National Institute of Technology Rourkela

Master Thesis

Load Balancing in MANET : Alleviating the center node

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Certificate

This is to certify that the work in the thesis entitled **Load Balancing in MANET : Alleviating the center node** by **Depally Subash Sudheer**, bearing roll number **211CS1061**, is a record of an original research work carried out by him under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of **Master of Technology** in **Computer Science and Engineering**. Neither this thesis nor any part of it has been submitted for any degree or academic award elsewhere.

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Declaration of Authorship

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"Good friends, good books, and a sleepy conscience: this is the ideal life."

Mark Twain

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Abstract

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Load Balancing in MANET : Alleviating the center node

by Depally Subash SUDHEER

Load balancing is an essential requirement of any multi-hop wireless network. A wireless routing protocol is accessed on its ability to distribute traffic over the network nodes and a good routing protocol achieves this without introducing unacceptable delay. The most obvious benefit is manifested in increasing the life of a battery operated node which can eventually increase the longevity of the entire network. In the endeavor of finding the shortest distance between any two nodes to transmit data fast the center nodes become the famous picks. The centrally located nodes connect many subnetworks and serve as gateways to some subnetworks that become partitioned from the rest of the network in its absence. Thus, the lifetime of the center nodes become a bottleneck for connectivity of a subnetwork prior to its partition from the rest of the network. An unbiased load can cause congestion in the network which impacts the overall throughput, packet delivery ratio and the average end to end delay. In, this thesis we have mitigated the unbiased load distribution on centrally located nodes by pushing traffic further to the peripheral nodes without compromising the average end to end delay for a greater network longevity and performances. We proposed a novel routing metric , load and a minimization criterion to decide a path that involves nodes with less load burden on them. The simulations of the proposed mechanism run on NS-2.34 for 16 and 50 nodes have revealed an average 2.26% reduction of load on the center node in comparison with AOMDV. ...

Acknowledgements

This thesis would not have been compiled without the help from many professors and friends. I would like to thank my supervisor for keeping faith in me to do something different from his area of interest. My uncles without who's support and encouragement I would not have been an engineer at the first place. Prof B.D. Sahoo for putting me on the right track when I went wrong ways in the research. Prof Ramakrishna M of Manipal Institute of Technology for aiding me in NS2 installation errors. Mr Jagadish for being the pateint listener. Mr Prem Depon Nayak and C.Shivva Prasad for being my moral support during my stay here....

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Abbreviations

RREP	**R**oute **R**eply
LB	**L**oad **B**alanced

In loving memory of my father...

Chapter 1

Introduction

1.1 Introduction

With the proliferation of Wi-Fi devices and Internet, MANET has gained considerable demand and popularity. MANETs are an infrastructure less networks, meaning no base station, of mobile nodes with a limited radio frequency. The communication among the nodes take place via wireless links of varying capacity on a hop by hop basis. Besides, these mobile nodes come with batteries that carry limited power and often operate in areas where the facility to recharge does not apply. Hence, we must utilize these limited resources very efficiently for better network performances and longevity. Otherwise, unbiased traffic and resource utilization may congest the network and deplete energy very quickly.

The inefficiency in the wireless networks is mostly attributed to load imbalance. Unfortunately, most current routing protocols do not take load distribution into account. In their analysis, Pham and Perreau [3] , show that centrally located nodes carry greater load compared to others. This is because central nodes participate in large number of routes. Since few nodes take most burdens of traffic transit they tend to yield undesirable results in the form of high average end to end delay, shortened network life, and lower packet delivery. Thus, we present a novel load balancing mechanism that alleviates the central nodes by pushing the traffic further from the center. A definite location of the center node cannot be established hence we depend on an intuitive definition of centrality based on the route reply messages forwarded by the destination.

The significance of center nodes and their ability in providing connectivity is eatablished in Chapter 3. Based on the conclusions drawn from existing research we are of the opinion that center nodes are the most important nodes of all and have to be effectively used. Hence, in our proposed load balancing scheme briefed in Chapter 4 we introduce novel routing metrics to alleviate load on center nodes to extend their lifetime and in the process defer the partition of subnetworks.

1.2 Motivation

Many routing protocols in the literature have concerned themselves with balancing load yeiding many performance benefits but very few have commented about the adverse effect of unbiased load on center node. Our motivation for carrying out this research is rooted from the analysis done by Pham ans Perreau [3] and the ideas put forth by Souhili et al [4].

Multi path routing employs 'k' optimal paths from source to destination to introduce fault tolerance but in real scenarios , shortest path routing has proven to be more useful and efficient than multi path routing as routing benfits in multi path routing become profound only when 'k' is very large approximately around 100 for 500 nodes [5] which is impractical due to route maintainance overhead. Irrespective of this reason multi path routing is still appreciated because of its fault tolerance nature in providing alternative paths during failures.

All research in this area have come up with o0ne unanimous conclusion about the center nodes in the network and how they are implicitly overloaded as many optimal paths tend to have center node as an intermediate hop. Thus, the center node becomes the bottleneck and in many cases becomes a reason for congestion.During this course of study we are convinced that unbiased distribution of load causes adverse and undesirable effects on network performances and load balancing is an obligation for every routing protocol.

1.3 Research Statement

The research statement is as follows :

- To incorporate load balancing mechanism into a multi hop multi path routing protocol (like AOMDV) for achieving better load distribution over nodes in a network.
- To alleviate load from hot-spots mostly the centrally located nodes in a network without introducing unaccepted delay.

1.4 Objectives

Our objectives are as follows :

- To incorporate our load balancing strategy into AOMDV.
- To implement the proposed modified AOMDV in NS2.34 on ubuntu 12.04.
- To analyze and validate the anticipated results through simulations.
- To compare both the AOMDV and AOMDV-LB for network performances plus the average load on center nodes.

1.5 Thesis organization

The rest of the thesis is organized as follows:

In Chapter 2, we discuss some fundamental background concepts related to our work.

In Chapter 3, we present a survey of the literature studied and researched. The chapter presents many existing solutions and ideas coherent to our topic.

