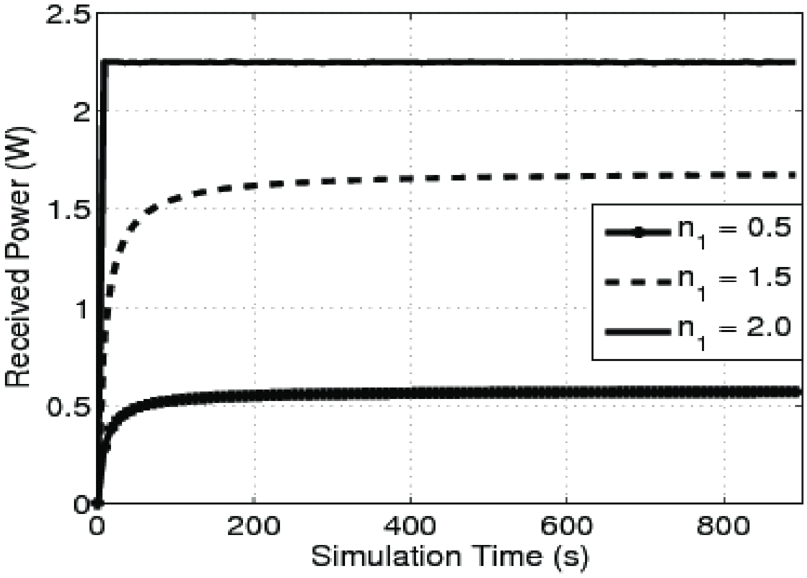

Figure 5.4: Received power at carrier frequency, f_c = 5.3 GHz and path loss exponent, n_1 = 0.5, 1.5 and 2

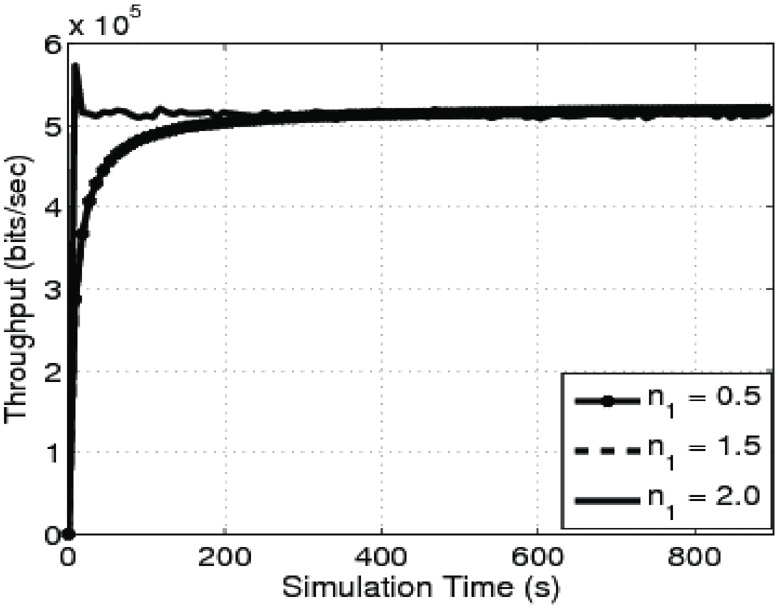

Figure 5.5: Throughput at carrier frequency, f_c = 900 MHz and path loss exponent, n_1 = 0.5, 1.5 and 2

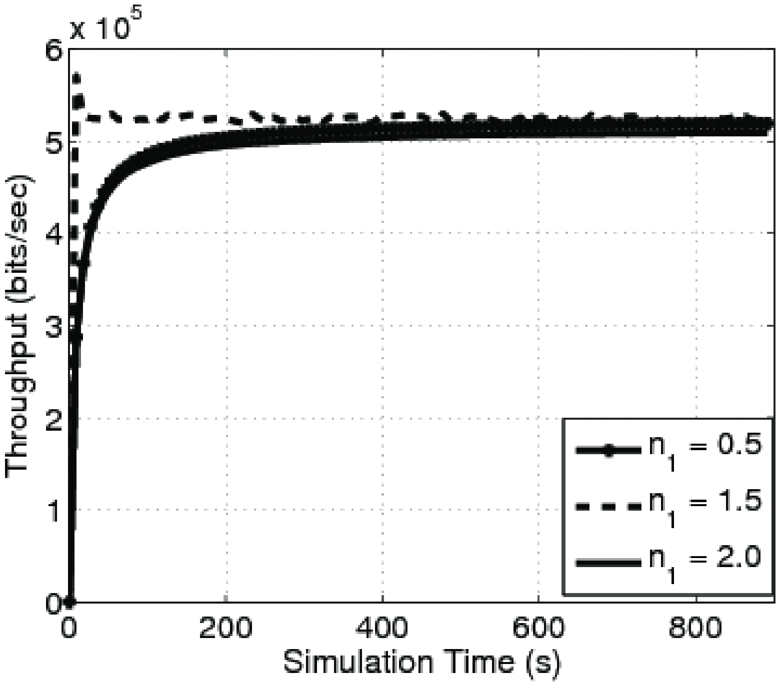

Figure 5.6: Throughput at carrier frequency, f_c = 2.4 GHz and path loss exponent, n_1 = 0.5, 1.5 and 2

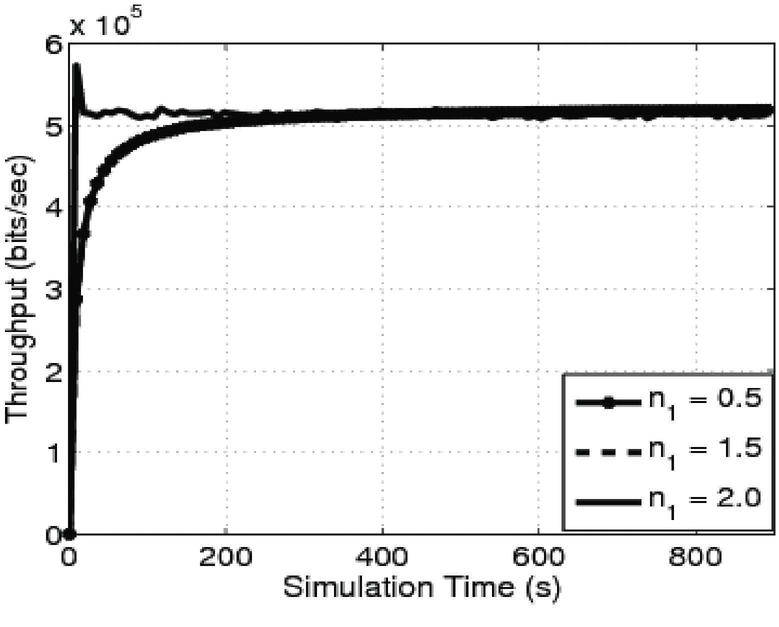

Figure 5.7: Throughput at carrier frequency, f_c = 5.3 GHz and path loss exponent, n_1 = 0.5, 1.5 and 2

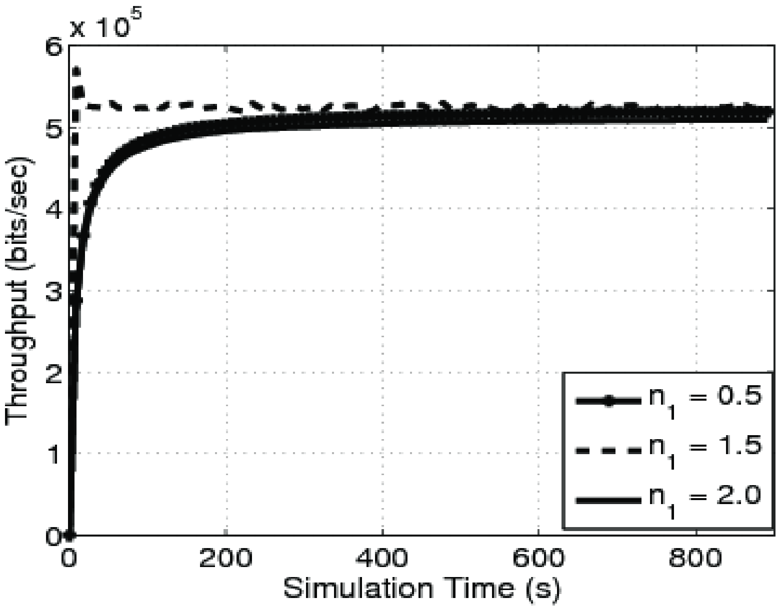

Figure 5.8: Throughput at carrier frequency, f_c = 2.4 GHz and path loss exponent, n_1 = 0.5, 1.5 and 2

5.5 Chapter Summary

This chapter describes a simulation study of the sensitivity of MANETs performance to wireless channel at microwave carrier frequencies greater than 2 GHz as well as the impact of wireless channel on the performance of the network. It was shown that at carrier frequencies greater than 2 GHz the break point distance affects the performance network. It is also shown that as the path loss exponent of the propagation model increases the received signal power at individual mobile nodes also increases. The path loss exponent has no effect on the throughput performance of the multi-hop wireless ad hoc networks. It therefore conclude that, MANETs can operate at higher frequency without having much effect on its quality of service and performance throughput as simulation analysis revealed. Building upon the work presented in this chapter, the next chapter, will choose an appropriate path loss with lowest received power to proposed a power model that can conserved power in the network.

Chapter 6

PROPOSED ADAPTIVE POWER ON DEMAND ROUTING PROTOCOL FOR MOBILE AD HOC WIRELESS NETWORK

6.1 Introduction

A Mobile Ad Hoc Network (MANET) is a collection of wireless mobile nodes dynamically forming a temporary network without the use of fixed networking infrastructure or centralized administration. However, power is consumed in this network due to frequent and unpredicted topology changes associated with the mobile nodes movements, as well as excessive utilization during network routing operations. Thus, a mobile node may cease to function as a result of power depletion. This problem consequently leads to mobile nodes dying early, which also results in mobile nodes not cooperating in routing operations and becoming critical mobile nodes, thus affecting the entire performance of the network as reported in the literature [111], [55], [112]. In [113, 114], critical mobile nodes were described as nodes that lack network resources such as power resources to carry out their network operation. On the other hand, critical mobile nodes are nodes participating in routing operations but may not be willing to use their computing and power resources to forward packets. They may be dropping packets instead of forwarding them to their respective neighboring nodes.

Different routing protocols have been proposed and can be classified either as reactive or proactive protocols [13]. Yuvaraju et. al in [111], [114], [113] and [115] reported that proactive routing protocols consume more power as compared to reactive routing protocols, which is due to a continuous periodic update of the proactive protocols. Routing protocols ensure the proper routing of packets from source to destination via intermediate nodes. The total power consumption and the received signal power strength depends on the distance between mobile nodes, signal path loss and the type of application running. Anderegg and Eidenbenz in [116], proposed an energy-efficient routing protocol called Ad Hoc-VCG protocol for detecting critical mobile nodes. This is to ensure that a packet from a source node to a destination node gets routed along the most energy-efficient path via intermediate nodes. The Ad Hoc-VCG protocol proposed by Anderegg and Eidenbenz works efficiently for networks where the communication session between mobile nodes does not change frequently (Static Network). Therefore, when considering the nature of MANETs, mobile nodes are free to move randomly and network topology keeps changing rapidly and unpredictably. Thus, this routing protocol is not suitable for practical applications in MANETs. However, there are two other techniques called WATCHDOG and PATHRATER proposed by Marti et al., in [117] for detecting critical mobile nodes within a network.

These techniques are incorporated in the reactive routing protocols in MANETs and the critical mobile nodes are recognized by listening to the next nodes to observe if the packets are forwarded. If not, the node is marked as a critical node after some time. However, the watchdog and pathrater techniques are detective rather than preventive techniques; they might not detect critical mobile nodes in the presence of limited power, network congestions and partial dropping of packets due to link or routing failure. Nie and Zhou in [118] proposed a model which detects critical nodes and forced them to cooperate. Forcing a mobile node with limited power resources to cooperate can affect other cooperative mobile nodes in the network.

Research carried out by Yuvaraju et. al., in [111] and Ramachandran et. al., in [115] showed that as network capacity increases, the total power consumption increases concurrently.This is because more routes are required to reach the destination, hence increasing the end-to-end delay. Therefore, to ensure the best routes with enough power are selected for packet transmission, there is a need for an adaptive power routing in the network, which can keep up the available power in the network up to date. In previous work of [41], they consider only DSR protocol without examining AODV protocol and an analytical approach to confirm the results. Other research conducted by [119] reported that the only way to reduce power consumption in radio communications is to shut them off and they use this observation to propose a power efficient MAC layer protocol which is suitable for use within one cell for communication between base station and the mobile nodes. However, the technique proposed can only work for the infrastructure wired network where mobility of mobile nodes is less. For this, the technique is not suitable for MANETs. [120], [121] reported that the Power Aware routing algorithm proposed which claims to maximize the network life by minimizing the power consumption during routing processes were incorporated to AODV protocol only and not tested on DSR protocol and assumed that the power consumption at idle state was 0.0 watt. While [122] observed that at idle state, power dissipation dominates the total power dissipation in an IEEE 802.11 network.

The research therefore motivated to propose power technique that can conserve power during the network routing operations. The proposed technique enables the mobile nodes to computes and conserves power adaptively by selecting the best route with enough power for proper transmission and reception of data packet.

6.1.1 Conventional AODV and DSR Packets Format

To improve the communication performances and reliability, traffic data sent between mobile nodes are subdivided into packets headers. The AODV and DSR protocol uses specific headers to carry information. The headers must be a multiple of 4 bytes. The DSR and AODV header format is given in Table 6.1.

Table 6.1: Conventional DSR headers

Next Header	Reserved	Payload	Options	Data
8 bits	8 bits	16 bits	0 bits	0 bits

The packets formats are defined as follows:

- **Next Header:** The size of the Next Header field is 8 bits. The Next Header field shows either the type of the first extension (if any extension header is available) or the protocol in the upper layer such as TCP, UDP.
- **Payload Length:** Specifies the length of the payload in bytes. The value of the Payload Length field defines the total length of all options carried in the AODV and DSR Options header, such as a route request option, and route reply option.

