East West University

Undergraduate Thesis Report

On

A New Routing Algorithm for Inter-cluster Load Balancing in Wireless Mesh Networks

By

Shourov Barua	(2012-1-80-018)
Hossain Mohammad	(2013-1-80-030)
Md Mamun Miah	(2013-1-80-034)

Submitted to the
Department of Electrical and Electronic Engineering
Faculty of Sciences and Engineering
East West University
Dhaka, Bangladesh

In partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering

(B.Sc in EEE)

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Approved by

Thesis Supervisor	Department Chairperson
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Abstract

When MANET is connected into the Internet, the gateways are the entry points of all traffic between the hybrid networks. Usually, a large amount of traffic load may become concentrated in some gateways and congestion occurs. To resolve this problem, this thesis paper proposes a load balancing routing algorithm, called LBRA, in MANET to distribute the traffic load among multiple gateways. Through simulation, we show that the proposed algorithm can distribute the traffic load uniformly among multiple gateways and suppress the increase in the routing path length at most 20% compared to the shortest path routing.

Keywords - Load balancing; multiple gateways; routing; MANET; Internet connectivity.

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Authorization

We hereby declare that we are the sole author of this thesis. We authorize East West University to lend this project to other institution or individuals for the purpose of scholarly research.

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Table of Contents

Page Number

List of Figures

Page Number

List of Tables

Page Number

Chapter 1

Introduction

1.1 History of Mesh Networks

Wireless system is one kind of communication process which connects two or more devices with each other. In 1880 Alexandar Graham Bell and Charles Sumner Tainter invented and patented a photophone which is known as the first wireless telephone. After that many wireless devices and systems were made to make our life easier. Wireless mesh network is one of many wireless systems which created a revolution in networking system. It is organized in a mesh topology. Before knowing about the wireless mesh network, we need to learn about the mesh network. Mesh network is one of the network topology. It is a topology where every single node is connected to other nodes. It means that if any node gets damaged or closed, they can use other ways to pass data. Wireless Mesh Network is one kind of communications network that is formed by adjoining radio nodes organized in a mesh topology. Each node relays data for the network and together they complete the distribution of data in the network. It can also be said that is one kind of ad hoc networking system built with the radio nodes. These nodes are divided into two parts: mesh routers and mesh clients. Mesh router is as like as the conventional router with gateway/bridge functionality to support mesh networking. Mesh routers basically send data from or to gateways. Mesh routers can be termed as the backbone of mesh clients. Mesh clients are the devices which are used by users such as computer, laptop, mobile phone and so on. Mesh clients can also work as a router but their hardware platform and software are much simpler than the mesh routers. It also means they do not have the gateway or bridge functionality.

Wireless mesh networks (WMNs) are very popular in wireless world now a days. Because of former communication system that is connected point to point with other devices. Mesh networks can pass on information through routing technique. In this method, the information is sent to the destination by hopping from one node to the next and so forth. If the system somehow fails then the connection will be lost. But wireless mesh network is a point to multipoint (multi-hop) communication system. Here one networking device is communicating with numerous other networking devices so that if any networking device fails there are multiple paths to use to communicate. In simple words, they have self-organizing, self-configuring and self-healing properties. Whenever a node breaks down or communication hinges self-healing property comes to its rescue. This makes the Wireless mesh networks reliable. Now-a-days, it is commercializing in many fields such as broadband home networking, community networking, building automation, high speed metropolitan area networks, enterprise networking and so on.

To provide a cost effective and dynamic high-bandwidth network over a particular coverage area wireless mesh network is one of the best infrastructures. Unlike WLAN access points; this network is constructed of peer radio devices which need not to be cabled. This infrastructure of a mesh network can also convey data over a vast distance. This can be done by chopping the distance into a series of short hops.

The wireless mesh network is different from the traditional wired access network as data is transported over multiple wireless hops. But this way of transportation increases the collision, packet corruption and other phenomena. As a result, gateway connection can get congested and become a bottleneck for the entire network. To lighten this problem we have to balance the gateway load of the wireless mesh router.

In this article we will discuss about the new multi-hop architecture called Wireless Mesh Networks (WMNs), the gateway load balancing and will show the negative percentage algorithm of the WMNs to provide ubiquitous Internet access.