In Chapter 4, we brief our proposed mechanism to balance load and alleviate load from center nodes.

In Chapter 5, simulation and results analysis is clearly manifested through graphs.

Chapter 6, concludes our work and gives scope for future work.

Chapter 2

Background information and theory

2.1 Introduction

In this chapter we shall briefly discuss the concepts that are prerequisite for understanding the contents of the thesis. We would encourage a novice reader to review this chapter for the fundamental concepts while an experienced one can skip to Chapter3. The concepts discussed here are basics of routing , a need for balancing load , and the popular AOMDV[2] routing protocol.

2.1.1 Routing

To put in simple terms , routing is a mechanism by which data packets are forwarded onto the next neighbor who either has a path to the solicited destination or is the destination itself. Routing in wireless networks is distinct from routing in wired networks , in the former the routing of packets happen on a hop by hop basis called multi hop routing while in the latter routing is done on a single dedicated path.

A node in a wireless networks is only aware of the next immediate neighbor who promises to deliver the packets to the desired destination and has no information of other criterion or intermediate nodes that form a valid path. Moreover, with the absence of any central authority or base station the nodes itself take up the burden of routing. Hence routing in the context of wireless networks is a complex task and needs efficient routing protocols that utilize the network resources judiciously. There are two known types of routing discussed below.

2.1.1.1 Single path routing

In this type of routing methodology aka shortest path routing , the source node stores information of only one immediate neighbor with the least distance to the destination. The routes are updated dynamically and on demand. When a node needs to transmit a data packet to a destination it only has to see which of its neighbor can deliver to the destination without regard to any other criteria since only one minimum hop path is stored.

2.1.1.2 Multi path routing

The variant of single path routing is the multi path routing where a nodes stores more than one hop neighbor to a desired destination in its routing table. The transmissions occur simultaneously on multiple paths. Multi path routing is more complicated than single path routing in this there arises the problem of interference with the simultaneous transmissions. Hence, multi path routing protocols have to design protocols to introduce no collisions.

2.1.1.3 Semi multi path routing

The nomenclature of this method does not exist in the literature and is a name coined only for the purpose of comprehension. This is a variant of multi path routing protocol where multiple paths to a destination are stored in the routing table of a node but transmission do not occur simultaneously. The alternative paths other than the least distance path serve as contingency paths in the events of link breakdowns or other failures. The purpose of this type of routing is to provide fault tolerance to the networks. Our proposed model of routing is semi multi path routing.

2.1.2 Load Balancing

As the name indicates we are required to balance load in a network but what does load and balance mean in the context of wireless networks? Load refers to the traffic or the data packets a node has to forward onto the the appropriate links for deliver at the destination. Balancing on the other hand means to distribute load over nodes in a network in an unbiased manner. This means that no node in the network must be burdened to transmit more packets than other nodes unless situation demands. The load imbalance in a network is attributed to the routing protocols and the way in which they pick up valid source-destination paths. Thus, a good routing protocol not only has good throughput and minimum latency but also strives in proper distribution of load.

When load is not balanced it introduces unnecessary delay in packet delivery , increases packet drop ratio , affects the overall throughput , prunes a node's lifetime , partitions the network and becomes a reason for congestion. Thus, it is important that a routing protocol lay emphasis on balancing load along with other considerations.

2.1.3 The center nodes

Though mostly overlooked, center nodes are the backbones of a network connecting numerous subnetworks with other subnetworks. The literature has very little mention about the significance of the center node but evidently they are the most dominant nodes in any wireless network due to their intrinsic nature in providing connectivity across subnetworks. Sometimes center nodes are the only gateway for certain networks to other networks and the livelihood of such networks depend on the life of the center node. Center nodes are the traffic carrying nodes and undertake the burden of forwarding relatively greater data packets compared to other peripheral nodes.

Evidently thus is the power and significance of center nodes in a wireless network. Hence, we must try to design routing protocols that avoid 'hot spots' and concerns with extending the lifetime of the center nodes.

2.2 The AOMDV routing protocol [1]

One of the most prevalent routing protocol in the context of multi path routing is the AOMDV[2]. Marina and Das present the AOMDV protocol, which uses the basic AODV route construction process, with extensions to create multiple loop-free and link-disjoint paths. AOMDV mainly computes the multiple paths during route discovery process and it consists of two main components: a rule for route updates to find multiple paths at each node, and a distributed protocol to calculate the link-disjoint paths.

In this protocol, each route request and route reply packet arriving at a node is potentially using a different route from the source to the destination. All of these routes cannot be accepted since they can lead to creation of loops (see Fig. 2.1). The proposed advertised hop count metric is used in such a scenario. The advertised hop count for a particular node is the maximum acceptable hop count for any path recorded at that node. A path with a greater hop count value is simply discarded and only those paths with a hop count less than the advertised value is accepted. Values greater than this threshold means the route most probably has a loop.

The following proven property allows to have disjoint routes : Let a node S flood a packet m in the network. The set of copies of m received at any node I (not equal S) each arriving via a different neighbor of S, defines a set of node-dis-joint paths from I to S. This distributed protocol is used in the intermediate nodes where multiple copies of the same route request packet is not immediately discarded. Each packet is checked whether it provides a node-disjoint path to the source.