6.1.2 Conventional and Modified AODV and DSR Protocols

Routing protocol is responsible for routing packets from the Internet Protocol datagram between mobile nodes, and also verifies if the packet is coming from the upper layer or lower layer of the network protocol stack and makes a decision as to where to forward the packet. Figure 6.1 shows the network protocol stack model with a network layer configured with conventional AODV and DSR routing protocols; Internet Protocol (IP) is

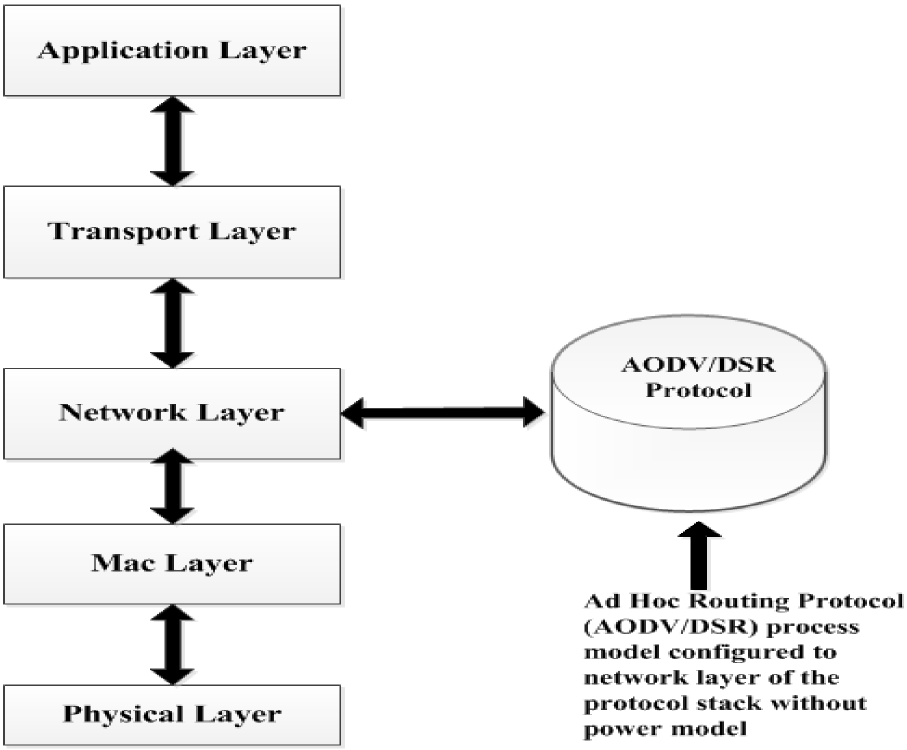

Figure 6.1: Coventional Network Protocol Stack configured with either AODV or DSR Protocol.

the root process for the network layer, and has as a child process. Sheetalkumar et. al., in [114] gave the modification cost for existing DSR protocol. The authors considered the minimum route maintenance energy, which involved the modification of routing software without considering the proper modification of AODV and DSR routing algorithm and transmits power control. Hence, this modification has not been applied to existing versions of the AODV and radio hardware of DSR protocol to achieve an optimized quality of service. This chapter describes the modification of AODV and DSR routing algorithm and power control as shown in figure 6.2.

6.2 Proposed Adaptive Power On demand Routing Protocol

While considering the MANET's applications, it is important for the existing routing algorithm to be modified to specifically accommodate power model for better routing in the

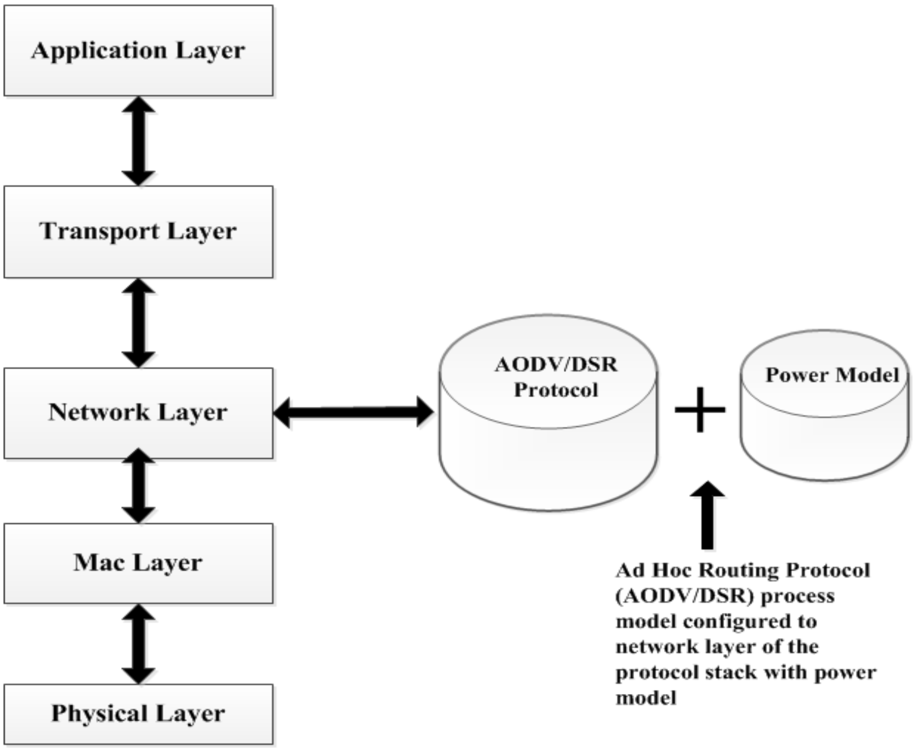

Figure 6.2: Modified Network Protocol Stack configured with Power Model.

network. The proposed model can be used on any of the reactive routing protocols. For this research, AODV and DSR protocols were chosen to incorporate the power model into the routing protocols. The setback to power management in MANETs communications is the choice of transmit power, as the transmitted power level determines the quality of the received signal. Most of the power is consumed during the network routing processes. The idea behind power conservation routing is to avoid unnecessary waste of packets as well as power consumption that can make nodes die very early, which can lead to poor network performance. At the network layer, the power decision algorithm was incorporated into the routing protocol's algorithm to ensure the routes with sufficient power are selected.

6.2.1 System and Propagation Model

This section describes the system model and outlines basic assumptions used for the analysis. The radio environment is characterized by: (1) path loss, (2) shadowing and (3) multipath fading. In this work, only path loss is considered as we assume a scenario in which an efficient antenna diversity-combining system is employed at the transmitting nodes to eliminate the effects of multipath fading. Path loss occurs due to the decay of the intensity of a propagating radio-wave and it requires an accurate estimation for proper determination of the electric field strength, signal-to-noise ratio, carrier-to-interference ratio, etc [108]. Therefore, this analysis considers only the free space path loss model, because other models, such as Okumura-Hata, COST 231-Hata, Walfish-Ikegami, COST 231-Walfish-Ikegami and Ercegs used for predicting path loss in mobile wireless systems are designed to operate in the frequency band from 100 MHz to 2000 MHz [123–127].

6.2.2 Free Space Path Loss

Assuming no obstruction exists between a transmitter and the receiver, signals will be transmitted through free space to the receiver located at a distance *d*[m] as shown in Figure 1.6. The free space path loss model used in this analysis is given by [105] as

$$P_d = P_t G_{Tx} G_{Rx} \left(\frac{\lambda}{4\pi d} \right)^2 \tag{6.1}$$

where P_d [W] is the mean received signal power,P_t [W] are the transmitted signal power, G_{Tx} and G_{Rx} is the transmitter and receiver antenna gains and λ is the carrier wavelength. The received signal power P_{Rx}, can be written as

$$P_{Rx} = P_{tx} \times G_{Tx} \times G_{Rx} \times P_d \tag{6.2}$$

where P_{tx}, is the transmitted signal power. However, due to frequent topology changes associated with movements of mobile nodes in the network, the transmitted power level for each mobile node is not the same. Therefore, in this technique, the minimum transmitted and received power Min_{tx}, Min_{rx} level was computed as shown in (6.3) and (6.4) for successful transmission and reception of data/control packets.

$$Min_{tx} = P_{tx} \times \beta_0 \times \eta_0 \times G_{Tx} \times G_{Rx} \tag{6.3}$$

$$Min_{rx} = P_{Rx} \times \beta_0 \times \eta_0 \times G_{Tx} \times G_{Rx} \tag{6.4}$$

where β_0 is the signal to noise ratio, η_0 is ambient noise level strength.

6.2.3 Conventional AODV and DSR Packet Format with Power model

This section describes changes made to the conventional AODV and DSR packet format. Four power values were added, which includes transmitted power level, received power level, minimum transmitted power level and minimum received power level as shown in Table 6.2. To ensure successful transmission and reception of data packets, the minimum transmitted and minimum received power levels are required. These power values are made available to the network layer configured with either AODV or DSR protocol.

Table 6.2: Modified DSR Packet Format

Header	Reserved	Payload	Options	Data
(8 bits)	(8 bits)	(16 bits)	(0 bits)	(0 bits)
Rx Power (W) 8 bit	Tx Power (W) 8 bit	Min Tx Power (W) 8 bit	Min Rx Power (W) 8 bit	

6.3 APRP Algorithm Implementation

The power metrics were declared in the C-code source of the wireless LAN pipeline stage at the MAC layer. This was done so that the parameters will be recognized by the functions in the source. The function block in the AODV/DSR route will get the power values during the routing processes in the MANET transactions in order to evaluate the codes of the scheme designed. During the network simulation time, a source node that does not have a route to the destination. When it has data packets to be sent to that destination, it initiates a RouteRequest packet. This RouteRequest is flooded throughout the network. Each node, upon receiving a RouteRequest packet, rebroadcasts the packet to its neighbors if it has not forwarded it already, provided that the node is not the destination node and that the packets time to live (TTL) counter has not been exceeded. All the these processes is done only if the condition of line 5 of the APRP's algorithm 6.3 is satisfied. This is very important because the nodes will make their decisions concerning their participation in transmission at this stage as well as to avoid mobile node(s) that are not power enough

```
1:  procedure Algorithm(                                  ▷ )Pconser Algorithm
2:      Time = Simulation time
3:      while $Time <= Simulationtime$ do
4:          Is there a valid route(s) ? and
5:          if ($P_{Tx} >= Min_{tx}) OR (P_{Rx} >= Min_{Rx}$) then
6:          transmit data $\leftarrow yes$
7:          else
8:          Initiate Route Request Process
9:          Is there a link failure or No alternative route(s) ?
10:         if yes then
11:         Perform line 8 and goto line 4
12:         else
13:         Successful data reception
```

Table 6.3: APRP's algorithm

to carry out the routing operation. The process continues till the end of the simulation time.

6.4 Simulation Model

OPNET Modeller (version 17.1), developed by OPNET Technologies, is used for all the simulations experiments [128]. Details about the experimental model are presented in the rest of this section.

6.4.1 Simulation Parameters

In order to validate the proposed power conserving model, extensive simulations experiments were carried out. Power expended by a network configured with either AODV or DSR protocol with and without power model were compared. The simulation time was 3600 seconds real time. Each simulation scenario was repeated six (6) times, which enabled the simulation to converge for an accurate result. The basic parameters used for the simulations experiment are summarized in Table 6.4.

Table 6.4: Simulation Parameters

Parameters	Values
Channel Type	Wireless Channel
Physical Characteristics	802.11g
Data Rate	2.0 Mbs
Topology	700 m X 500 m
Routing Protocols	AODV, DSR
Number of Nodes	80
Transmit Power	0.1 W
Packet Size	4096 bits
Mobility Model	Random Way Point
Simulator	OPNET 17.1 version
Simulation Time	3600 sec
Traffic Source	CBR
Speed	0 - 20 m/sec
Ambient noise level	1.0E-26
Number of trial	Six (6)
Packet Inter-arrival time	0.5 seconds

6.4.2 Performance Metrics

The following performance metrics were used to compare the performance of network with proposed power model as well as conventional network.

- **Throughput:** represents the total number of successful packets in (bits/sec) received from all mobile nodes of the network.
- **Delay:** represents the end-to-end delay of all the packets received by the wireless LAN of the mobile nodes in the entire network.
- **Power Loss (Nano-watt):** this measures how much power is lost during network routing operation over each period of time.

6.5 Results and Discussion

The goal of the evaluation is to show the effectiveness of the proposed technique. The performance evaluation was studied at every 500 real seconds of time for the entire network, not on an individual mobile node basis. The power model is incorporated into the

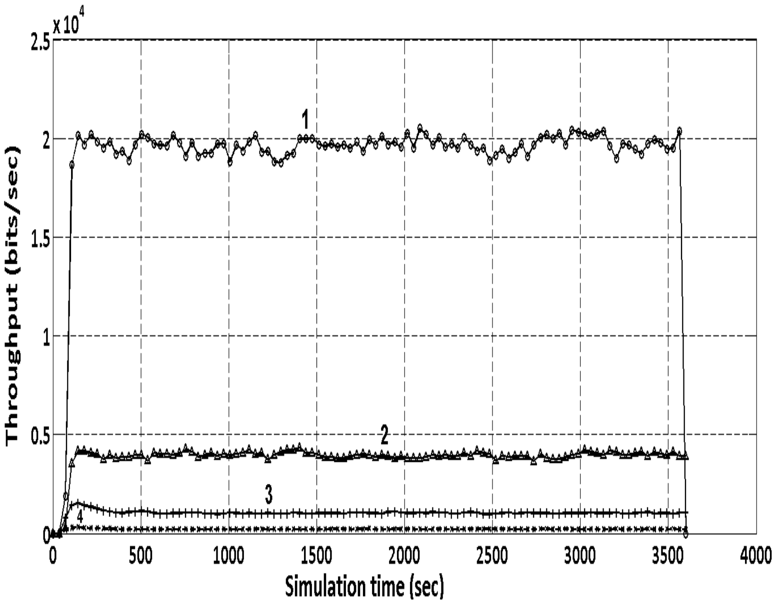

Figure 6.3: Throughput comparison with and without the power model for the two networks configured with AODV and DSR protocols.

1. Throughput of AODV-Network configured with power model
2. Throughput of AODV-Network configured without power model
3. Throughput of DSR-Network configured with power model
4. Throughput of DSR-Network configured without power model

route request packet for the two protocols i.e AODV and DSR protocols.

In figure 6.3, the throughput performance with and without the ARPR power model with DSR protocol was compared. At the beginning of the simulation, the network with power model delivered up to 1550 bits of packets successfully, compared to the conventional network which delivered on average 500 bits of packets. The initial rise of throughput by the network is due to a route discovery process initiated by the DSR protocol. But when the network stabilized, the throughput performance dropped to an average of 1000 bits, compared to the conventional network of 200 bits, and remains stable for the entire simulation time. The significant differences between the traditional and modified DSR protocol is that the delivery of the packets depends on the stated power condition. If the condition becomes true, then the packets will be delivered. However, the conventional DSR will continue to operate whether the condition is met or not. Therefore, packets will

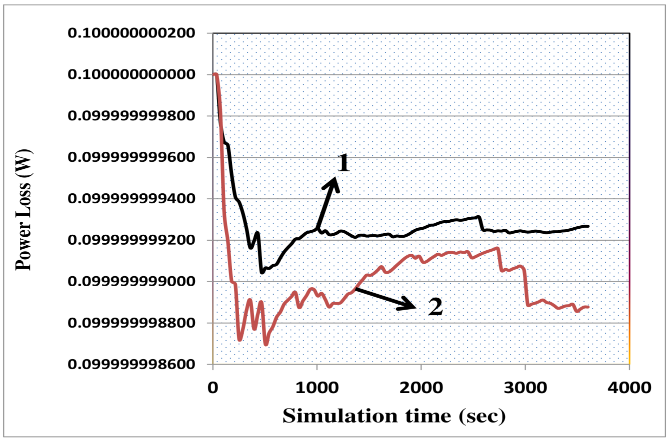

Figure 6.4: Power Loss comparison with and without the power model for DSR protocol performance measure.