1.2 Wireless Mesh Networks

Wireless mesh network is a type of computer network system which is created with mesh topology. In this thesis we will discuss about the wireless mesh network, the gateway load balancing and we will find out its negative percentage using algorithms. Besides these, we will also learn where we use the wireless mesh networking system.

We also focus on the backbone which is basically a part of a computer network, interconnecting different pieces of network. It provides the path for the information to be exchanged between different local area networks (LAN). Different kinds of networks from the same building or from different buildings can be tied together by a backbone. Recently, wireless mesh networks have been on top of interests for researchers. Among the mesh networks backbone mesh network is one.

Backbone mesh networks (BMNs) usually provide high speed wireless internet to the users and is consisted of wireless mesh routers (WMRs). Wi-Fi based backbone mesh networks have become an economical and efficient alternate for the wireless local area networks (WLANs). In BMNs, specialized WMRs called gateways provide the interconnection between the mesh network and fixed IP networks. Mesh routers perform backhaul routing and can be additionally served as access points (APs) for clients.

Although, BMNs have become exceedingly popular to provide broadband wireless internet, it faces quite a few problems. Selecting an optimal gateway and route is significant for the performance of the backbone network. For networks that have a single gateway connecting them to the internet, can become congested. This is a serious problem for the network and is an obstruction for the entire network. To dispel this problem and to improve the performance, we can assign multiple gateway nodes to distribute the load. But assigning multiple gateway nodes does not alleviate the problem totally. Efficient gateway and route selection is essential to extract the best outcome.

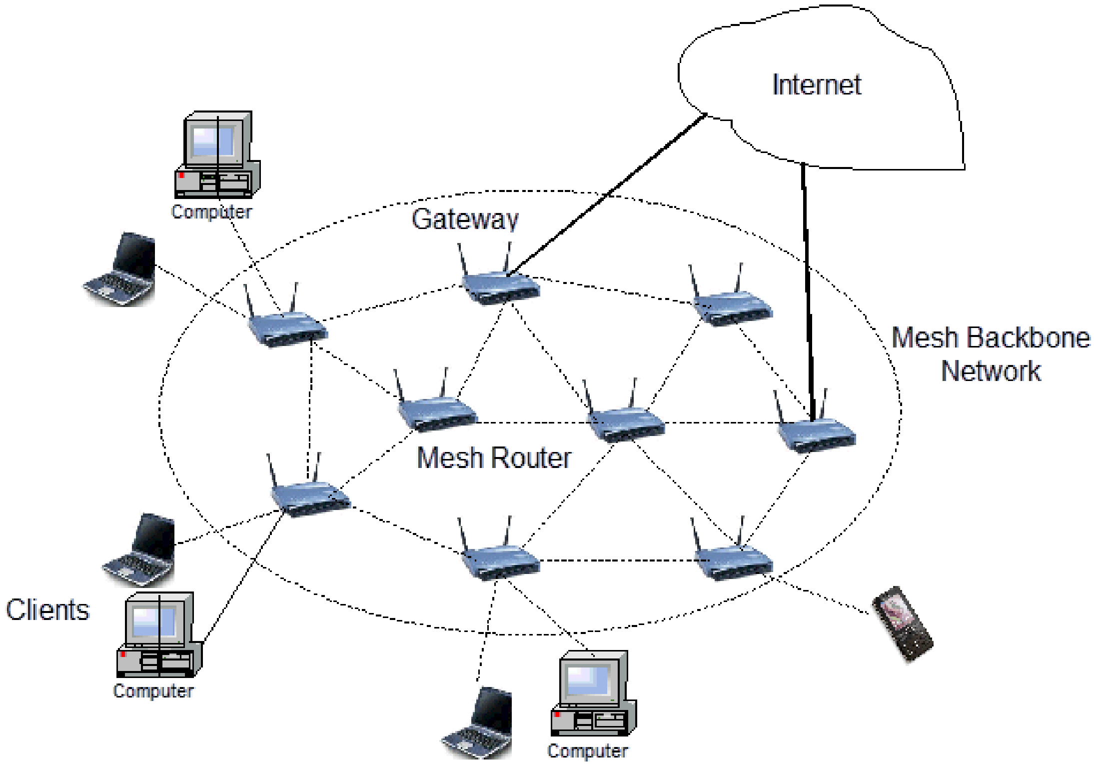

Figure 1.1: An example of a Wireless Mesh Network [1]