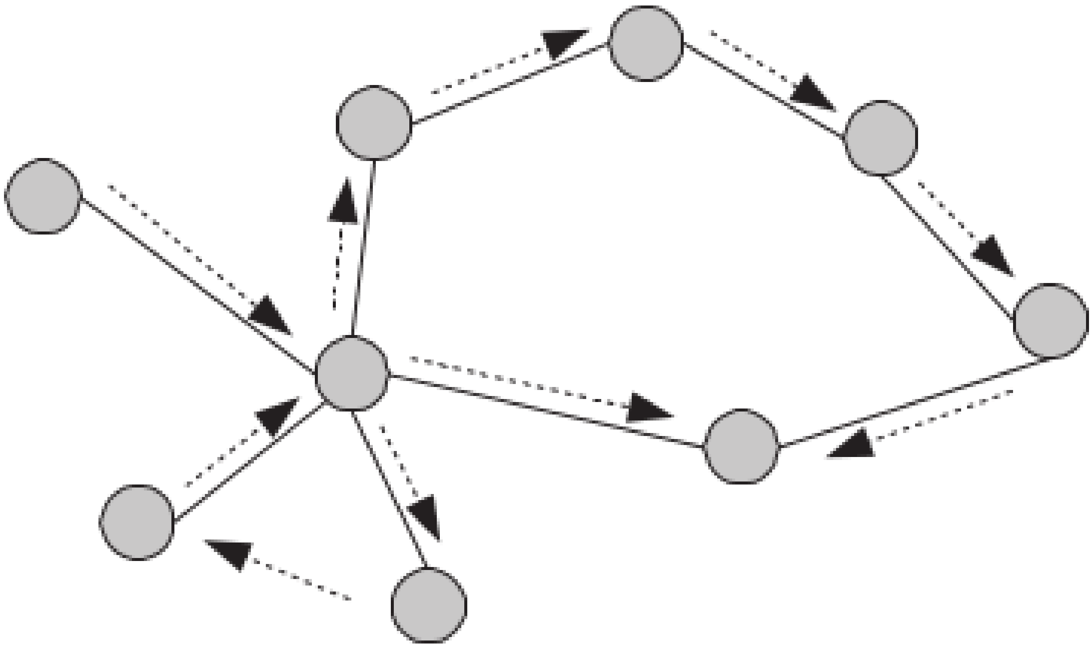


FIGURE 2.1: Example of a potential routing loop scenario with multiple path computation [2]

2.3 Conclusion

Having reviewed some of the fundamental concepts pertaining to the thesis topic we are ready to embark a journey into understanding the research work undertaken by us. The concepts provided are not complete but are sufficient enough to read and understand our proposed work. Please note that our work is entirely derived from the implementation of AOMDV routing protocol and all modifications suggested are directly associated with it.

Chapter 3

Literature Review

3.1 Introduction

In the sections that follow, we present a brief overview of the existing literature centered around load balancing in wireless networks. The work is not exhaustive but effort has been made to list the most appropriate ones that are coherent to the topic. It is our endeavour to prepare the foundation for better understanding and appreciation of the work carried out.

3.2 The Literature

The literature has a vast mention of routing protocols for both single path routing and multi path routing. Each routing protocol has a different objective to achieve and researchers have come up with unique solutions to improve upon the existing ones or bring about something entirely new. While no definitive argument can be made about the effectiveness or popularity of a particular routing protocol we rely on a comparative study presented in the research community. In any case , we appreciate and acknowledge all work studied and researched under the canvas of routing and load balancing in wireless networks.

3.2.1 Mechanisms in multi path routing

The articles below are some of the associated load balancing mechanisms in the multi path routing protocols where more than one path information is available for a destination at the source.

MALB is a multi path routing protocol by Shouyi YIN and Xiaokang LIN [6] that employs a filtering model that combines both per packet and per flow filtering to shift traffic among multiple paths thereby facilitating the data packets not to be received out of order. The mechanism of load balancing to distributing traffic across many paths is a decision taken based on the measurement of path statistics like traffic load and packet delay. The path statistics are gathered by sending probe packets periodically. The operation of the protocol is broadly divided into two stages :

1. balance phase and
2. imbalance phase

In the balance phase the congestion measures (a function of path statistics) on multiple paths are equalized but when the congestion measures become unequal the paths are said to exhibit an imbalance phase which then moves to balance phase for equalization.

The modification proposed on DSR [7] by Lianfang Zhang et al [8] is yet another protocol running on the same lines of MALB. It is essentially a multi path source routing protocol that forwards packets on multiple arbitrary paths without consideration to the path calculation in intermediate hops. The load balancing methodology in this protocol is again based on probing packets periodically but here to calculate the RTT(round trip time) using the Karn's algorithm [9] that aids in the estimation of delay in a path. Such delay calculation gives the picture of congested or heavy traffic paths and helps us in dispatching fewer packets on paths that report greater delay than the anticipated and greater packets on paths with accepted delay.

Wu and Harms [10] coined a metric correlation factor , η , defined as the number of links connecting two node disjoint paths. The η value equals zero when there are no links between the paths and we conclude that the paths are completely unrelated. When the η value is non-zero the paths are said to be η related. The analogy they draw is : larger the η value greater the average end to end delay on both the paths. However, they do not base the path selection criteria solely on correlation factor but also on relatively shorter alternative paths and node disjointness. This approach not only tries to improve better load distribution on paths but also decreases the average latency.

Another yet subtly different metric interference correlation factor defined by Evan et al, [11] counts not the connecting links between paths but only those connecting links that fall within the interference range of the paths. The interference range is assumed to be twice the transmission range. Their load balancing criteria is purely based on this parameter which has shown considerable improvements in terms of throughput from

0.25 up to 0.8 when multiple paths are introduced. Based on the interference correlation factor the authors have tried to achieve a global schedule of packet transit on paths that causes no collision thereby improving overall throughput on that path.

3.2.2 Mechanisms in single path routing

In the shortest path routing or popularly known as single path routing there is absolutely only one path information to a destination at any given instant of time. Lets look into some of the load balancing solutions introduced into the research community in this regard.

L. Wang et al , introduced a new routing protocol called Multi path Source Routing (MSR) [12] where the load balancing mechanism was achieved through the metric *weight*. The *weight* featured in every path information and is a per-destination based load distribution *weight* between all the routes that have the same destination. Its value is calculated by a heuristic equation given below :

$$W_i^j = Min_j(\left\lceil d_{max}^j \div d_i^j \right\rceil, U) * R \tag{3.1}$$

where
d_{max}^j : max delay of all routes to the same destination
d_i^j : delay of route with index i
R : factor to control the switching frequency
U : bound value to insure W_i^j should not be too large

CHAMP routing protocol by Valera , Rao and Seah [13] , uses cooperative packet caching and shortest multi path routing to reduce packet loss due to frequent route breakdowns. Their load balancing mechanism is to use a five-packet data cache, where CHAMP exhibits excellent improvement in packet delivery, outperforming AODV [14] and DSR [7] by at most 30% in stressful scenarios. Furthermore, end-to-end delay is significantly reduced while routing overhead is lower at high mobility rates.