1. Power Loss, DSR-Network configured with power model
2. Power Loss, DSR-Network configured without power model

be dropped due to the inefficiency of the power resource of the mobile node to convey the packets to the desired destination. Also in figure 6.3 shows the performance of a network configured with AODV protocol with and without the power model. The network with power model delivered an average throughput of 20000 bits for the entire simulation time, compared to the traditional network which delivered an average of about 5000 bits for the entire simulation time as well. As described earlier, the margin of difference is attributed to the work of the power model employed to the routing protocol. However, compared to the network with DSR protocol's performance, network with AODV protocol outperformed the network with DSR and this is due to the fact that only the stable route(s) are used by the AODV forwarding algorithm for routing the packets. Figure 6.4 shows the power saved in the network at every 500 seconds. It can be seen that, the proposed power model reduces power consumption by almost 50% for the entire simulation time, compared to the network with the traditional DSR protocol. The reason for this saving is that the best routes with enough power are computed adaptively and selected for transmission and reception. As compared to the normal operation of the network with the conventional

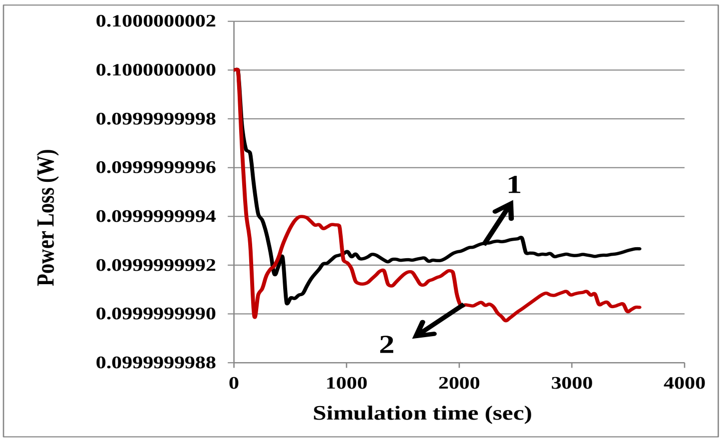

Figure 6.5: Power Loss comparison with and without the power model for AODV protocol performance measure.

1. Power Loss, AODV-Network configured with power model
2. Power Loss, AODV-Network configured without power model

DSR protocol whereby mobile nodes participate in the routing operations whether they are capable or not. Therefore, the ones that are not capable will eventually drop the packet and power is wasted in the course of transmitting the packets. However, Figure 6.5 compared the performance of the network configured with AODV protocol with and without the power model. The simulation results showed that network with power model reduces power consumption by 48% for the entire simulation time as well. As described earlier, the margin of difference is attributed to the work of the power model employed to the protocol. Generally, the network configured with AODV protocol outperformed the network with DSR protocol and this is due to the fact that only the stable route(s) are used by the AODV forwarding algorithm for routing the packets.

Figure 6.6 shows the delay for the network with DSR protocol with and without the power model. At the start of the simulation, the network experienced a huge delay of an average of about 70 seconds for the two networks, and this is due to the initial stage of route discovery processes of the routing protocol. However, as the network stabilized, the delay dropped to 50 seconds for the network with the power model and remained stable

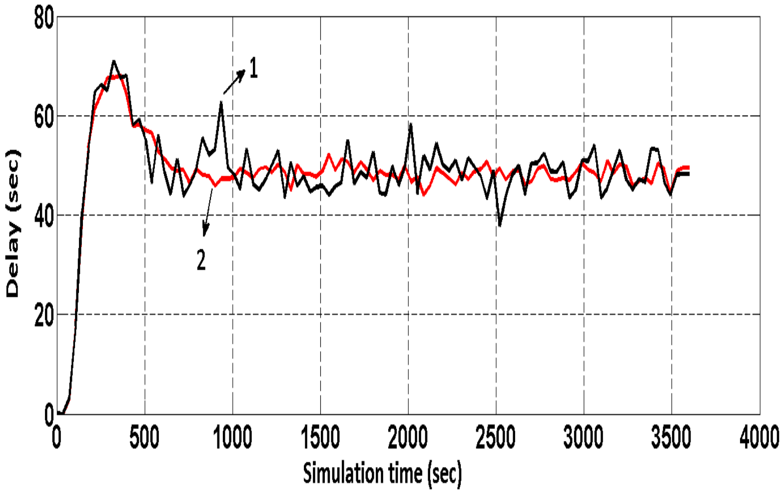

Figure 6.6: Delay comparison with and without the power model for DSR protocol performance measure.

1. Delay DSR-Network configured without power model
2. Delay DSR-Network configured with power model

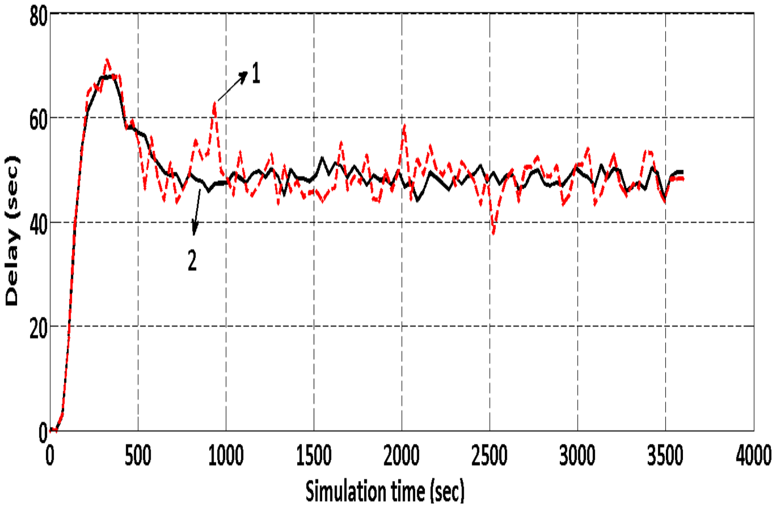

Figure 6.7: Delay comparison with and without the power model for AODV protocol performance measure.

1. Delay AODV-Network configured without power model
2. Delay AODV-Network configured with power model

for the entire simulation time, compared to 55 seconds delay with conventional network. The results further shows that, there was frequent link failure in the network which causes the protocol to initiate fresh route request operation and leads to high delay in the network. Also in Figure 6.7, less delay was observed in the network using AODV protocol. From the delay curves, the network with the power model recorded less delay as compared to the network without the power model. In comparison with the network with DSR protocol, the network with AODV protocol recorded a delay almost two and a half (2 1/2) times less than the network with DSR protocol.

In general, based on the simulation results, the proposed model has no effect on quality of service looking at the less delay recorded for different network scenarios as well as performance throughput of the network.

6.6 Chapter Summary

In this chapter, an adaptive approach was used to develop model for calculating power metrics in MANETs. It has been shown that network configured with the proposed power model conserved more power than the conventional network with no delay effect in the network.

The technique is based on the modification of the conventional on-demand routing protocols with the addition of power model in the routing protocol. The greater most part of this chapter is that, the mobile node(s) conserves power adaptively and enhances throughput whereby mobile nodes send out a route request, as well as data packets, if they have enough power to carry out the routing operations. This is achieved by comparing the proposed model with the conventional model via computer simulations. The proposed model is incorporated into the Ad Hoc On demand Distance Vector (AODV) and Dynamic Source Routing (DSR) protocols. The results showed that power savings of 50% were achieved with no delay effect in the network and increased in throughput by 60%, as compared to conventional networks. Therefore, the next chapter will look at the other factors that contributes to the power consumption in the network as power consumption metrics of a mobile host in an ad hoc mode are dependent upon the transmission power. The evaluation of these metrics will take into consideration such things as how transmit power is utilized during communications among the nodes. Attempts have been made towards introducing some possible quantities of power consumption and structuring them around the transmit power in order to obtain a better evaluation of power usage in MANET.

Chapter 7

COMPUTATIONAL POWER CONSERVATION TECHNIQUE USING MOBILITY ADAPTATION METHOD IN MANET

7.1 Introduction

Mobile devices depend on batteries for power supply and since battery power is limited, power conservation depicts one of the utmost issues in designing routing algorithms for mobile devices [129]. Several works carried out in battery technology show that only slight improvement in the battery life is expected in the near future [130]. So, it is essential that, power management should be optimized efficiently by identifying different mediums to reduce the usage of power without affecting the efficiency of the network. Limitations on battery life and the extra power requirements for assisting network operations such as transmission or reception in each mobile node in MANET makes the issue of power management one of the main concerns in ad hoc networking. Power management techniques have been proposed at several levels of a mobile device including the physical layer transmissions, as well as the operating system [131].

Takeuchi et al., in [132], observed from their work that power is wasted when wireless interfaces are in idle state, and hence concluded that due to the fact that the interfaces remain in the ideal state for a long period of time, turning off the interfaces radio while not in use would reduce power consumption in the network. An experiment carried out by Zheng and Kravets in [133] has shown that the consumption of power in wireless ad hoc is marginally lower than that consumed in transmitting and receiving state. They also proposed an extensible on demand power management framework for ad hoc networks that adapts to traffic load. Each mobile node keeps soft state timers that observe routing control and data transmission to decide power management transitions. This process enables nodes to go off temporarily as supported by the MAC protocol. A prototype of the specified framework is then incorporated into the conventional IEEE 802.11 MAC protocol. Simulation results showed that using the power management framework reduces power consumption to about half the rate at which mobile nodes without power management framework would consume. The power management framework integrates power management capabilities from MAC layer and also routing information from the ad hoc routing protocols. Arulanandam and Parthasarathy in [134] proposed a power conservation scheme to reduce idle power consumption. The functionality of this scheme is not dependent on the design and operation of routing protocol. Simulation results show that energy consumption patterns between these two algorithms seem very close. DSR performs slightly better than AODV in cases where high mobility conditions are present.

In order to derive the utilization of mobile nodes between the algorithms, the standard deviation of remaining power on the nodes after utilization was measured. A lower standard deviation leads to a more balanced node utilization. From the comparisons made on the two algorithms based on their node utilization, AODV show a slightly more balanced utilization than the DSR. Arulanandam and Parthasarathy in [134] concluded that DSR algorithm provides the most reliable combination of power conservation performance and data delivery performance. However, power conservation and control have become paramount issues that receive greater attention in recent times [57]. The IEEE 802.11 power control mechanism is the basic platform most widely deployed when it comes to wireless networks power conservation protocols development [58], [57], [60], [24]. But empirical information concerning the power consumption behaviour of well-known wireless network interfaces is not available [60], [24] and vendor device specifications do not provide enough information in a form that may be helpful to protocol developers. Therefore, power control design and evaluation of network protocols demand the knowledge of power consumption characteristics of actual wireless interfaces [60], [57]. Most research on power conservation schemes has targeted wireless networks that are structured around base stations and centralized servers [24] which do not have the limitations associated with small, portable devices. By contrast, MANETs, as explained earlier do not operate with the services of such fixed network cabling infrastructure [24]. Therefore, it is cumbersome as well as challenging to design and develop power control strategies in an ad hoc fashion [135]. Some researchers have conducted practical experiments on the actual wireless devices [73], for instance, Laptop, PDA, etc. measuring the consumed power in a real time environment, which serves as an experimental reference for this design. Literature [60], [57] and [24] are some of these works. Power conservation in MANET, as a challenge is receiving the first and foremost responses because every other activity of the network depends on the ability of the network to maintain live connectivity, which is an exclusive role of the power source. Therefore, in this chapter, a power conservation technique is proposed for MANETs that computes power less costly in terms of computation and conserves adaptively for proper transmission and reception of data packet.

7.2 Proposed Power Conservation Techniques

While considering the MANET's applications, it is important to modify the existing routing algorithm to specifically conserve power adaptively. The proposed model can be used on any of the on-demand routing algorithms.

7.2.1 Description of the Power Conservation Model

The setback to power management in ad hoc mobile communications is choice of transmit power. Most of the research work was done in trying to establish the transmitted power of the mobile devices. For instance, the actual amount of power allotted to the transceiver of the mobile device is not actually included in vendor specification, and such a parameter is very important when it comes to protocol development and enhancement. The impact of transmission power on power reduction for mobile devices that depend on battery power such as those in ad hoc mode is paramount. The typical transmission power of the CISCO Aironet 340 Access Point that utilizes power generating meter is in the range of -10 dBm (0.1 mW) to +30 dBm (1 W) is 32mW (15dBm) [80], [136]. This is the wireless LAN transmission power in laptops. However, that for typical cellular phone transmission power (Power Class 2 Mobiles) is 500mW (27dBm). Therefore, in this research work, the simulation set up is modelled with laptops as the mobile nodes, and the transmit power is implemented accordingly using the value of 32mW. The IEEE802.11 standard's power control management support power utilization in two modes: (1) Continuous Aware Mode and (2) Power Save Polling Mode. It is shown that IEEE 802.1b in an idle network interface has a power consumption of 800mW. This is comparable to the power consumed while receiving or transmitting (l000mW-1300mW respectively). However, in the sleeping mode case, the power consumption is (66mW-30mW). These values can vary depending on manufacturer and model, so they are only representative. Researchers have explored this doze mode in order to extend the lifetime of networks in MANET. Among the literature that used this mechanism as a basis for their research are [58], [60] and [135]. The scheme designed is to enable the mobile nodes to avoid power drainage by maintaining a certain level of power in all possible routes.