1.3 Gateways

Gateways can be termed as network nodes that are prepared for interfacing with other networks having different protocols. By performing necessary protocol conversions, a gateway can interconnect a network with different network protocol technologies. Although, the actions of a gateway and router are similar, the activities of a gateway are more complex. Gateways can operate at any network layer. A good example of a gateway is the computers used by Internet Service Providers (ISPs). The computers that ISPs use work as the gateways which connects the user with the Internet. A gateway is a vital facet of mesh routers. However, computers or servers can work as gateways.

1.4 Load Balancing

In communications, load balancing mainly translates into optimizing usage of resources. Optimizing can be done through maximizing throughput, minimizing response time or avoiding overload in any single source. When gateways are connected in a hybrid network or in mesh network, load balancing may occur due to heavy concentration at gateways. So using multiple gateways may give us more reliable solutions. There are many techniques to balance the load on gateways such as shortest path routing which we will be using as a baseline algorithm in this thesis.

1.5 Routing

Routing is defined as the selection of path for traffic in any kind of network. Routing can be used in multiple networks or in single network such as the Internet. In routing, packets are sent from a source node to a destination node with the view of forwarding data. Routing process typically directs forwarding on the basis of routing tables. In this process, routing tables preserve a record of the routes to various network destinations. Most of the times, routing path algorithms use only one network path at a time. Multiple routing techniques can also be used for alternative multiple paths.

There are many routing schemes based on the way of delivering a message. There are many routing algorithms too. Our baseline algorithm for this thesis is the shortest path routing. In shortest path routing algorithm, the shortest path is determined between two nodes or vertices in a way that minimizes the constituents of the sum of the weights of the nodes.

1.6 Mobile Ad Hoc Networks (MANET)

When mobile devices are connected wirelessly, in a self-configuring and infrastructure less network, it is called as mobile ad hoc network or MANET. Each device moves independently in a MANET irrespective of its direction. Each device is connected with other devices and can change its link to those devices frequently. Each of the devices work as routers by forwarding traffic not related to its own use. MANETs can be connected to the Internet as well. Multiple gateways can be connected in such networks resulting in a more dynamic topology. MANETs can also be termed as one kind of wireless ad hoc network.

Chapter 2

Wireless Mesh Technology and Potential Restraining Factors

2.1 Introduction

In this ever changing world of technologies, nothing remains static. The motto is always to keep improving. If you do not adapt with the change of time and environment, you cannot sustain your growth. Such is a wireless networking technology that needs to evolve. The growth of this technology has been eye catching and a tale to tell for. The global reliability of wireless mesh networks have increased rapidly since it came to the fore as an efficient broadband internet networking service.

Wireless mesh networks (WMNs) have enormous potential in terms of complementing the wired backbone with a wireless support. WMNs also have the edge over other networking technologies as it has self-organizing, self-configuring and self-healing properties. It is cost effective, can be used rapidly and it is easy to install as well.

Even though WMNs are efficient networking technologies, they also have some vital restraining factors. These factors hamper the deployment of WMNs. The problems include load balancing, frequent link fluctuations, excessive load on selective links, congestion, limited capacity due to half duplex nature of radios, improper buffer management etc.

2.2 Different Methods of Load Balancing

A lot of works have been done about load balancing in wireless networks. The proposed methods are usually different from each other in terms of gateway discovery method (reactive/proactive) and various measures. In "Efficient Traffic Diversion and Load-balancing in Multi-hop Wireless Mesh Networks" *by* Nandiraju, T. [2], a method has been proposed for which in case of excessive packet drops (more than a threshold) a gateway detects the active source and asks the source to send its traffic to other gateway. In "Multiple Path Routing using Tree-Based Multiple Portal Association for Wireless Mesh Networks" by P. Lin, K.H. Yeung and K. Y. Wong [3], another method has been proposed that uses a combination of wired and wireless networks to select the appropriate gateway. MR nodes select the desired gateway based on the order received from the central dispatcher. In "Gateway Selection in Backbone Wireless Mesh Networks" by U. Ashraf, S. Abdellatif and G. Juanole [4], a method called Back Bone Selection (BGS) is proposed that is a combination of Link Interface Factor (LIF), Expected Link Quality (ELQ), and hop count measures. Although the combination of measures leads to better load balancing, it increases routing overhead. In Ref [5], a distributed method is used and the measure for this algorithm is a combination of bandwidth utilization and hop count. In TBMGA protocol, each gateway broadcasts a Root Announcement (RANN) message to the network in constant intervals. This message is received by all mesh nodes. Each node selects the best message (among all of received RANN messages), and sends a RREP message towards the gateway. Therefore, each mesh node builds its own tree route to the gateway and sends its packets through the route.