Roy et al, [15] demonstrated through simulations that route coupling cannot be mitigated with only node disjoint paths but either zone disjoint or partial zone disjoint paths are used for data communication. The zone disjoint paths are those paths that do not interfere with transmission on other paths. These paths are very difficult to find and hence the use of directional antennas have proven to improve a lot better than omni-directional antennas.

The degree of nodal activity defined as the number of active paths through a node given by Zhu et al, [16] in their new routing protocol LBAR, dictates the amount of load a node should undertake for a better load balance in the network. The path with least degree of nodal activity is selected for traffic transit.

Lee and Riley [17] propose a solution where overloaded nodes have the freedom to forbid further establishing of routes through them until their overloaded status get dissolved.This serves as a mechanism to avoid an unbiased load distribution on nodes. The merit of the protocol lies in the fact that the decision of overloading in bestowed on an individual node without the intervention of any central authority.

3.3 End is just the beginning

Until this point we have witnessed the existing research in single path and multi path load balancing mechanisms. We have established an understanding of the solutions proposed and their potential to improve various network performances. What is imperative at this juncture is to know the importance of the centrally located nodes and their role in routing packets.

It all began with the analysis conducted by Pham and Perreau [3] in the year 2003. Their analysis has concluded that when routing protocols pick up shortest paths between any source-destination pair it often so happens that the centrally located nodes in the network participate in many routes and apparently have greater load to transit than other peripheral nodes. Their argument is augmented by the fact that the minimum distance between any two points separated by a large distance always passes through the radius; called displacement.

With [3]'s work as a motivation Oussama et al [4] have introduced the load balancing strategy for both reactive routing protocols and proactive routing protocols. Their metric of concern is the routing table size calculated by a recurrence relation for reactive routing protocols and the size of a node's MPR list in case of proactive routing protocols. Both strategies have shown remarkable mitigation of load on centrally located nodes.

Our work is inspired and based on the ideas and analogies put forth by the above two works along with the popular AOMDV[2] routing protocol.

Chapter 4

Load Balanced AOMDV

4.1 Introduction

In our efforts to balance load in a network of mobile nodes, we have improvised AOMDV to incorporate load balancing mechanism for efficient use of network resources resulting in prolonged node and network lifetime. For this, we have based our proposal on the existing routing protocol AOMDV and introduced the mechanism of load balancing naming our modified AOMDV a Load balanced AOMDV(AOMDV-LB). AOMDV is a popular multi-hop multi-path routing protocol that is largely prevalent and in use for real time applications in MANET.

The complete understanding of the model, working and implementation of AOMDV was briefed in the previous chapter. The reader is advised to review /refChapter3 for better understanding of our protocol. Only the mechanism used for load balancing is explained here. . .

4.2 The strategy to load balancing

In shortest path routing the criterion on which a path is selected relies on the minimum hop distance between the source-destination pair. Such a criterion picks up paths that have central nodes as intermediate hops for many source-destination pairs. This is the reason why center nodes have more traffic to transmit than other nodes. The shortest path between any two points always passes through the center, and shortest path routing picks the shortest possible route. Thus, it can be established that load imbalance can be mitigated if we come up with a strategy that can push the traffic further the center nodes and allow active node participation and diversity as a whole. One way to achieve this is by not choosing the center nodes of the network when another path with peripheral nodes promises a relatively optimal hop distance. Relatively optimal is rather not an absolute unit of measurement but a hop distance that does not introduce an unaccepted delay. The participation of the center node is not ignored but it is important to emphasize its role in providing shortest paths to many source-destination pairs and hence its mitigation an obligation. Hence, we state our solution here:

4.2.1 The Idea

New metric called load will tells us the approximate load a node is subjected to in a network, its value will indicate the measure of current load. This Load will then feature in every RREP packets to enable the source in choosing a path that promises better load balance based on two criteria quoted below:

1. minimum value of load among all possible candidate nodes as next hop and
2. relatively smaller hop count than the optimal path

The number of routes a node can support, in essence be an intermediate hop to a valid source-destination path can be judged by the number of RREP messages that route back to sources. Intuitionally, we can argue that if a RREP is routed back then there is a high chance that the corresponding node will participate as an intermediate hop for data transfer. So, the conclusion is, greater the RREPs routed back through a node, greater the load and greater the possibility for it to be the center node of the network. Or, if locational implication is not to be enforced, then we can still comment on the unbiased load distribution on that node which should be alleviated.

4.2.2 The metric load

Every node maintains a counter labeled load which will count all the unique RREPs routing back through it. Now, whenever a node routes back a RREP, it will sum the load field in the RREP with its own load counter and then routes back the RREP to the upper node. Hence, every node in a valid source-destination path will add its counter to the counter in the RREP packet until this RREP finally reaches the source. The source and the intermediate nodes then choose from among the valid RREPs they receive the best load balancing path with the help of the criterions stated above. Therefore, we have two alias for load yet they are distinct in the context of node and RREP, the former being an indication of a node's load and the latter a measure of a path's load.

4.2.3 The criteria

The first criterion helps us in finding a path which has very fewer loads or in other words does not have much traffic in transit. The additive value of load that features in RREP is the measure of the load across all the nodes below that node. The mobility of the nodes cause to change this value often but due to regular purging of routes the routing table ensures to keep a fresh value of load rather than stale ones.

The second criterion is to make sure that in pursuit of load balance we may not end up choosing larger routes resulting in greater latency. Hence, we choose those routes that are relatively optimal. The relatively optimal can be achieved by allowing only those next hops that differ by only an admissible number of hops from the optimal. The admissible number of hops is dependent upon the network diameter and is another area of research but in our approach the max hop difference was fixed to 4, an experimental value beyond which no good results were yielded.