7.2.2 System and Propagation Model

This section describes the system model and outlines basic assumptions used for the analysis. The radio environment is characterized by: (1) path loss, (2) shadowing and (3) multipath fading. In this work, only path loss is considered as we assume a scenario in which an efficient antenna diversity-combining system is employed at the transmitting mobile nodes to eliminate the effects of multipath fading. Path loss occurs due to the decay of the intensity of a propagating radio-wave and it requires an accurate estimation for proper determination of the electric field strength, signal-to-noise ratio, carrier-to-interference ratio, etc [108]. This work considers only the free space path loss model, because other models, such as Okumura-Hata, COST 231-Hata, Walfish-Ikegami, COST 231-Walfish-Ikegami and Erceg used for predicting path loss in mobile wireless systems are designed to operate in the frequency band from 100 MHz to 2000 MHz [123–127]. Also assumed that no obstruction exists between a transmitter and a receiver, signals is transmitted through free space to the receiver located at a distance *d*[m]. The free space path loss model used in this analysis is given by [105] as

$$P_d = P_t G_{Tx} G_{rx} \left(\frac{\lambda}{4\pi d} \right)^2 \tag{7.1}$$

where P_d [W] is the path loss in a free space, P_t [W] are the transmitted signal power, G_{tx} and G_{rx} is the transmitter and receiver antenna gains and λ is the carrier wavelength. From [102], the received signal power P$_{rx}$, can be written as

$$P_{rx} = P_{tx} \times G_{tx} \times G_{rx} \times P_d \tag{7.2}$$

7.2.3 Establishing Relationship among the metrics

To ensure that no single mobile node is overused, the relationship among these metrics as a function is structured around how much power is incurred by any mobile node at a given time. Therefore, the power consumed P_c [W], as a function of idle power consumption, number of packets received and receive power is designed to be able to give account of extent of usage of power at a given time in a network as shown in equ. 7.3

$$Power_{consumed} = dP_{tx}/dt_{Ti} + n \times P_{rx} \tag{7.3}$$

```
 1: procedure Algorithm(                         ▷ )Pconser Algorithm
 2:     Time = Simulation time
 3:     while $Time <= Simulationtime$ do
 4:         Idle mode
 5:         Compute power
 6:         Mobile node has packet to be routed
 7:         Initiate Routing processes
 8:         if (($P_c <= SPL_w$) then
 9:         if yes
10:         Send Packets
11:         else
12:         Go to line 4
13:         Perform line 5
```

Figure 7.1: Power Conservation algorithm.

where dP_{tx} [W] is power consumption at idle mode, and n is the total number of packets a node received at a given time.

7.2.4 Algorithm Development

The algorithm design and development aimed to incorporate the transmitted power consumption function in such a manner that mobile nodes are able to evaluate their power status to decide if they are fit for packet forwarding and reception. These values are to be shared between the physical layer, Mac layer and Network layer. The Physical layer, wireless mac layer, sends the adaptive power values to the network routing layer, where it is stored and used for routing decision making process as shown in fig. 7.2. Therefore, for successful transmission and reception of data packets the remaining power in the mobile nodes must be less than or equal to the sustainable power as shown in equ. 7.4.

$$Sustainable_{powerlevel} = P_{tx} - T_p \tag{7.4}$$

Where T_p [W] is the threshold power

7.2.5 Quantifying the Metrics

Since this scheme tries to enable the nodes to avoid power drainage by maintaining a certain level of power in all possible routes, the values which will be assigned to these quantities will reflect the objective of fair and controlled usage of power in order that nodes will continue to maintain the network for a longer period of time.

1. Transmit Power: The quantity of this metric has been established by research made in section 7.2.1 which is 0.032W.
2. Idle Power Consumption: This quantity was assigned as a percentage of the transmit power, using the power usage at idle mode obtained in [137]. The value is taken to be 5% of the transmit power: Idle$_{power} = 5\% of P_{tx}$
3. Threshold Power: The value of this parameter considers the residual power, after hectic network participation, needed to ensure nodes connectivity till the end of a network scenario. The value is given as: T$_p = 20\% of P_{tx}$
4. Received Power: This value has a default formula set in the OPNET Modeller software. Although it is actually modifiable in the source codes, it will be deduced from the graphical result representation for the final computation.
5. Number of Received Packets: This will also be determined from result.

7.2.6 The Flow Chat of the Algorithm

The flow chart depicts the steps involved in the algorithm pseudo code in a diagrammatic representation, and gives a pictorial under-standing of the algorithm. At the beginning of the network operation, the communicating mobile node initiate and compute the power quantities needed to participate in the routing operations. The mobile node evaluates control statement. If the statement is true then, the mobile node will participate in the routing operation and send the packets to the desired destination else the mobile node re-compute the power values again. The process continues till end of simulation time. This is very important because the nodes will make their decisions concerning their participation in transmission at this stage and help to avoid power drainage by maintaining a certain level of power in all possible routes in the network. The C++ -code was generated from the scheme which comprises of power metrics with their associated relationships, and the implementation was done in a cross-layer interaction between the MAC and the network

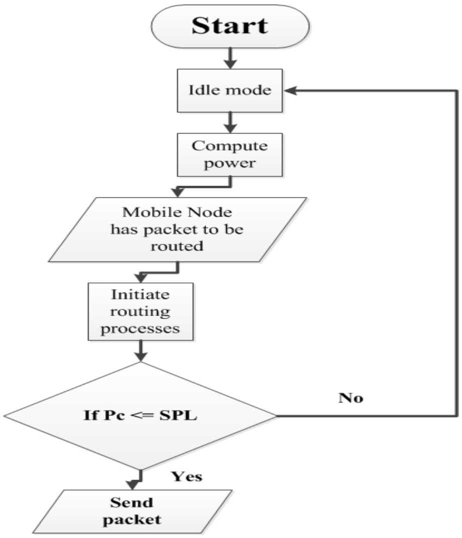

Figure 7.2: Flow chart of Power conservation Algorithm

layers. However, the power quantities needed by the mobile nodes for routing decisions were updated in the AODV and DSR packet header and the routing protocol will recognize the packets and evaluate the control statements of the inherent algorithms. The function block in the AODV and DSR route(s) will get the power values during the routing processes in the MANET transactions in order to evaluate the codes of the scheme designed.

7.3 SIMULATION MODEL

OPNET Modeller (version 17.1), developed by OPNET Technologies, is used for all simulations [138]. Details about the simulation model and environment are presented in the rest of this section.

7.3.1 Simulation Parameters

In order to validate the proposed power model, extensive simulations are conducted where the power expended by a network configured with either AODV or DSR protocol with and without the power model was compared (shown in appendix [A and B]). The simulation

Table 7.1: Simulation Parameters

Parameters	Values
Channel Type	Wireless Channel
Physical Characteristics	802.11n
Data Rate	6.5 Mbs
Topology	100 m X 100 m
Routing Protocols	AODV, DSR
Number of Nodes	18
Transmit Power	0.032 watt
Packet Size	4096 bits
Mobility Model	Random Way Point
Simulator	OPNET 17.1 version
Simulation Time	500 sec
Traffic Source	CBR
Speed	0 - 20 m/sec
Number of trial	Six (6)
Packet Inter-arrival time	0.25 seconds

time is 500 seconds real time. Each simulation scenario was repeated 6 times, which enabled the simulation to converge for an accurate result. The basic parameters used for the simulations are summarized in Table 7.1.

7.4 RESULTS AND DISCUSSION

The goal of the evaluation is to show the effectiveness of the proposed power saving model. The performance evaluation was studied at every 100 real seconds of time for the entire network simulation time as shown in appendix [A and B] , not on an individual mobile node basis. The power model is incorporated into the two on demand routing protocols algorithms i.e AODV and DSR protocols. In figure 7.3, it is easy to see that the proposed power model reduces power consumption by more than 15% for the entire simulation time, compared to the network with the traditional network configured with either AODV or DSR protocol. The algorithm did not allow the mobile nodes to experience a surge in power dissipation as can be seen in Figure 7.3.

The algorithm maintained a steady control of power with crests of minimal power upsurge. However, in this model, the mobile nodes have been enhanced to refer to their

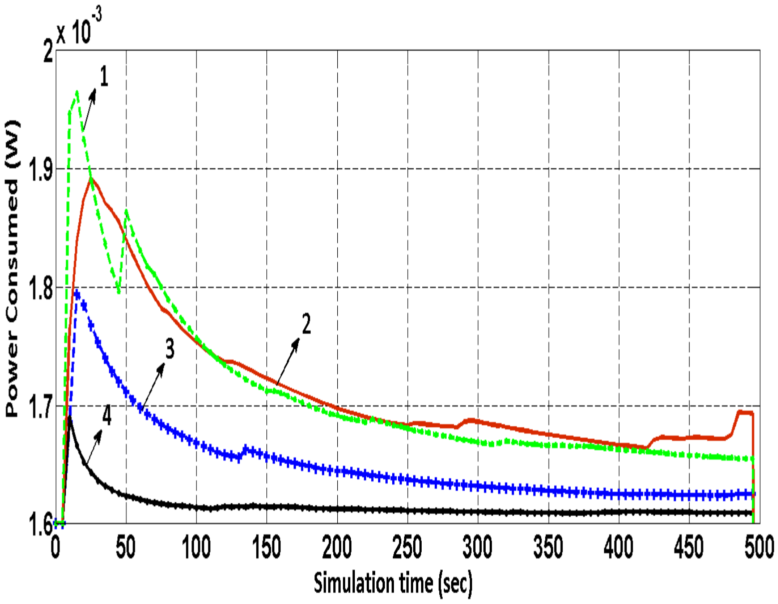

Figure 7.3: Power consumed comparison with and without the power model for the network configured with AODV and DSR protocols performance measure

1. Power consumed AODV-Network configured with power model
2. Power consumed AODV-Network configured without power model
3. Power consumed DSR-Network configured without power model
4. Power consumed DSR-Network configured with power model

residual power in order to make a decision concerning their participation in packet forwarding transactions. Therefore, they make sure that they have enough power prior to packet reception. This quantity (power consumed) was computed, implemented and measured to verify the actual amount of power consumed by mobile nodes during the entire network duration. Comparison was made for the two scenarios to give a clearer knowledge of the performance difference. The power consumed was calculated using equ. 7.3.

However, power was conserved at the expense of the throughput. The throughput was negatively affected by the proposed model as the throughput with the power model fell drastically as shown in Figure 7.4.

As the algorithms repeat the routing search until the route(s) that satisfied the conditions, then the packet is routed to the desired destination(s) which can lead to the time

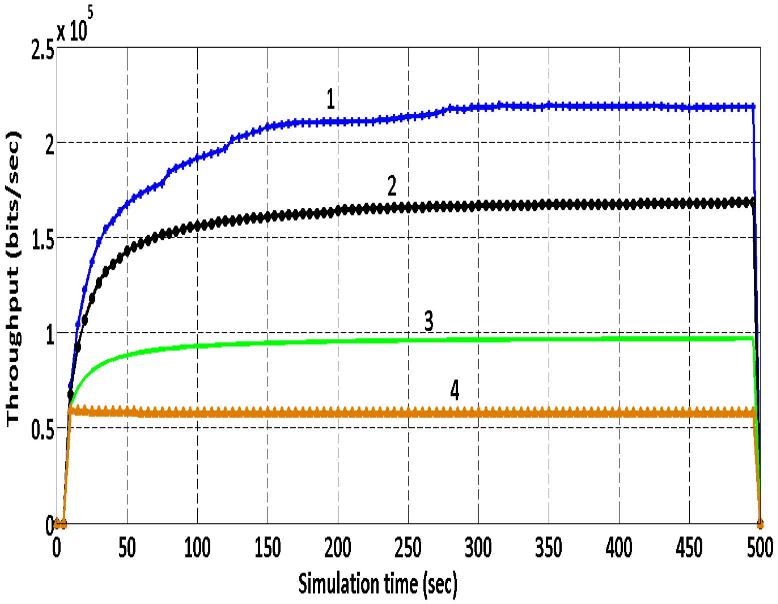

Figure 7.4: Throughput comparison with and without the power model for the network configured with AODV and DSR protocols performance measure

1. Throughput AODV-Network configured without power model
2. Throughput AODV-Network configured with power model
3. Throughput DSR-Network configured with power model
4. Throughput DSR-Network configured without power model

to live (TTL) of the routing protocols expiration. For that packet will be dropped and consequently effect the throughput performance of the network as shown in Figure 7.4. At the beginning of the simulation, the scenario without power model delivered more than 200000 bits and 150000 of bits per second with the power model, all configured with AODV protocol, compared to the other network scenario without power model delivered less than 100000 bits of data per second and more than 50000 bits with the scheme incorporated all configured with DSR protocol. The initial rise of throughput for all the scenarios is due to a route discovery process initiated by the routing protocols. The significant differences between the modified and unmodified network is that the delivery of packets to the desired destination depends on the stated power model condition.

However, the traditional network configured with AODV and DSR protocols will

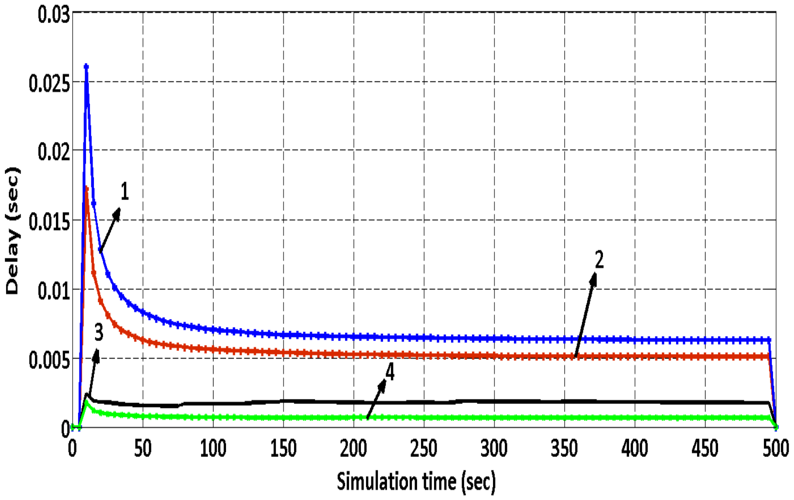

Figure 7.5: Delay comparison with and without the power model for the network configured with AODV and DSR protocols performance measure.

1. Delay DSR-Network configured without power model
2. Delay DSR-Network configured with power model
3. Delay AODV-Network configured without power model
4. Delay AODV-Network configured with power model

continue to operate conventionally whether the condition is met or not and so packets will be dropped due to the inefficiency of the power resource of the mobile node to convey the packets to the desired destination. Therefore, the network configured with AODV protocol outperformed the network configured with DSR protocol and this is due to the fact that only the stable route(s) are used by the AODV forwarding algorithm for routing the packets.

Figure 7.5 shows the delay curves for the network with and without the power model. At the start of the simulation, the network configured with AODV protocol experienced a huge delay of an average of about 0.026 seconds without the power model and 0.017 seconds with power model. Meanwhile, the other network scenario configured with DSR protocol experienced a little delay of about of 0.0035 seconds without power model and 0.002 seconds with the power model. However, the initial rise in delay is due to the initial stage of route discovery processes of the routing protocols. But the proposed power model does not have much of an effect on the performance scenarios with power model as shown in fig. 7.5. However, less delay was observed in the network scenario configured with DSR protocol with least delay recorded with the power model. From the delay curves, the network using AODV protocol with the power model recorded less delay compared to the network with AODV without the power model. All these margin differences are attributed to the differences in routing operations of the routing protocols.