Each mesh node compares RANN messages based on the ETX measure. The mesh node checks the ETX measure of the RANN message. If the measure is better than previous measures then it will be stored by the node. Otherwise, the node discards the packet. In the end, each mesh node has selected its best gateway which is a new RANN with the best measure. Anyway, to ensure a bidirectional connection, the gateway has to also be aware of new routes to reach mesh nodes. To do so, each mesh node – after selecting its main gateway (based on the ETX measure) – sends a RREP message to the gateway through the new route. Once the gateway receives the message, it updates its routing table and detects the nodes in its neighborhood.

But after a while it is possible that some queues of a gateway become congested compared to other gateways. In that case, the congestion must be distributed among the other gateways. To have a balanced load among the control nodes, the average of gateways' queue congestion must not exceed a threshold.

In the case of exceeding the threshold, the gateway must find one of the connected mesh nodes with the highest value and send a CHANGE – PKT message to it and ask the node to find another gateway (if that is possible) for transmitting its packets. Once the mesh node receives the CHANGE- PKT message, it sends a GW- REQ to other gateways. Those gateways that receive the message and can accept a new MN responds to it with a GW- REP message. Then the MN will be an associate of the first respondent gateway. Once a GW- REP is arrived at a MN, the node sends all of its extra traffic towards its new gateway, but if the traffic is not accepted by any gateway, the MN node continues sending its packets towards its last gateway. The first drawback of this method is that when a gateway sends a CHANGE-PKT to a node and changes the route of that node, it cannot anticipate the status of queue congestion at other gateways compared to its own queue. Thus, each node has to send some extra messages to other gateways. It is possible that the queues of other gateways are much busier than the default gateway, and hence, the packets are sent towards the last gateway which will possibly be rejected by that gateway and causes excessive rush. The second drawback is if a CHANGE- PKT causes a node to change its route, leaf nodes of that node also change their route. In other words, a CHANGE- PKT can change multiple nodes at the same time, and other gateways reject the MN. Thus, finding the best node for change and separating from the gateway has to be in such a way that does not cause a problem for other gateways. Changing the gateways might forms a ping-pong state. It means other gateways suffer from congestion and send CHANGE- PKT. If this situation continues, the network becomes unstable. Sending CHANGE- PKT has to be done periodically not simultaneously, because if the congestion at all gateways exceeds the threshold at the same time, the network will be flooded by CHANGE- PKT messages, and hence all mesh nodes have to send their packets towards their former gateway which is an unstable situation.

2.3 Various Researches to Topple Restraining Factors

In the paper titled as “Efficient Traffic Diversion and Load-balancing in Multi-hop Wireless Mesh Networks”, Deepti V. S. Nandiraju discussed about the aforementioned problems and proposed novel algorithms to solve them. She argued that her proposed solutions enhanced the network’s performance significantly. She provided a traffic differentiation methodology and Dual Queue Service Differentiation (DQSD) that helped her in fair throughput distribution of network traffic irrelevant of spatial location of its nodes. The author also addressed managing Internet Gateways (IGWs) in WMNs as one serious bottleneck candidate due to massive volume of traffic that needs to flow through them. She proposed a load balancing protocol, LoaD BALancing (LDBAL) to improve the problem. It can efficiently distribute the traffic load among a given set of IGWs. The author also talked about the load balancing and traffic distribution over multiple traffic paths in WMNs. In achieving the desired, reliable and robust performance she proposed another protocol named Adaptive State-based Multipath Routing Protocol (ASMRP). After extensive simulations she observed that ASMRP considerably improved the achieved throughput and significantly minimized end to end latencies.