4.2.4 The routing table

The convention route table at any node stored the two most important parameters, the possible next-hops and the corresponding hop-counts to the indexed source. With our model a new entry load will also be associated with each next-hop record indicating the load measurement in that path. The new format of the route table record is as follows:

TABLE 4.1: Routing Table

next-hop	hops	load	expire
A	12	87	–

This change in the routing table is the only means by which we can get a peek into the complete load picture of the possible paths and the network aiding us in determining our next hop.

4.3 The math behind

Having done with all preliminaries of our basic objective in finding a best load balanced path, our next job is to choose one. We assume that a source has initiated an RREQ to a destination and in response it has received few RREPs. It is necessary to iterate the way AOMDV or any multipath routing protocol stores more than one next hop for a destination. All possible next hops to a destination will be stored in a linked list indexed by the corresponding destination. Now, we are ready for the math, we have the possible next hop entries for a destination along with our new load measurement. So, we choose the next hop with the minimum load from among all list entries in that list. Remember, we have only those path entries that do not introduce an unaccepted delay, a prerequisite for becoming a list member. In the mathematical jargon, we must use:

$$nexthop = \forall_{nexthops} min(load) \tag{4.1}$$

4.4 The algorithms

The following shows the way in which our proposed algorithm picks up a path which will guarantee fewer loads. And by fewer loads we mean a node farther away from center. Thus alleviating the center nodes from the load imbalance and helping in longevity of connected sub-networks.

Algorithm 1 Algorithm1 pathFind algorithm

```
if path = rt → rtfind(dst) ≠ 0 then
    while path ≠ 0 do
// fetch that record with min load among next-hop records

        if path → load ≤ rtminload then
// rtminload will have the min load among all next-hops for that destination
forward(path,pkt);
break;
        end if
        path = path → next
    end while
end if
```

The algorithm below is building the RREP packet. Notice that it now includes the load field in the packet. This load is the summation of the load that path undergoes and the nodes load as the node will now become an intermediate node. The details pertaining to load only are emphasized other considerations are omitted for clarity.

Algorithm 2 Algorithm2 send reply algorithm

if $path = rt \rightarrow rtfind(dst) \neq= 0$ **then**
  while $path \neq 0$ **do**
// fetch that record witn min load among next-hop records
    if $path \rightarrow load \leq rtminload$ **then**
// rtminload will have the min load among all next-hops for that destination
      $rpdst = path \rightarrow nexthop$
      $rphopcount = path \rightarrow hopcount$
      $rpload = path \rightarrow load + load$
      $rpexpire = path \rightarrow expire + CURRENTTIME$
break;
    end if
    $path = path \rightarrow next$
  end whileforward(rpdst,p);
end if

4.5 Remarks

In this chapter we have developed a brief understanding of our routing protocol which was predominantly similar to the popular AOMDV algorithm but subtly different. One can appreciate the mechanism in which the protocol is trying to choose those nodes which are not heavily loaded and yet do not introduce unnecessary delay in the packet delivery time. The improvements found can be visualized by simulations which is detailed in Chapter 5.

Chapter 5

Simulation and Results Analysis

5.1 Introduction

In the following sections we will discuss the approach in validating our model, the tools necessary for simulating the network environment, the visual manifestation of the validity of the model, the improvements seen and the compromises made. The following states the utilities used in completing the implementation:

- NS version 2.34 : implementing the protocol functionality
- NSG version 2.1 : jar file for genrating TCL scripts to mimic a desired topology
- NAM version 1.15: network animator to visualize the network in real time
- GAWK version 4.0.1: scripting tool for analyzing the trace file
- LibreOffice Calc version 3: to plot bar and line graphs

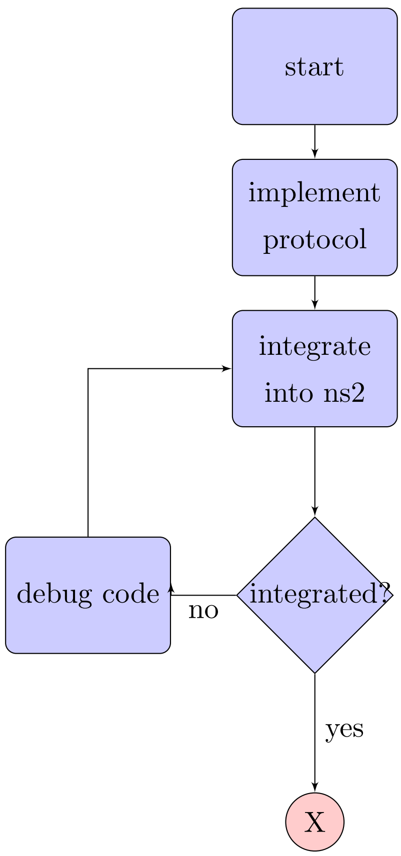
The details of the above packages is beyond the scope of this thesis and the reader is redirected to the internet for complete information and working knowledge.