7.5 Chapter Summary

In this chapter, a new technique is developed for conserving power in MANETs. The power model is based on the existing on-demand ad hoc routing protocols with the addition of power model. The unique feature of the technique is that mobile nodes are be able to evaluate their power status to decide if they are fit for packet forwarding and reception. The research illustrates the power conserving behavior of the new model using computational approach supported by computer simulations over mobile ad hoc wireless network containing 18 mobile nodes. The proposed model is incorporated into the Ad Hoc On demand Distance Vector (AODV) and Dynamic Source Routing (DSR) protocols. The results showed that using power saving technique reduces power consumption more than 15% rate at which mobile nodes achieved with no much delay in the network as compared to the conventional network configured with AODV and DSR routing protocols. To derive the utilization of the mobile nodes in the network, standard deviation of the network performance metric after utilization was measured. The comparison, shows that a lower standard deviation leads to a more balanced mobile node utilization in the network.

Chapter 8

CONCLUSION AND FUTURE WORK

8.1 Conclusions

The power conservation in MANET has emerged as one of the promising quality of service solutions for future next generation wireless networking systems. This research commenced with a historical review of the existence of mobile ad hoc networking as well as the technical challenges affecting the performance of the network. More specifically, the history of power conservation was presented in the literature. Furthermore, an overview of the advances in power techniques was provided, where some of the associated contributions found in the literature were outlined and acknowledged.

The state of the art review of power conservation as well as impact of traffic and mobility models further discussed the specific limitations of existing techniques designed for MANET's systems. More specifically, this research investigates the MANET's vulnerability due to its fundamental characteristics of open wireless medium, constantly changing network topology, distributed and cooperative communication and inherently constrained power capabilities, which manifest in the exhaustible sources of power. The research describes some of these technical challenges that affect the MANET's performance and proposed techniques to solving them, with a special emphasis on power conservation. Explicitly, most of the proposed power reduction schemes presented in past literature are too complex to implement in MANET. However, these challenging difficulties overcome with the advent of the proposed power conservation technique, resulting in attractive and efficient solutions to the above mentioned vulnerabilities.

In view of the significance importance of MANETs in wireless communications system, in Chapter 3, simulations was carried out to evaluate the impact of traffic models. Despite criticism and assumption from various research on TCP's weaknesses on MANET, the simulated results shows that TCP traffic model can be used for small networks where frequent topology changes are limited and could be controlled by DSR routing protocol. It is believed that most packets dropped are due to high delay, time-to-live (TTL) of the routing protocol and end of simulation time.

From Chapter 4, performance analysis of network configured with AODV and DSR protocols in the presence of multiple access interference was carried out. As interference, high mobility, and high noise level degrades the performance of MANET but this effects was overcome by adaptively setting the received signal threshold from range of levels in accordance with speed of nodes and topology of its operating environment.

In Chapter 5, it was concluded that at carrier frequencies greater than 2 GHz the break point distance affects the performance network. Also, as the path loss exponent of the propagation model increases, the received signal power at individual mobile nodes also increases. The path loss exponent has no effect on the end-to-end throughput of the multi-hop wireless ad hoc networks.

In Chapter 6 and 7, based on the conclusion from previous chapters, the research looked at the case of power conservation in MANETs. The research proposed an adaptive power conservation technique for MANETs that computes and conserves power by evaluating the mobile nodes power status to decide if they are fit for packet reception and forwarding. It was computed, implemented and measured the performance of this scheme and showed that more than 15% of the power was conserved. The unique aspect of the proposed scheme is that it achieves these power savings without experiencing huge delay as compared to the conventional network configured with AODV and DSR routing protocols. This leads to the conclusion that using the proposed power model algorithm to establish the routing processes saved mobile nodes from dying as a result of power depletion during the network routing operation. The proposed technique performs better in terms of power saving, delay reduction as compared to work in [113, 115, 139], despite the fact that they have used different simulation parameters as well as routing protocols. However, [139] agreed that their techniques were extremely expensive in terms of power consumption and this warrants investigation into more techniques that can save more power of the mobile nodes in the network.

8.2 Future Work

While the thesis provide an in depth insight into power conservation in MANETs. There are a variety of fruitful areas for future research on power conservation and related topics. It was mentioned many issues in earlier chapters, but we repeat some of the larger and more important ones here.

In order to estimate the amount of power consumed during network routing operation in, the research have presented a simplified power model that computes power less costly in terms of computation. While it can be argued that the accuracy of the simplified model used for the analysis may be poor in terms of throughput performance (Chapter 7). The future work suggest the following in order to optimize the simplified power model as well as improving the quality of service and performance throughput of the network .

- Inclusion of the power model degrades the MANETs performance. Therefore, clear understanding of the trade off between the benefit obtained and the overhead required can help to tune the operation of wireless networks into its optimal performance.
- Power Control is a good strategy to improve the network performance and conserve power but there is a need to find out in what situation power control is helpful and in what situation power control is helpless. Analysis on this problem is still a critical issue that disturbs the research of transmission power control problem in MANETs.
- Cross layer designs for the Mobile Ad Hoc Wireless Network are required with the use of proposed adaptive systems.
- Further exploration in the context of power management is required to investigate the effect of hardware on power control, effect of load on power control as well as on different capacity and throughput. There is also a need to address the issue of antenna correlation, particularly in mobile devices.

Finally, this work would have been more valuable if the simulated proposed power model were experimented using real test bed. Unfortunately, it will be very expensive to carry out such experiment.

REFERENCES

REFERENCES

[1] H. Bakht, “The history of mobile ad-hoc networks,” August 2005.

[2] C.-K. Toh, “Origins of ad hoc:packet radio networks,” in *Ad Hoc Mobile Wireless Networks: Protocols and Systems*, Dec. 2001.

[3] B. Leiner, R. Ruther, and A. Sastry, “Goals and challenges of the darpa glomo program [global mobile information systems],” vol. 3, pp. 34–43, Dec. 1996.

[4] R. Ruppe, S. Griswald, P. Walsh, and R. Martin, “Near term digital radio (ntdr) system,” vol. 3, pp. 1282–1287, Nov. 1997.

[5] L. Kenny, “What is packet radio?” in *INTRODUCTION TO PACKET RADIO - PART 1*, Feb. 1997.

[6] J. Bang-Jensen and G. Gutin, “The bellman-ford moore algorithm,” Dec. 2008.

[7] J. Andrew, Goldsmith, and B. S. Wicker, “Design challenges for energy constrained ad hoc wireless networks,” *IEEE Wireless Communications*, pp. 2–22, Aug. 2002.

[8] J. Haarsten, “The bluetooth radio system,” *IEEE Pers. Commun.,*, pp. 28–36, Feb. 2000.

[9] J. Broch, D. A. Maltz, D. B.Johnson, Y.-C. Hu, and J. Jetcheva, “A performance comparison of multi-hop wireless ad hoc network routing protocols,” in *In Proc. Fourth Annual ACM/IEEE Int. Conf. on Mobile Computing and Networking (Modicom’98)*, Dallas, Texas, USA, Oct. 1998.

[10] S. Toumpis and A. Goldsmith, “Capacity regions for ad hoc networks,” in *In Proc. Int. ICC 2002*, April 2002.

[11] P. Gupta and P. Kumar, “The capacity of wireless networks,” *IEEE Trans. Inform. Theory*, pp. 388–404, March 2000.

[12] SreeRangaRaju and J. Mungara, “Performance evaluation of zrp over aodv and dsr in mobile adhoc networks using qualnet,” *European Journal of Scientific Research*, vol. 45, pp. 658–674, 2010.

[13] B. D. Johnson, A. D. Maltz, and J. Broch, “The dynamic source routing protocol for multi-hopwireless ad hoc networks,” in *Networks.Computer Science Department Carnegie Mellon*, University, Pittsburgh, PA 15213-3891.

[14] S. Basagni, M. Conti, S. Giordano, and I. Stojmenovic, *Mobile Ad Hoc Networking*. IEEE Press, 2004.

[15] A. Shrestha and F. Tekiner, “On manet routing protocols for mobility and scalability,” in *International Conference on Parallel and Distributed Computing, Applications and Technologies*, Dec. 2009, pp. 451–456.

[16] N. Qasim, fatin Said, and H. Aghvami, “Mobile ad hoc networking protocols evaluation through simulation for quality of service,” *IAENG International Journal of Computer Science*, vol. 36, no. 1, 2009.

[17] B. R. A. Kumar, L. C. Reddy, and P. S. Hiremath, “Performance comparison of wireless mobile ad hoc network routing protocols,” *IJCSNS International Journal of Computer Science and Network Security*, vol. 8, no. 1, 2008.

[18] J. Broch, A. D. Maltz, B. D. Johnson, Y.-C. Hu, and J. Jetcheva, “A performance comparison of multi-hop wireless ad hoc network routing protocols,” in *Networks Computer Science Department Carnegie Mellon*, University, Pittsburgh, PA 15213-3891, 1998.

[19] M. A. Rahman, M. S. Islam, and A. Talevski, “Performance measurement of various routing protocols in ad hoc network,” in *Proceedings of the International MultiConference of Engineers and Computer Scientist*, vol. I, Hong Kong, 2009.

[20] S. Z. Yang, B. Qi, and J. He, “Simulation comparison of four wireless ad hoc routing protocols,” *Information Technology Journal*, vol. 3, no. 3, pp. 219 – 226, 2004.

[21] A. Boukerche, *Algorithm and Protocols for Wireless and Mobile Ad Hoc Networks*. Wiley Seris on Parallel and Distributed Computing.

[22] L. Quakil, S. Senouci, and G. Pujolle, “Performance comparison of ad hoc routing protocols based on energy consumption,” in *Ambience Workshop*, Torino, Italy, 2002.

[23] Q. Zhao, Member, IEEE, L. Tong, Fellow, IEEE, D. Cousil, Member, and IEEE, “Energy-aware adaptive routing for large-scale ad hoc networks: Protocols and performance analysis,” *IEEE Transactions on Mobile Computing*, vol. 6, no. 9, pp. 1048 – 1059, Sept. 2007.

[24] L.Feeney and M. Nilsson, “Investigating the energy consumption of a wireless network interface in an ad hoc networking environment,” in *This paper appears in: INFOCOM 2001. Twentieth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings*, vol. 3, Swedish Inst. of Comput. Sci., Kista, April 2001, pp. 1548 – 1557.

[25] I. Chlamtac, M. Conti, and J. J. Liu, “Mobile ad hoc networking: Imperatives and challenges,” *Ad Hoc Networks: ELSERVIER*, pp. 1–64, 2003.

[26] E. C. Jones, M. K. Sivalingam, P. Agrawal, and J. C. Chen, “A survey of energy efficient network protocols for wireless networks,” in *In Proc. of Academic Publishers*, no. 7, Netherlands, 2001, pp. 343–358.

[27] A. Michail and A. Ephremides, “Energy efficient routing for connection oriented traffic in ad hoc wireless networks,” in *In Proc. IEEE PIMRC*, vol. 2, London, Sept. 2000, pp. 762 – 766.

[28] J. H. Chang and L. Tassiulas, “Energy conserving routing in wireless ad hoc networks,” in *In Proc. IEEE INFOCOM*, vol. 1, Tel-Aviv, Israel, Mar. 2000, pp. 22 – 31.

[29] S. Singh and C. Raghavendra, “Pamas:power aware multi-access protocol with signalling for ad hoc networks,” in *in Pro. Computer Communication Review 28(3)*, 1998, pp. 6–26.

[30] Y.-C. Huang, S.-Y. Chuang, and S.-D. Wang, “A dynamic node degree management scheme for energy-efficient routing protocols in wireless ad hoc networks,” in *Parallel and Distributed Systems, 2005. Proceedings. 11th International Conference*, vol. 2, Fukuoka, Jul. 2005, pp. 7 – 11.

[31] F. Hamady, A. Chehab, and A. Kayssi, “Energy consumption breakdown of a modern mobile platform under various workloads,” in *ICEAC 2011 IEEE*, Istanbul, Nov. 2011, pp. 1–4.

[32] J.-H. Chang and L. Tassiulas, “Energy conserving routing in wireless ad-hoc networks,” in *In Proc. INFOCOM 2000 19th Joint Annual conference of the IEEE*, vol. 1, March 2002.

[33] L. X. Yang, Y. Wang, C. Haiming, C. Xiaowen, W. Yanwei, and Q. Yong, “Reliable and energy efficient routing for static wireless ad hoc networks with unreliable links,” *IEEE Transactions on Parallel and Distributed Systems*, vol. 20, no. 10, pp. 1408–1421, Oct. 2009.

[34] G. Zussman and A. Segall, *Energy Efficient Routing in Ad Hoc Disaster Recovery Networks*. CCIT Report 392, Techion-Dept. of Electrical Engineering, July, 2002, pp. 1–26.

[35] J. Zhu, C. Qiao, and X. Wang, “On accurate energy consumption models for wireless ad hoc networks,” *IEEE Transactions on Wireless Communications*$_J, vol.\ 5, no.\ 11, pp.3077 - -3086, Nov.2006.$

[36] C. Young-rong, Y. Hai-bo, L. Ban-teng, and C. Ju-hua, “Transmission power optimization algorithm in wireless ad hoc networks,” in *CMC 2010 IEEE*, Shenzhen, China, Apr. 2010, pp. 358–363.

[37] S. Narayanaswamy, V. Kawadia, R. S. Sreenivas, and P. R. Kumar, “Power control in ad-hoc networks: Theory, architecture,algorithm and implementation of the compow protocol,” in *Proceedings of the European Wireless Conference 2002*, 2002.

[38] F. Bai, N. Sadagopan, and A. Helmy, “A framework to systematically analyze the impact of mobility on performance of routing protocols for adhoc networks,” in *In Proc. INFOCOM 2003*, vol. 2, Mar. 2003, pp. 825 – 835.

[39] F. Bai, N. Sadagopan, B. Krishnamachari, and A. Helmy, “Modeling path duration distributions in manets and their impact on reactive routing protocols,” in *In Proc. IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS*, vol. 22, no. 7, Sept. 2004, pp. 1357 – 1373.

[40] C. Sungsoon and P. J. Hayes, “Impact of mobility on connection stability in ad hoc networks,” in *in Proc. Wireless Communications and Networking Conference, 2005 IEEE*, vol. 3, Mar. 2005, pp. 1650 – 1656.

[41]

[42] B. Lawal, A. K. Anang, P. Bakalis, P. Rapajic, and T. Eneh, “Sensitivity of dsr protocol performance to propagation loss models at higher microwave frequencies,” in *Proceedings of the 2012 UKSim 14th International Conference on Computer Modelling and Simulation (UKSim)*, Cambridge, United Kingdom, Mar. 2012, pp. 561 – 565.

[43] A. K. Anang, B. Lawal, I. Eneh, P. Bakalis, and B. P. Rapajic, “The performance of dynamic source routing protocol to path loss models at carrier frequencies above 2 ghz,” in *Proceedings of the 2011 13th International Conference on Communication Technology*, Jinan, China, Sept. 2011, pp. 151 – 155.

[44] P. Bakalis and B. Lawal, “Performance evaluation of cbr and tcp traffic models on manet using dsr routing protocol,” in *Proceedings of the 2010 International Conference on Communications and Mobile Computing (CMC)*, vol. 3, Shenzhen, China, Apr. 2010, pp. 318 – 322.

[45] P. Bakalis, L. Bello, O. L. Jagun, A. K. Anang, T. Eneh, and A. Muhammad, “Performance evaluation of constant bit rate and variable bit rate traffic models on vehicular ad hoc network using dynamic source routing protocol,” in *Proceedings of the 2011 3rd IEEE International Conference Adaptive Science and Technology (ICAST)*, Abuja, Nigeria, Nov. 2011, pp. 187– 191.

[46]

[47] N. Qasim, F. Said, and H. Aghvami, “Mobile ad hoc networking protocols evaluation through simulation for quality of service,” *Int. Journal of Computer Science*, vol. 36, no. 1, Feb. 2009.

[48] S. Rajagopalan and C.-C. shen, “What does using tcp as an evaluation tool reveal about manet routing protocols,” *Vancouver, British Columbia, Canada. ACM 1595933069*, Jul. 2006.

[49] D. Triantafyllidou and K. A. Agha, “Evaluation of tcp performance in manets using an optimized scalable simulation model,” pp. 31 – 37, Oct. 2007.

[50] J. Wiley, *Algorithms and Protocols for Wireless and Mobile Ad Hoc Networks*. New York, NY: John Wiley&Sons, 2009.

[51] B. R. A. Kumar, L. C. Reddy, and P. S. Hiremath, “Performance comparison of wireless mobile ad hoc network routing protocols,” *Int. Journal of Computer Science and Network Security*, vol. 8, no. 6, pp. 337–343, Jun. 2008.

[52] S. Sesay, Z. Yang, B. Qi, and J. He, “Simulation comparison of four wireless ad hoc routing protocols,” *Information Technology Journal*, vol. 3, no. 3, pp. 219–226, Mar. 2004.

[53] A. Abdullah, N. Ramly, A. Muhammed, and M. N. Derhman, “Performance comparison study of routing protocols for mobile grid environment,” *IJCSNS International Journal of Computer science and Network security*, vol. 8, no. 2, 2008.

[54] A. M. Rahman, S. M. Islam, and A. Talevski, “Performance measurement of various routing protocols in ad hoc network,” *Proceeding of the International Multi-Conference of Engineers and Computer Scientist*, vol. 1, 2009.

[55] X.Li, Y. Wang, H. Chen, X. Chu, Y. Wu, and Y. Qi, “Reliable and energy-efficient routing for static wireless ad-hoc networks with unreliable links,” $\mathit{IEEE}_{JP}DS, vol.\ 20, no.\ 10, pp.1408 - -1421, Oct.2009.$

[56] G. Hernández-Valdez, F. A. Cruz-Pérez, and D. Lara-Rodríguez, “Sensitivity of the system performance to the propagation parameters in los microcellular environments,” $\mathit{IEEE}_{JV}T, vol.\ 57, no.\ 6, pp.3488 - -3508, November2008.$

[57] Y. He, R. Yuan, X. Ma, and J. Li, “The ieee 802.11 power saving mechanism: An experimental study,” pp. 1362 – 1367, Apr. 2008.

[58] J. Cano and P. Manzoni, “A low power protocol to broadcast real-time data traffic in a clustered ad hoc network,” vol. 5, pp. 2916 – 2920, 2011.

[59] J. C. Derek and E. David, “A partitioned power and location aware mac protocol for mobile ad hoc networks,” in *IEEE European Wireless*, Nicosia, Cyprus, Apr. 2005, pp. 1–7.

[60] H.-Y. Hsu and R. A. Hurson, “Pean: A probabilistic energy aware neighbor monitoring protocol for mobile ad hoc networks,” pp. 201–206, May 2007.

[61] F. W. Liu, Y. Zhang, and Y. Fang, “Conserve energy through multiple-packets transmission in heterogeneous mobile ad hoc networks,” in *Military Communications Conference, 2005. MILCOM 2005. IEEE*, vol. 3, Atlantic City, NJ, Oct. 2005, pp. 1516 – 1522.

[62] A. Zabian, “Power management mechanism for routing in ad-hoc wireless networks,” in *Mobile Computing and Wireless Communication International Conference. MCWC*, Amman, Sept. 2006, pp. 44 – 49.

[63] L. Gallina, S. Hamadou, A. Marin, and S. Rossi, “A framework for throughput and energy efficiency in mobile ad hoc networks,” pp. 1–6, October 2011.

[64] A. Mahimkar and R. Shyamasundar, “S-mecra: a secure energy-efficient routing protocol for wireless ad hoc networks,” vol. 4, pp. 2739 – 2743, Oct. 2004.

[65] C. Xiaohu, F. Michalis, and S. Krishnamurthy, “Power adaptive broadcasting with local information in ad hoc networks,” in *Network Protocols, 2003. Proceedings. 11th IEEE International Conference*, Nov. 2003, pp. 168 – 178.

[66] M. Subbarao, “Dynamic power-conscious routing for manets: an initial approach,” in *Vehicular Technology Conference, 1999. VTC 1999 - Fall. IEEE VTS 50th*, vol. 2, Sept. 1999, pp. 1232 – 1237.

[67] S. Baboo and B. Narasimhan, “An energy-efficient congestion-aware routing protocol for heterogeneous mobile ad hoc networks,” in *Advances in Computing, Control, and Telecommunication Technologies, 2009. ACT ’09. International Conference*, Trivandrum, Kerala, Dec. 2009, pp. 344 – 350.

[68] D. Anand and S. Prakash, “A short survey of energy-efficient routing protocols for mobile ad-hoc networks,” in *Advances in Recent Technologies in Communication and Computing (ARTCom), 2010 International Conference*, Kottayam, Oct. 2010, pp. 327 – 329.

[69] S.-H. Wu, C.-M. Chen, and M.-S. Chen, “Aaa: Asynchronous, adaptive, and asymmetric power management for mobile ad hoc networks,” in *INFOCOM 2009, IEEE*, Rio de Janeiro, Apr. 2009, pp. 2541 – 2545.

[70] G. Nikolakopoulos, A. Panousopoulou, and A. Tzes, “Manet-issues and their effects on control applications,” vol. 2, Sept. 2005.

[71] J. hu Zhang, H. Peng, and F.-J. Shao, “Energy consumption analysis of manet routing protocols based on mobility models,” in *Fuzzy Systems and Knowledge Discovery (FSKD), 2011 Eighth International Conference*, vol. 4, Shanghai, Jul. 2011, pp. 2275 – 2280.

[72] R. Ismail and R. Hassan, “Performance of aodv routing protocol in mobile ad hoc network,” in *Information Technology (ITSim), 2010 International Symposium*, vol. 1, Kuala Lumpur, June 2010, pp. 1 – 5.

[73] W. Alsalih and H. Hassanein, “Energy-aware task scheduling: towards enabling mobile computing over manets,” Apr. 2005.

[74] C. Tang, C. S. Raghavendra, and V. P. V, “Energy efficient adaptation of multicast protocols in power controlled wireless ad hoc networks,” in *Parallel Architectures, Algorithms and Networks 2002. I-SPAN ’02. Proceedings. International Symposium*, Makati City, Metro Manila, May 2002, pp. 80 – 85.

[75] L. La-Yuan, F. Zheng, L. Chun-Lin, and P.-Y. Yuan, “An energy constrained routing protocol for manet,” in *Machine Learning and Cybernetics, 2007 International Conference*, vol. 6, Hong Kong, Aug. 2007, pp. 3205 – 3210.

[76] S. Vaithiyanathan and N. E. Elizabeth, “A novel method for self management of the energy consumption of nodes dying out of low battery capacity in a ntp based routing environment of manets,” in *Networking and Information Technology (ICNIT), 2010 International Conference*, Manila, June 2010, pp. 86 – 90.

[77] S. Gomathi, S. Krishnamurthi, and R. Chbeir, “Design of extended optimal energy drain rate algorithm for mobile adhoc network,” in *Digital Information Management, 2006 1st International Conference*, Bangalore, Dec. 2006, pp. 240 – 247.

[78] Z. Jinhua, Q. Chunming, and X. Wang, “A comprehensive minimum energy routing scheme for wireless ad hoc networks,” in *INFOCOM 2004. Twenty-third AnnualJoint Conference of the IEEE Computer and Communications Societies*, vol. 2, Mar. 2004, pp. 1437 – 1445.

[79] J. Garcia, A. Kallel, K. Kyamakya, and K. Jobmann, “A novel dsr-based energy-efficient routing algorithm for mobile ad-hoc networks,” in *Vehicular Technology Conference, 2003. VTC 2003-Fall. 2003 IEEE 58th*, vol. 5, Oct. 2003, pp. 2849 – 2854.

[80] C. S. Inc., “Wireless, lan (wlan): Rf power values,” 2008.

[81] D. Hongmei, W. Li, and D. P. Agrawal, “Routing security in wireless ad hoc networks,” *Communications Magazine, IEEE*, vol. 40, no. 10, pp. 70 – 75, Oct. 2002.

[82] M. A. Rahman, F. Anwar, J. Naeem, and M. S. M. Abedin, "A simulation based performance comparison of routing protocol on mobile ad-hoc network (proactive, reactive and hybrid)," in *Computer and Communication Engineering (ICCCE)*, Kuala Lumpur, May 2010, pp. 1 – 5.

[83] X. M. Cheng, M. Cardei, X. Cheng, L. Wang, X. Yinfeng, and D. Ding-Zhu, "Topology control of ad hoc wireless networks for energy efficiency," *Proc. IEEE*, vol. 53, pp. 1629–1635, Dec. 2004.

[84] H. Limin, "Topology control for multihop packet radio networks," *Proc. IEEE*, vol. 41, pp. 1474–1481, Oct. 1993.

[85] L. Li and J. Halpern, "Minimum energy mobile wireless networks revisited," *In conf. Comm.*, pp. 278–283, June 2001.

[86] L. Li, J. Halpern, V. Bahl, Y. Wang, and R. Wattenhofer, "Analysis of a cone-based distributed topology control algorithm for wireless multihop networks," *in conf. Principles of Distributed Computing*, pp. 264–273, Aug. 2001.

[87] N. Li, J. Hou, and L. Sha, "Design and analysis of an mst based topology control algorithm," *In conf. INFOCOM*, vol. 3, pp. 1702–1712, March/April 2003.

[88] V. Rodoplu and T. Meng, "Minimum energy mobile wireless networks," *IEEE*$_{MC}OM, vol.\ 17, no.\ 8, pp.1333 - -1344, Aug.1999.$

[89] G. Toussaint, "The relative neighborhood graph of finite planar set, pattern recognition," vol. 12, no. 4, pp. 261–268, 1980.

[90] Y. Wang, X. Li, P. Wan, and O. Frider, "Distributed spanners with bounded degree for wireless ad hoc networks," *Int'l J. Foundations of Computer Science*, vol. 14, no. 2, pp. 183–200, 2003.

[91] "Network simulator 2." [Online]. Available: http://www.isi.edu/nsnam/ns/ns-build.htmlallinone/

[92] B. D. Johnson, A. D. Maltz, and J. Brochüber, *The Dynamic Source Routing Protocol for Multi-Hop Wireless Ad Hoc Networks*. Computer Science Dept. Carnegir Mellon University: Citeseer, 2001, pp. 15 213 – 3891.

[93] S. Tragoudas and S. Dimitrova, "Routing with energy consideration in mobile ad-hoc networks," *Proceedings of IEEE wireless Communications and Networking Conference (WCNC),Chicago, IL*, vol. 3, pp. 1258–1261, 2000.

[94] K. J. Man and J. J. Wook, "Aodv based energy efficient routing protocol for maximum lifetime in manet." *Advanced International Conference on Telecommunications and International Conference on Internet and Web Applications and Services*, 2006.

[95] H. Pucha, S. M. Das, and Y. C. Hu, "The performance impact of traffic pattern on routing protocols in mobile ad hoc networks," *MSWiM,Venezia, Italy*, 2004.

[96] A. A. Pirzada, M. Portmann, and J. Indulska, "Performance comparison of multi-path aodv and dsr protocols in hybrid mesh networks," *14th IEEE International Conference*, vol. 2, pp. 1 – 6, Sept. 2006.

[97] L. Ain and T. Kunz, "Increasing packet delivery ratio in dsr by link prediction," in *In Proc. of 36th Annual Hawaii International Conference on System Sciences*, Hawaii, USA, Jan. 2003, p. 10.

[98] V. Gauthier, R. D. Rasse, M. Marot, and M. Becker, "On comparison of four ad hoc routing protocols when taking into account the radio interferences," *Institute National des telecommunications- GET-INT*, 2001.

[99] M. S. M. Usop, A. Abdullah, A. Faisal, and A. Abididn, "Performance evaluation of aodv, dsdv, and dsr routing protocol in grid environment," *International Journal of Computer Science and Network Security*, vol. 19, no. 7, 2009.

[100] Z. Chang, G. Gaydadjiev, and S. Vassiliadis, "Routing protocols for mobile ad hoc networks: Current development and evaluation," 2005.

[101] J. Broch, D. A. Maltz, D. B. Johson, Y. Hu, and J. Jetcheva, “A performance comparison of multi-hop wireless ad hoc network routing protocols,” *MOBICOM 1998*, 2005.

[102] G. Zanca, F. Zorzi, A. Zanella, and M. Zorzi, “Experimental comparison of rssi-based localization algorithms for indoor wireless sensor networks,” in *Workshop on Real-World Wireless Sensor Networks (RealWSN’08)*, Glasgow, UK, Apr. 2008.

[103] A. T. Cabrera, J. G. de-la Nava, and E. Casilari, “An analytical model to estimate path duration in manets,” *ACM international symposium on Modeling analysis and simulation of wireless and mobile systems*, pp. 183–186, 2006.

[104] J. Liu and L. Baochun, “Mobilegrid: capacity-aware topology control in mobile ad hoc networks,” in *Computer Communications and Networks, 2002. Proceedings. Eleventh International Conference*, Oct. 2002, pp. 570 – 574.