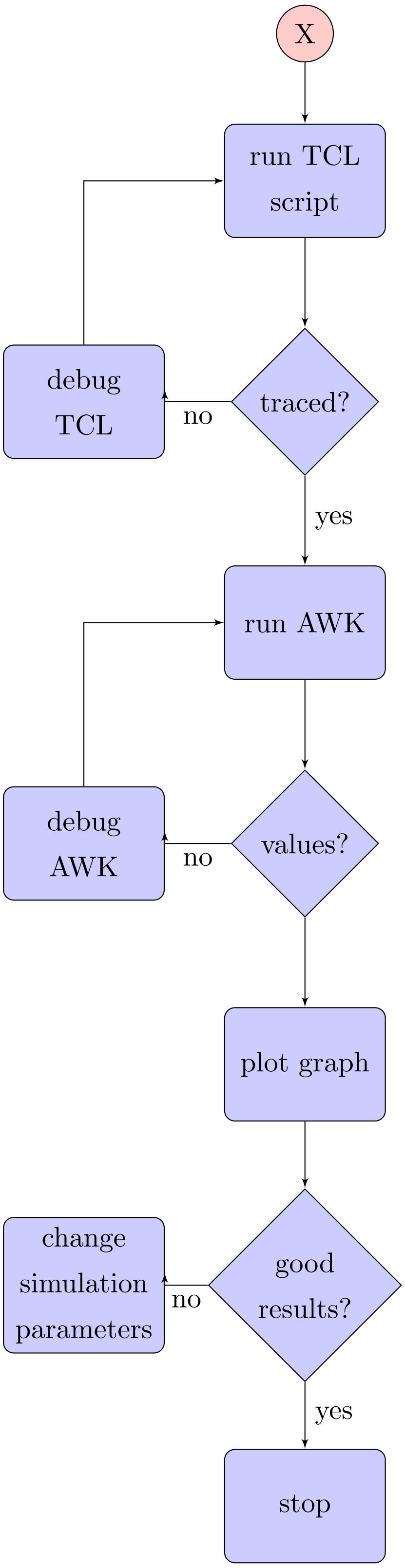
5.2 Simulation Parameters

Table 5.1: Simulation Parameters

S.No	parameters	values
1	Channel	Channel/WirelessChannel
2	Antenna	Antenna/OmniAntenna
3	Propogation Model	Shado
4	Interface Queue Length	50
5	MAC	802.11
6	Routing Protocol	AOMDV,$AOMDV - LB$
7	No of Nodes	16,50
8	Density	4096 nodes per kmsq
9	Simulation time	1000s
10	Mobility	Static
11	Traffic	Node-UDP
12	CBR rate	$\leq$ 5.4 mbps
13	Transmission range	250m

5.3 The Process




X
run TCL script
traced?
no
debug TCL
yes
run AWK
values?
no
debug AWK
plot graph
good results?
no
change simulation parameters
yes
stop

5.4 The Results

In what follows we display the visual intepretation of the results acieved during and after simulation of the proposed scheme. The bar graphs show how both the existing and the modified protocols distribute load on nodes of a network. The xy plot helps us in concluding the adverse effect of the protocols on the center node.

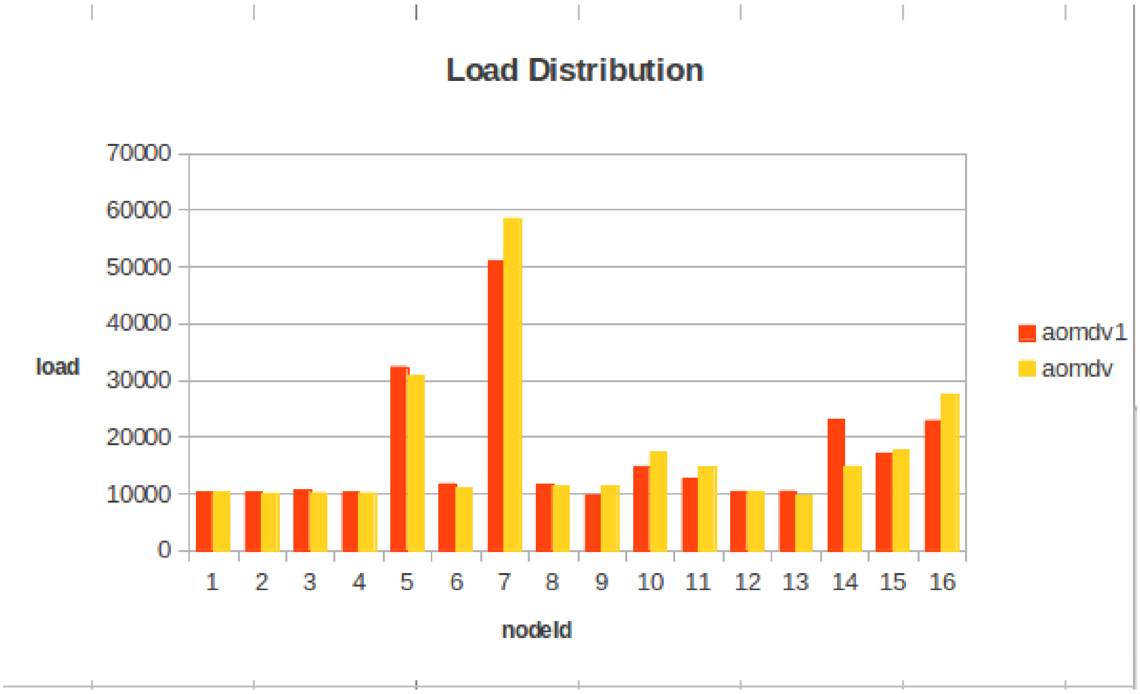


FIGURE 5.1: load on each node in a network of 16 nodes

In figure 5.1 we see the load distribution of AOMDV colored yellow and in red of AOMDV-LB. The visual intepretation tells us that AOMDV-LB maintains a proper distribution than AOMDV owing to its sharp peeks at some nodes in which places AOMDV-LB has a relatively less load. The difference in load at nodes prove that AOMDV-LB is balancing load better than AOMDV.

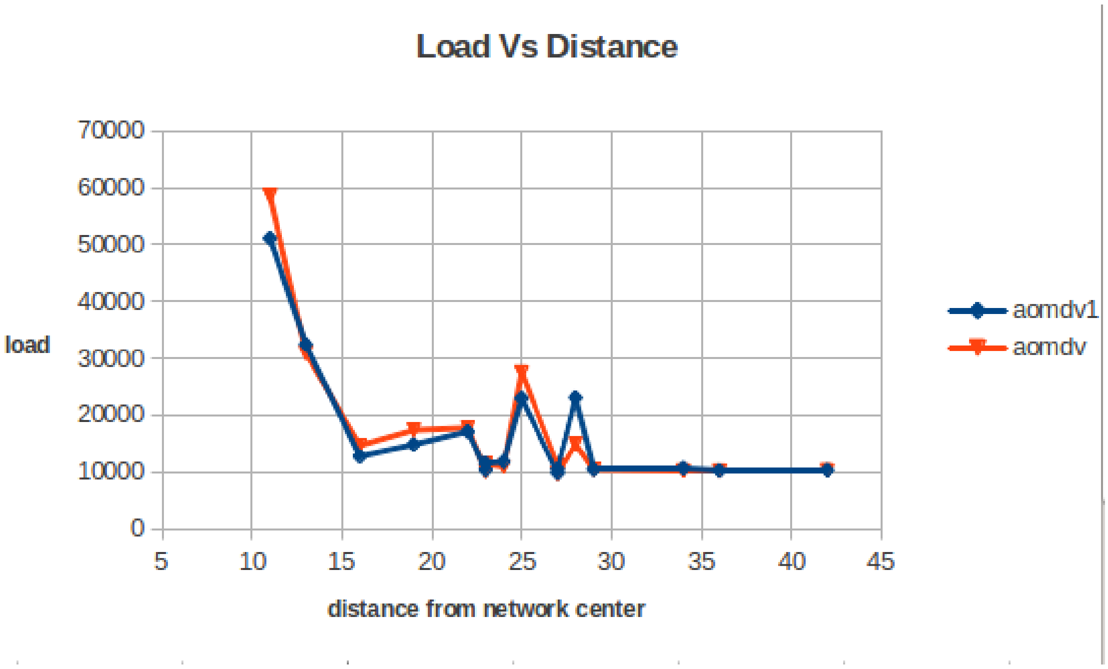


FIGURE 5.2: load Vs distance from network center (16 nodes)

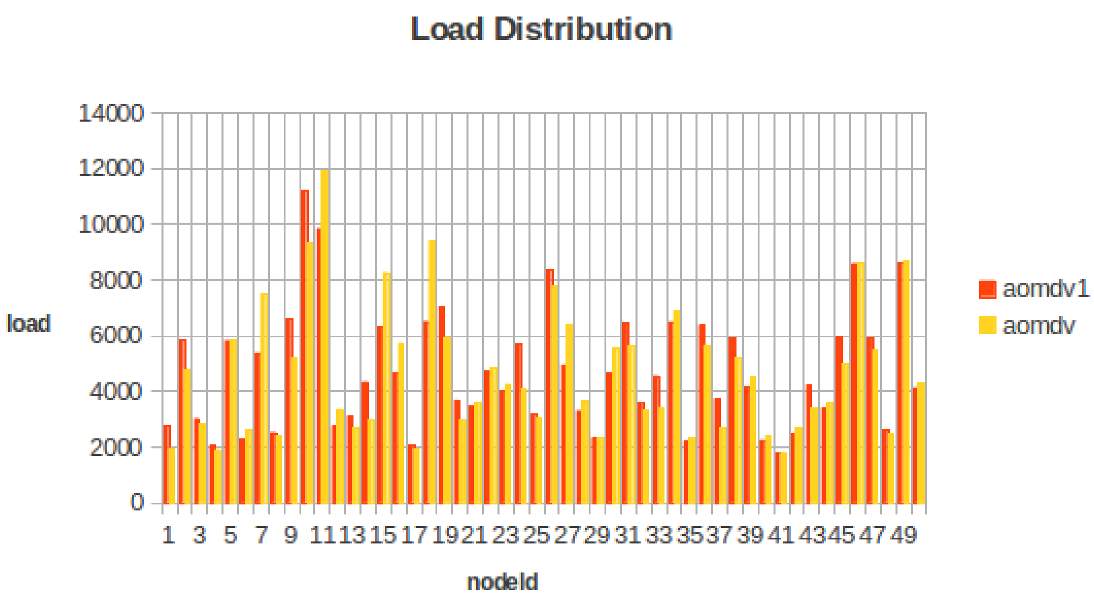


FIGURE 5.3: load on each node in a network of 50 nodes

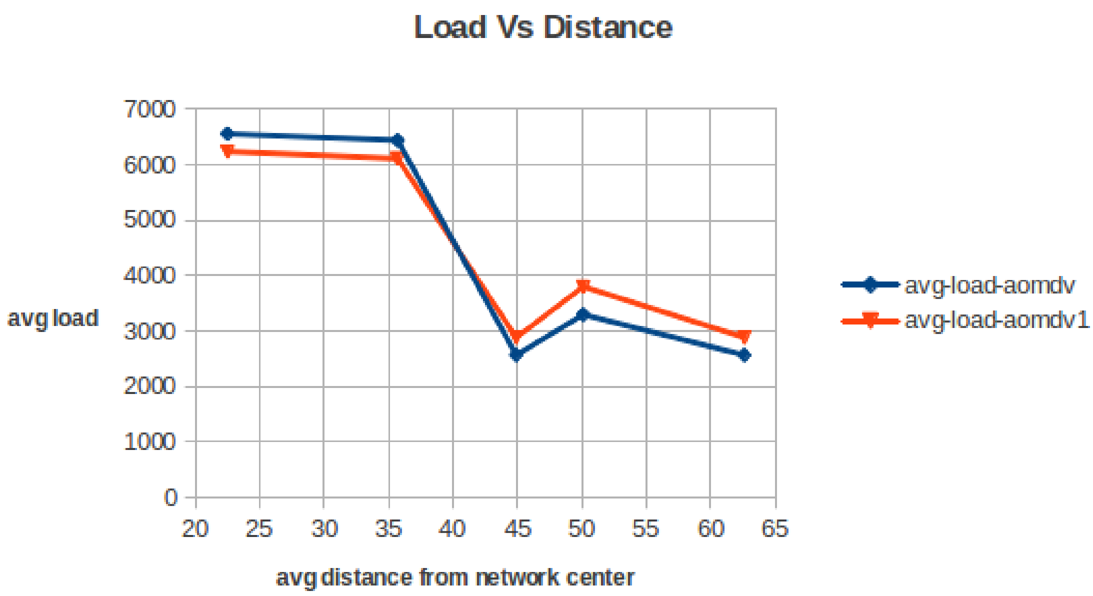


FIGURE 5.4: avg-load Vs avg-distance from network center (50 nodes)

5.5 The Pros and Cons

It this section we shall carry out a comparative study on the performances of both the protocols under the simulation parameters oputlined in Table 5.1. The table data are self explanatory and require only the knowledge about the metrics defined.