[105] A. Goldsmith, *Wireless communication.* New York, NY: Cambridge University, 2005, pp. 31–35.

[106] T. H. Clausen, P. Jacquet, and L. Viennot, “Investigating the impact of partial topology in proactive manet routing protocols,” in *In Proc. IEEE 5th International symposium on wireless personal multimedia communications (WPMC’2002)*, vol. 3, Hawaii, USA, Oct. 2002, pp. 1374–1378.

[107] A. Boukerche, “Performance evaluation of routing protocols for ad hoc wireless networks,” *Mobile Networks and Applications*, vol. 9, no. 3, pp. 333–342, May 2004.

[108] A. Nešković, N. Nešković, and D. Paunocć, “Macrocell electric field strength prediciton model based upon artificial neural networks,” *IEEE*$_{JJ}SAC, vol.\ 20, no.\ 6, pp.1170 - -1176, Aug.2002.$

[109] P. Harley, “Short distance attenuation measurements at 900 mhz and 1.8 ghz using low antenna heights for microcells,” *IEEE*$_{JJ}SAC, vol.\ 7, no.\ 1, pp.5 - -11, Jan.1989.$

[110] O. T. Inc., “Opnet simulator,” 2011. [Online]. Available: http://www.opnet.com/

[111] B. N. Yuvaraju, T. Mohit, and N. C. Niranjan, “Enhancing the performance of manets by monitoring the energy consumption and use of mobile relays,” in *Proceedings of the IEEE International Association of Computer Science and Information Technology - Spring Conference*, Singapore, Apr. 2009, pp. 85 – 89.

[112] M. Conti, E. Gregori, and G. Maselli, “Cooperation issues in mobile ad hoc networks,” in *Proceedings of the 24 International Conference on Distributed Computing Systems Workshops (ICDCSW ’09)*, vol. 7, 2009, pp. 803 – 808.

[113] S. Singh, M. Woo, and C. S. Raghavendra, “Power-aware routing in mobile ad hoc networks,” in *Proceedings of the 4th annual ACM/IEEE international conference on Mobile computing and networking Dallas*, 1998, pp. 181 – 190.

[114] S. Doshi, S. Bhandare, and X. Timothy, “An on-demand minimum energy routing protocol for a wireless ad hoc network,” in *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 6, no. 3, June 2002, pp. 50–66.

[115] B. Ramachandran and S. Shanmugavel, “Received signal strength-based cross-layer designs for mobile ad hoc networks,” *IETE Technical Review*, vol. 25, no. 4, 2008.

[116] L. Anderegg and S. Eidenbenz, “Ad hoc-vcg: A truthful and cost-efficient routing protocol for mobile ad hoc networks with selfish agents,” in *Proceedings of the 9th annual international conference on Mobile computing and networking (MobiCom ’03)*, San Diego, California, USA, Sept. 2003, pp. 245 – 259.

[117] S. Marti, T. J. Giuli, and M. Baker, “Mitigating routing misbehaviour in mobile ad hoc networks,” in *Proceedings of the 6th annual international conference on Mobile computing and networking (MobiCom ’00)*, Boston, MA, USA, Aug. 2000, pp. 255 – 265.

[118] J. Nie and Z. Zhou, “An energy based power-aware routing protocol in ad hoc networks,” in *Proceedings of the International Symposium on Communications and*

Information Technologies (ISCIT '04), vol. 1, Sapporo, Japan, Oct. 2004, pp. 280 – 285.

[119] M. Stemm, P. Gauthier, and D. Harada, "Reducing power consumption of network interface in hand-held devices," in *3rd International Workshop on Mobile Multimedia Communications*, Sept. 1996, pp. 25–27.

[120] V. Rishiwal, M. Yadav, S. Verma, and S. Bajapai, "Power aware routing in ad hoc wireless networks," *JCS and T*, vol. 9, no. 2, pp. 101–109, October 2009.

[121] C.-W. Tan and S. K. Bose, "Modifying aodv for efficient power-aware routing in manets," pp. 1–6, November 2005.

[122] Y. Xu, J. Heidemann, and D. Estrin, "Adaptive energy conserving routing for multihop ad hoc networks," pp. 1 – 14, Oct. 2000.

[123] Y. Okumura, E. Ohmori, T. Kawano, and K. Fukua, "Field strength and its variability in uhf and vhf land-mobile radio service," *Rev. Elec. Commun. Lab.*, vol. 16, no. 9, 1968.

[124] M. Hata, "Empirical formula for propagation loss in land mobile radio services," *IEEE Trans. Veh. Technol.*, vol. VT-29, no. 3, p. 317 □ 325, Sept. 1980.

[125] J. Walfisch and H. L. Bertoni, "A theoretical model of uhf propagation in urban environments," *IEEE Trans. Antennas Propag.*, vol. 36, no. 12, pp. 1788 – 1796, Dec. 1988.

[126] V. Erceg, L. J. Greenstein, S. Y. Tjandra, S. R. Parkoff, A. Gupta, B. Kulic, and A. A. Julius, "An empirically based path loss model for wireless channels in suburban environment," *IEEE J. Sel. Areas Commun.*, vol. 17, no. 7, pp. 1205–1211, July 1999.

[127] M. A. Nisirat, M. Ismail, L. Nissirat, and S. Al-Khawaldeh, "A terrain roughness correction factor for hata path loss model at 900 mhz," *Progress In Electromagnetics Research*, vol. 22, pp. 11–22, 2011.

[128] "Opnet simulator," http://www.opnet.com/.

[129] G. Forman and J. Zahorjan, “The challenges of mobile computing,” in *Proceedings of the IEEE Computer Society*, Apr. 1994, pp. 38 – 47.

[130] S. Sheng, A. Chandrakasan, Brodersen, and R.W, “A portable multimedia terminal,” in *Proceedings of the IEEE Communications Magazine*, Dept. of Electr Eng and Comput Sci and California Univ and Berkeley, Dec. 1992, pp. 64 – 75.

[131] C. Jones, K. Sivalingam, P. Agarwal, and J. Chen, “A survey of energy efficient network protocols for wireless and mobile networks,” *ACM:Wireless Networks*, vol. 7, pp. 343 – 358, Jan. 2011.

[132] S. Takeuchi, Yamazaki, K. Sezaki, K., and Y. Yasuda, “An improved power saving mechanism for mac protocol in ad hoc networks,” in *Proceedings of the Global Telecommunications Conference, 2004. GLOBECOM ’04. IEEE*, Grad. Sch. of Sci. Eng., Waseda Univ., Tokyo, Japan, Dec. 2004, pp. 2791 – 2796.

[133] R. Zheng and R. Kravets, “On-demand power management for ad hoc networks,” in *This paper appears in: INFOCOM 2003. Twenty-Second Annual Joint Conference of the IEEE Computer and Communications. IEEE Societies*.

[134] K. Arulanandam and B. Parthasarathy, “A new energy level efficiency issues in manet,” *International Journal of Reviews in Computing*, pp. 104 – 109, 2009.

[135] W. Liu, Y. Zhang, and Y. Fang, “Delar: A device-energy-load aware relaying framework for heterogeneous mobile ad hoc networks,” *This paper appears in: IEEE Journal on Selected Areas in Communications,*, vol. 29, no. 8, Sept. 2011.

[136] H. S. Berger and A. Tsaliovich, “Unlicensed pcs product emc compliance measurement rationale and alternatives,” pp. 396 – 401, Aug. 1996.

[137] A. N. S. D. for Technologies of Electromagnetic Compatibility, *American National Standard Dictionary for Technologies of Electromagnetic Compatibility (EMC), Electromagnetic Pulse (EMP), and Electrostatic Discharge (ESD)*. IEEE Xplore Digital Library, 1998.

[138] “Opnet simulator,” http://www.opnet.com/.

[139] B. Chen, K. Jamieson, and H. Balakrishnan, “Span: An energy-efficient coordination algorithm for topology maintenance in ad hoc wireless networks,” in *Proceedings of the 7th ACM MOBICOM*, Rome, Italy, July 2001.

APPENDICES

8.3 Network configured with power model computational results

Appendix A Keys:

Sim.time = Simulation time

Rxpow = Received Power of the network configured with either AODV or DSR protocol

thrpt = Throughput of the network configured with either AODV or DSR protocol

Pcon = Power consumed in a network configured with either AODV or DSR protocol

N/A = Not Available

Table 8.1: Network with Power Model Results

Sim.time (S)	Rxpow.aodv (W)	Rxpow.dsr (W)	thrpt.aodv (bits/s)	thrpt.dsr (bits/s)	Pcon.aodv (W)	Pcon.dsr (W)
0	0	0	0	0	0.0016000000	0.0016000000
5	0	0	0	0	0.0016000000	0.0016000000
10	5.143E-09	1.497E-09	67470.933	59398.4	0.0019470030	0.0016889194
15	3.935E-09	1.124E-09	92334.4	58948.8	0.0019633359	0.0016662585
20	3.048E-09	8.94E-10	106653.44	58679.04	0.0019250797	0.0016524591
25	2.471E-09	7.42E-10	117697.07	58499.2	0.0018908295	0.0016434064
30	2.077E-09	6.31E-10	126227.2	58370.74	0.0018621739	0.0016368319
35	1.794E-09	5.47E-10	132223.2	58274.5	0.0018372084	0.0016318761
40	1.578E-09	4.86E-10	135579.73	58199.47	0.0018139448	0.0016282849
45	1.408E-09	4.4E-10	139313.28	58139.52	0.0017961531	0.0016255814
50	1.848E-09	4.04E-10	142640.29	58090.47	0.0018635993	0.0016234686
55	1.691E-09	3.79E-10	145038.4	58049.6	0.0018452599	0.0016220008
60	1.573E-09	3.53E-10	146491.57	58015.02	0.0018304312	0.0016204793
65	1.468E-09	3.29E-10	148272	57985.37	0.0018176633	0.0016190772
70	1.404E-09	3.07E-10	150014.72	57959.68	0.0018106207	0.0016177936
75	1.323E-09	2.89E-10	151352.4	57937.2	0.0018002392	0.0016167439
80	1.247E-09	2.74E-10	152180.33	57917.36	0.0017897689	0.0016158694
85	1.18E-09	2.7E-10	153161.24	57899.73	0.0017807303	0.0016156329
90	1.116E-09	2.61E-10	154358.57	57883.96	0.0017722642	0.0016151077
95	1.059E-09	2.54E-10	155286.4	57869.76	0.0017644483	0.0016146989
100	1.007E-09	2.43E-10	155840.61	57856.91	0.0017569315	0.0016140592
105	9.61E-10	2.34E-10	156412.51	57845.24	0.0017503124	0.0016135358
110	9.18E-10	2.26E-10	157195.1304	57834.57391	0.0017443051	0.0016130706

Sim.time (S)	Rxpow.aodv (W)	Rxpow.dsr (W)	thrpt.aodv (bits/s)	thrpt.dsr (bits/s)	Pcon.aodv (W)	Pcon.dsr (W)
115	8.8E-10	2.33E-10	157850.1333	57824.8	0.0017389081	0.0016134732
120	8.49E-10	2.52E-10	158392.832	57815.808	0.0017344755	0.0016145696
125	8.19E-10	2.48E-10	158778.5846	57807.50769	0.0017300397	0.0016143363
130	7.9E-10	2.53E-10	159246.6963	57799.82222	0.0017258049	0.0016146234
135	7.64E-10	2.49E-10	159734.8571	57792.68571	0.0017220374	0.0016143904
140	7.41E-10	2.62E-10	160137.7103	57786.04138	0.0017186620	0.0016151399
145	7.21E-10	2.56E-10	160363.9467	57779.84	0.0017156224	0.0016147916
150	6.99E-10	2.5E-10	160768.8258	57774.03871	0.0017123774	0.0016144435
155	6.97E-10	2.47E-10	161148.4	57768.6	0.0017123204	0.0016142688
160	6.85E-10	2.55E-10	161459.5879	57763.49091	0.0017105998	0.0016147297
165	6.65E-10	2.49E-10	161664.3765	57758.68235	0.0017075068	0.0016143819
170	6.47E-10	2.44E-10	161862.2171	57754.14857	0.0017047249	0.0016140920
175	6.29E-10	2.38E-10	162169.2444	57749.86667	0.0017020045	0.0016137445
180	6.13E-10	2.33E-10	162419.2	57745.81622	0.0016995630	0.0016134548
185	5.99E-10	2.28E-10	162616.5895	57741.97895	0.0016974073	0.0016131652
190	5.84E-10	2.24E-10	162803.8564	57738.33846	0.0016950775	0.0016129334
195	5.7E-10	2.2E-10	163056.64	57734.88	0.0016929423	0.0016127017
200	5.57E-10	2.17E-10	164243.3561	57731.59024	0.0016914835	0.0016125278
205	5.44E-10	2.14E-10	164453.181	57728.45714	0.0016894625	0.0016123539
210	5.35E-10	2.16E-10	164510.6605	57725.46977	0.0016880132	0.0016124687
215	5.29E-10	2.15E-10	164769.7455	57722.61818	0.0016871632	0.0016124104
220	5.21E-10	2.13E-10	164950.7556	57719.89333	0.0016859393	0.0016122943
225	5.33E-10	2.09E-10	165140.0348	57717.28696	0.0016880196	0.0016120629
230	5.23E-10	2.07E-10	165146.1447	57714.79149	0.0016863714	0.0016119470
235	5.14E-10	2.05E-10	165308	57712.4	0.0016849683	0.0016118310
240	5.04E-10	2.02E-10	165554.9388	57710.10612	0.0016834397	0.0016116574
245	4.94E-10	1.99E-10	165552.384	57707.904	0.0016817829	0.0016114839
250	4.85E-10	1.96E-10	165549.9294	57705.78824	0.0016802917	0.0016113103
255	4.77E-10	1.94E-10	165691.5692	57703.75385	0.0016790349	0.0016111945
260	4.7E-10	1.91E-10	165884.3774	57701.79623	0.0016779657	0.0016110210
265	4.63E-10	1.89E-10	165959.1111	57699.91111	0.0016768391	0.0016109053
270	4.55E-10	1.87E-10	166003.8982	57698.09455	0.0016755318	0.0016107895
275	4.48E-10	1.85E-10	166100.5714	57696.34286	0.0016744131	0.0016106738
280	4.41E-10	1.83E-10	166220.1263	57694.65263	0.0016733031	0.0016105581
285	4.33E-10	1.82E-10	166283.9172	57693.02069	0.0016720009	0.0016105001
290	4.27E-10	1.81E-10	166345.5458	57691.44407	0.0016710295	0.0016104422
295	4.2E-10	1.78E-10	166405.12	57689.92	0.0016698902	0.0016102688
300	4.14E-10	1.76E-10	166511.8426	57688.4459	0.0016689359	0.0016101532