TABLE 5.2: Performance Comparision for 16 nodes

S.No	Metric	Aomdv	$Aomdv - lb$
1	Total CBR sent	161954	161954
2	Total CBR received	154093	152268
3	recv/sent ratio	95.146	94.0193
4	Total forwards	20000	19960
5	avg-end-to-end-delay	0.0726s	0.0490s
6	routing overhead	0.0725	0.0740
7	avg throughput	315kbps	311kbps
8	pkt loss	13675	16068
9	pkt loss in Bytes	6585208	7788012
10	pkt loss ratio	4.85	5.98
11	No of collisions	689527	677127

TABLE 5.3: Performance Comparision for 50 nodes

S.No	Metric	Aomdv	$Aomdv - lb$
1	Total CBR sent	910250	910250
2	Total CBR received	827180	816280
3	recv/sent ratio	90.87	89.67
4	Total forwards	117684	124151
5	avg-end-to-end-delay	0.0307s	0.0329s
6	routing overhead ratio	0.504	0.5263
7	avg throughput	169kbps	167kbps
8	pkt loss	18424	20756
9	pkt loss in Bytes	6973860	7987892
10	pkt loss ratio	9.12	10.32
11	No of collisions	1442582	1487410

A comprehensive yet a consice study and analysis of the experimental values as depicted by the graphs and tables follows:

Our protocol, AOMDV-LB being a modified version of its counterpart AOMDV has exhibited certain characteristics that run along the same lines. We see from the aforementioned values the significant difference of about 0.3 sec in average end to end latency over the existing protocol for 16 nodes. The reason for such a reduction can be augumented by the fact that the center nodes are now a bit relieved from unbiased traffic as briefed in the previous section. The same is not consistent when the nodes are scaled to 50 and we witness a 0.0022 sec latency, a condition that can be attributed to high node density in a smaller topological area which has caused the nodes to cluster around each other thereby increasing the waiting time in the queue. Another rather an albeit benefit has been seen in the number of collisions, a massive 11 thousand decrease but alike the latency does not scale to 50 nodes for the same reason mentioned above.

There has been no significant improvements in throughput or packet delivery fraction but at the same time the same difference cannot qualify to degrade the performance given the subtle graceful decrease. Eventually, we can conclude quoting that the experimental values as showcased encourage us to bring our protocol live at the meager cost of throughput and pdf. We believe, given a larger topographical area the improvements can equal or outpar the existing AOMDV. Having said,this can only be validated by proper simulations which was beyond our timeframe. Hence, we will carry out the same as our future work and try improvising the performances.

5.6 Possible Applications

As per the conclusions drawn from this chapter , we are of the understanding that AOMDV-LB is ready to embark upon a new journey into the real time applications of MANET. Given the conflicting performances and non scaling we might very well restrict its applications to those networks where network longevity or node's extented lifetime is of priority rather than the packet delivery fraction or throughput. Throughput and packet delivery fraction are the most important requirements of a good routing protocol but we would like to reiterate our objective in alleviating the unbiased load at center nodes and we have succeeded in mitigating center node's load. The other performances were just the byproducts of this improvement.

But we believe that emulating a real time network will enable us in comprehending the pluses and minuses clearly. And surely we would like to extend our work to come up with a concrete and a better routing protocol sooner and later. Finally the list of possible applications are stated below:

- Search and Rescue Operations
- Replacement of fixed infrastructure in case of environmental disasters
- Wireless P2P networking
- Virtual classrooms
- Networks at construction sites
- Outdoor Internet access and many more...

Chapter 6

Conclusion and Future Work

6.1 Things Done!

All through the thesis we have tried to bring clarity to the reader in understanding and appreciating the research work undertaken. In Chapters 1 and 2, we have developed a background of MANET and its growing popularity, the evidence of load imbalance in the network and the partiality or favouratism in picking up centrally located nodes for data transfer. The way in which this unbiased load on center node became the reason for many subnetwork partitions and early death of nodes. Hence, it became the problem of interest requiring mitigation.

In Chapter 3 we have explored the existing models and solutions in this regard and have come to believe the complexity of multipath routing has given rise to a new definition of multipath routing (inherently singlepath routing with multiple next hops for contingencies).

In Chapter 4 we have proposed a modified AOMDV routing protocol called Load Balanced AOMDV, the complete mechanism employed in balancing load. The changes that were obligatory for its implementations.

In Chapter 5 we have presented our experimental results and outlined a brief comparative analysis of both AOMDV and AOMDVLB. The average 2.26% load reduction on center nodes have been evident from the graphs plotted.

6.2 Things to Do...

The Multiple Next Hop Protocol needs a special mention here especially for being coined as one of the most efficient multipath routing protocol in the research community.The MNH highlights the flaws in AOMDV and also overcomes them very elegantly.Therefore our plan is to extend our load balancing mechanism to MNH, study the intricacies and report the differences that manifest thereafter.The description of MNH is beyond the scope of the thesis yet we try to give you a peek into the details in the Appendix

Appendix A

The Multiple Next Hop Routing Protocol

The multiple next-hop routing (MNH) [?] , protocol is one of the most efficient multipath routing protocols published in the literature. Its objective is to have multiple next-hop entries to a destination. While it uses only the optimal route to transmit data the other hops are contingency paths in case of failure. These paths give the protocol the fault tolerance capability and reduces path searching time.

The protocol is essentially an AODV [14], routing protocol with the additional feature of having multiple next-hops. It exploits the RREP dropping in [aodvref] to build multiple next-hops. The beauty of the protocol lies in the reduction of control packets generated in events of failure as the route errors are now handled by the immediate upper node rather than the source that originated the RREQ. This idea has indeed reduced the control messages and the route construction times required to find an alternative route.

The MNH indeed has no mention of the load balance but based on its partiality to optimal paths we may draw the same conclusion that the central node is burdened to carry more load that other peripheral nodes, in sync with Pham and Perreau [3]. For a complete study of the protocol the reader is redirected to mnh paper.

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