Sim.time (S)	Rxpow.aodv (W)	Rxpow.dsr (W)	thrpt.aodv (bits/s)	thrpt.dsr (bits/s)	Pcon.aodv (W)	Pcon.dsr (W)
305	4.08E-10	1.73E-10	166519.8452	57687.01935	0.0016679401	0.0016099799
310	4.02E-10	1.7E-10	166621.3587	57685.6381	0.0016669818	0.0016098066
315	4.1E-10	1.68E-10	166696.3	57684.3	0.0016683455	0.0016096910
320	4.18E-10	1.67E-10	166768.9354	57683.00308	0.0016697094	0.0016096331
325	4.14E-10	1.68E-10	166793.9879	57681.74545	0.0016690527	0.0016096905
330	4.09E-10	1.68E-10	166885.3493	57680.52537	0.0016682561	0.0016096903
335	4.04E-10	1.67E-10	166952	57679.34118	0.0016674486	0.0016096324
340	4.02E-10	1.66E-10	166973.3101	57678.1913	0.0016671233	0.0016095746
345	3.98E-10	1.64E-10	167036.8	57677.07429	0.0016664806	0.0016094590
350	3.96E-10	1.63E-10	167119.5944	57675.98873	0.0016661794	0.0016094012
355	3.97E-10	1.61E-10	167179.2889	57674.93333	0.0016663702	0.0016092857
360	3.96E-10	1.6E-10	167278.3781	57673.90685	0.0016662422	0.0016092278
365	3.94E-10	1.59E-10	167236.4973	57672.90811	0.0016658912	0.0016091700
370	3.92E-10	1.59E-10	167312.2133	57671.936	0.0016655864	0.0016091698
375	3.92E-10	1.6E-10	167331.2	57670.98947	0.0016655938	0.0016092274
380	3.9E-10	1.62E-10	167385.3506	57670.06753	0.0016652803	0.0016093426
385	3.86E-10	1.65E-10	167360.2462	57669.16923	0.0016646011	0.0016095154
390	3.83E-10	1.69E-10	167449.519	57668.29367	0.0016641332	0.0016097459
395	3.79E-10	1.71E-10	167499.12	57667.44	0.0016634822	0.0016098611
400	3.75E-10	1.73E-10	167565.9852	57666.60741	0.0016628372	0.0016099763
405	3.71E-10	1.76E-10	167558.1659	57665.79512	0.0016621641	0.0016101492
410	3.68E-10	1.77E-10	167568.5783	57665.00241	0.0016616652	0.0016102067
415	3.67E-10	1.77E-10	167667.8857	57664.22857	0.0016615341	0.0016102066
420	3.64E-10	1.76E-10	167676.7624	57663.47294	0.0016610343	0.0016101488
425	3.61E-10	1.75E-10	167720.2605	57662.73488	0.0016605470	0.0016100910
430	3.57E-10	1.74E-10	167765.6276	57662.01379	0.0016598923	0.0016100332
435	3.53E-10	1.72E-10	167809.3818	57661.30909	0.0016592367	0.0016099177
440	3.5E-10	1.71E-10	167782.6157	57660.62022	0.0016587239	0.0016098600
445	3.47E-10	1.7E-10	167889.5644	57659.94667	0.0016582577	0.0016098022
450	3.45E-10	1.68E-10	167928.3341	57659.28791	0.0016579353	0.0016096868
455	3.43E-10	1.67E-10	167949.9826	57658.64348	0.0016576068	0.0016096290
460	3.4E-10	1.66E-10	167970.271	57658.0129	0.0016571099	0.0016095712
465	3.37E-10	1.65E-10	168070.6723	57657.39574	0.0016566398	0.0016095135
470	3.35E-10	1.66E-10	168079.6295	57656.79158	0.0016563067	0.0016095710
475	3.32E-10	1.65E-10	168098.8	57656.2	0.0016558088	0.0016095133
480	3.3E-10	1.64E-10	168133.0144	57655.62062	0.0016554839	0.0016094555
485	3.27E-10	1.63E-10	168166.5306	57655.05306	0.0016549905	0.0016093978
490	3.27E-10	1.61E-10	168304.8727	57654.49697	0.0016550357	0.0016092824
495	3.28E-10	1.6E-10	168434.304	57653.952	0.0016552465	0.0016092246
500	N/A	N/A	N/A	N/A	N/A	N/A

8.4 Conventional Network without Power Model Results

Appendix B

Table 8.2: Conventional Network without Power Model Results

Sim.time (S)	Rxpow.aodv (W)	Rxpow.dsr (W)	thrpt.aodv (bits/s)	thrpt.dsr (bits/s)	Pcon.aodv (W)	Pcon.dsr (W)
0	0	0	0	0	0.0016000000	0.0016000000
5	0	0	0	0	0.0016000000	0.0016000000
10	2.311E-09	1.385E-09	71633.06667	61685.33333	0.00176554	0.00168543
15	2.293E-09	2.742E-09	103721.6	70744	0.00183783	0.00179398
20	2.246E-09	2.434E-09	122232.32	76179.2	0.00187453	0.00178542
25	2.128E-09	2.103E-09	137168	79802.66667	0.00189189	0.00176783
30	1.931E-09	1.857E-09	147327.0857	82390.85714	0.00188449	0.00175300
35	1.757E-09	1.663E-09	154255.2	84332	0.00187103	0.00174024
40	1.662E-09	1.505E-09	158892.8	85841.77778	0.00186408	0.00172919
45	1.558E-09	1.376E-09	163416.96	87049.6	0.00185460	0.00171978
50	1.436E-09	1.268E-09	167369.8909	88037.81818	0.00184034	0.00171163
55	1.329E-09	1.177E-09	170484.8	88861.33333	0.00182657	0.00170459
60	1.236E-09	1.096E-09	172860.5538	89558.15385	0.00181366	0.00169816
65	1.154E-09	1.03E-09	174896.9143	90155.42857	0.00180183	0.00169286
70	1.083E-09	9.75E-10	176753.92	90673.06667	0.00179142	0.00168841
75	1.022E-09	9.21E-10	178388.4	91126	0.00178231	0.00168393
80	9.67E-10	8.75E-10	183998.8706	91525.64706	0.00177793	0.00168008
85	9.18E-10	8.37E-10	186087.8222	91880.88889	0.00177083	0.00167690
90	8.75E-10	8.02E-10	187905.3474	92198.73684	0.00176442	0.00167394
95	8.36E-10	7.67E-10	189664	92484.8	0.00175856	0.00167094
100	8.01E-10	7.34E-10	191452.6476	92743.61905	0.00175335	0.00166807
105	7.7E-10	7.03E-10	192719.1273	92978.90909	0.00174839	0.00166536
110	7.44E-10	6.74E-10	194002.3652	93193.73913	0.00174434	0.00166281
115	7.17E-10	6.47E-10	195098.6667	93390.66667	0.00173989	0.00166042
120	6.98E-10	6.24E-10	196339.968	93571.84	0.00173705	0.00165839
125	6.81E-10	6.14E-10	201303.8769	93739.07692	0.00173709	0.00165756
130	6.64E-10	5.99E-10	202711.4667	93893.92593	0.00173460	0.00165624

Sim.time (S)	Rxpow.aodv (W)	Rxpow.dsr (W)	thrpt.aodv (bits/s)	thrpt.dsr (bits/s)	Pcon.aodv (W)	Pcon.dsr (W)
135	6.47E-10	6.66E-10	203449.3714	94037.71429	0.00173163	0.00166263
140	6.27E-10	6.46E-10	204992.2207	94171.58621	0.00172853	0.00166083
145	6.09E-10	6.25E-10	206091.52	94296.53333	0.00172551	0.00165894
150	5.92E-10	6.05E-10	207763.4065	94413.41935	0.00172300	0.00165712
155	5.76E-10	5.87E-10	208346.8	94523	0.00172001	0.00165549
160	5.6E-10	5.69E-10	208811.0545	94625.93939	0.00171693	0.00165384
165	5.46E-10	5.53E-10	209391.0588	94722.82353	0.00171433	0.00165238
170	5.33E-10	5.38E-10	210069.3943	94814.17143	0.00171197	0.00165101
175	5.2E-10	5.24E-10	210209.6	94900.44444	0.00170931	0.00164973
180	5.08E-10	5.11E-10	210301.4054	94982.05405	0.00170683	0.00164854
185	4.96E-10	4.99E-10	210388.3789	95059.36842	0.00170435	0.00164743
190	4.86E-10	4.87E-10	210470.8923	95132.71795	0.00170229	0.00164633
195	4.75E-10	4.78E-10	210549.28	95202.4	0.00170001	0.00164551
200	4.65E-10	4.7E-10	210556.4098	95268.68293	0.00169791	0.00164478
205	4.55E-10	4.62E-10	210661.9429	95331.80952	0.00169585	0.00164404
210	4.46E-10	4.54E-10	210737.5628	95392	0.00169399	0.00164331
215	4.37E-10	4.45E-10	210814.9818	95449.45455	0.00169213	0.00164248
220	4.29E-10	4.36E-10	210784.8533	95504.35556	0.00169043	0.00164164
225	4.21E-10	4.27E-10	210846.1913	95556.86957	0.00168877	0.00164080
230	4.14E-10	4.19E-10	211540.1532	95607.14894	0.00168758	0.00164006
235	4.07E-10	4.11E-10	211706.8	95655.33333	0.00168616	0.00163931
240	4.01E-10	4.03E-10	212220.3429	95701.55102	0.00168510	0.00163857
245	3.95E-10	3.95E-10	212768.768	95745.92	0.00168404	0.00163782
250	3.91E-10	3.88E-10	213227.4196	95788.54902	0.00168337	0.00163717
255	3.98E-10	3.82E-10	213572.4308	95829.53846	0.00168500	0.00163661
260	3.96E-10	3.75E-10	213930.5057	95868.98113	0.00168472	0.00163595
265	3.91E-10	3.69E-10	214249.7185	95906.96296	0.00168377	0.00163539
270	3.86E-10	3.63E-10	215289.4836	95943.56364	0.00168310	0.00163483
275	3.82E-10	3.57E-10	216194.2857	95978.85714	0.00168259	0.00163426
280	3.78E-10	3.52E-10	217560.5895	96012.91228	0.00168224	0.00163380
285	3.76E-10	3.47E-10	217330.4276	96045.7931	0.00168172	0.00163333
290	3.98E-10	3.42E-10	217106.7661	96077.55932	0.00168641	0.00163286
295	3.99E-10	3.37E-10	218140.9067	96108.26667	0.00168704	0.00163239
300	3.95E-10	3.33E-10	218178.2033	96137.96721	0.00168618	0.00163201
305	3.9E-10	3.28E-10	218185.8065	96166.70968	0.00168509	0.00163154
310	3.84E-10	3.23E-10	218188.2921	96194.53968	0.00168378	0.00163107
315	3.79E-10	3.19E-10	219190.1	96221.5	0.00168307	0.00163069
320	3.73E-10	3.14E-10	218891.52	96247.63077	0.00168165	0.00163022
325	3.68E-10	3.1E-10	218773.0424	96272.9697	0.00168051	0.00162984
330	3.63E-10	3.06E-10	218749.5164	96297.55224	0.00167941	0.00162947
335	3.58E-10	3.02E-10	218635.4824	96321.41176	0.00167827	0.00162909
340	3.54E-10	2.98E-10	218502.4928	96344.57971	0.00167735	0.00162871

Sim.time (S)	Rxpow.aodv (W)	Rxpow.dsr (W)	thrpt.aodv (bits/s)	thrpt.dsr (bits/s)	Pcon.aodv (W)	Pcon.dsr (W)
345	3.49E-10	2.94E-10	218432.5486	96367.08571	0.00167623	0.00162833
350	3.44E-10	2.91E-10	219103.1887	96388.95775	0.00167537	0.00162805
355	3.4E-10	2.87E-10	219031.1111	96410.22222	0.00167447	0.00162767
360	3.36E-10	2.84E-10	219006.6849	96430.90411	0.00167359	0.00162739
365	3.32E-10	2.8E-10	218805.7081	96451.02703	0.00167264	0.00162701
370	3.28E-10	2.77E-10	218768.9813	96470.61333	0.00167176	0.00162672
375	3.24E-10	2.74E-10	218759.3263	96489.68421	0.00167088	0.00162644
380	3.2E-10	2.71E-10	218771.8649	96508.25974	0.00167001	0.00162615
385	3.16E-10	2.68E-10	218766.359	96526.35897	0.00166913	0.00162587
390	3.12E-10	2.66E-10	218725.9949	96544	0.00166824	0.00162568
395	3.08E-10	2.63E-10	218721.2	96561.2	0.00166737	0.00162540
400	3.05E-10	2.61E-10	218729.7975	96577.97531	0.00166671	0.00162521
405	3.02E-10	2.59E-10	218741.9317	96594.34146	0.00166606	0.00162502
410	2.99E-10	2.58E-10	218687.1518	96610.31325	0.00166539	0.00162493
415	2.96E-10	2.59E-10	218650.1333	96625.90476	0.00166472	0.00162503
420	2.93E-10	2.59E-10	218662.7765	96641.12941	0.00166407	0.00162503
425	3.26E-10	2.59E-10	218886.5488	96656	0.00167136	0.00162503
430	3.35E-10	2.57E-10	218584.1287	96670.52874	0.00167323	0.00162484
435	3.33E-10	2.56E-10	218483.9273	96684.72727	0.00167276	0.00162475
440	3.31E-10	2.54E-10	218353.7618	96698.60674	0.00167228	0.00162456
445	3.3E-10	2.52E-10	218241.8489	96712.17778	0.00167202	0.00162437
450	3.33E-10	2.51E-10	217996.5187	96725.45055	0.00167259	0.00162428
455	3.36E-10	2.51E-10	218098.2261	96738.43478	0.00167328	0.00162428
460	3.34E-10	2.5E-10	218174.0731	96751.13978	0.00167287	0.00162419
465	3.32E-10	2.48E-10	218240.9532	96763.57447	0.00167246	0.00162400
470	3.3E-10	2.47E-10	218248.2189	96775.74737	0.00167202	0.00162390
475	3.3E-10	2.46E-10	218284.1333	96787.66667	0.00167203	0.00162381
480	3.45E-10	2.51E-10	218294.7629	96799.34021	0.00167531	0.00162430
485	4.31E-10	2.63E-10	218371.7878	96810.77551	0.00169412	0.00162546
490	4.3E-10	2.62E-10	218433.2929	96821.9798	0.00169393	0.00162537
495	4.28E-10	2.6E-10	218465.92	96832.96	0.00169350	0.00162518
500	N/A	N/A	N/A	N/A	N/A	N/A