In terms of providing multiple path routing for WMNs, we perceive another paper titled as “Multiple Path Routing using Tree-Based Multiple Portal Association for Wireless Mesh Networks” by P. Lin, K.H. Yeung and K. Y. Wong. In this paper, the authors described that the single portal association used in current WMN has bottleneck problem as it makes WMN potentially inefficient and unfriendly for users. To devour this problem, they have proposed Multi-path Routing using Tree-Base Multi-Portal Association or MR-TBMPA. It allows low-work-load nodes to take part in packet forwarding through multi-portals by reducing the impact brought by WMN's bottleneck problem. The authors also insisted that MR-TBMPA can bring about 70% reductions in the number of packet dropped as they have observed through OMNET++ simulation.

Another problem for WMN technology is the gateway selection. Normally in a Backbone Wireless Mesh Network gateway plays an important role. In the paper titled as "Gateway Selection in Backbone Wireless Mesh Networks" by U. Ashraf, S. Abdellatif and G. Juanole we notice that the authors discuss about the gateway selection problem. In this paper, they have emphasized on Backbone Mesh Networks (BMNs). BMNs are consisted of Wireless Mesh Routers (WMRs) that can generate wireless multihop backbone to provide high speed last mile wireless internet access. The authors proposed an efficient gateway and route selection scheme for BMNs in this paper. They also argued that it can be adopted for IEEE 802.11s mesh standard with minimal changes. They used gateway load, route interference and path quality metrics to choose the best available gateway and the route to that gateway. The authors also stated that simulation results have shown greater performance compared to other schemes.

The same authors also discussed about Expected Link Performance (ELP) metric for finding high throughput and low delay paths in 802.11 mesh networks in the paper titled as "An Interference and Link-Quality Aware Routing Metric for Wireless Mesh Networks" [6]. The authors here presented that ELP merges three different mechanisms to establish expected link performance precisely. They demonstrated that link quality information combining with cross-layered link interference estimation can select optimal paths. Simulation results showed that ELP has higher throughput as close as 12% and delays 40% less compared to Expected Transmission Count metric (ETX).

We know more about the ETX in the paper titled as "A High-Throughput Path Metric for Multi-Hop Wireless Routing" by D. S. J. De Couto, D. Aguayo, J. Bicket and R. Morris [7]. In this paper the authors illustrated how the ETX can locate high-throughput paths on multi-hop wireless networks. ETX lessens the expected total number of packet transmissions required to successfully deliver a packet to the eventual destination. The authors confirmed that ETX can improve performance. In doing so, they have designed and implemented ETX as a metric for the DSDV and DSR routing protocols. The end result was that for long paths the throughput improvement is more often a factor of two or more than not. The authors also suggested that ETX may practically give more positive outcome when networks grow larger and paths become longer.

In WMNs load balancing is a crucial part along with inter domain mobility. Load balancing is needed mainly due to congestion in a network. In order to obtain load balancing and inter domain mobility Bin Xie, Yingbing Yu and Anup Kumar proposed a scheme in the paper titled as “Load-balancing and Inter-domain Mobility for Wireless Mesh Networks” [8]. The proposed scheme was for domain partition with a view to realize the tradeoff between load-balancing and inter-domain mobility to trim down the impact of host mobility. In times of requirement, the load-balancing proposal contained a primary procedure to divide a mesh network into domains and a load adjustment procedure to rebalance the traffic load of neighboring domains. The authors suggested that the proposed method offered inter-domain mobility in support of multi-hop communication with the help of Multi-hop cellular IP (MCIP) mobility protocol. They finished off by implying that the experimental results were evident of the effectiveness of the proposed protocol that controls the migrations of mesh routers as well as mobile stations.

Chapter 3

Implementation of WMN

3.1 OLSR

One of the oldest mesh routing protocols is Optimized Link State Routing (OLSR). This protocol is used for mobile ad hoc networks and used as wireless ad hoc networks for IP routing protocol optimization.

3.2 BATMAN and BATMAN-Advance

BATMAN And BATMAN-Adv both are a routing protocol. Batman is protective layer 2 protocol, which means they only exchange routing information by sending UDP packets and bring their routing decision into effect by manipulating the kernel routing table. In the most version of the LINUX kernel BATMAN is compiled. And BATMAN Advance is an implementation of BATMAN. It is a layer 2 protocol, which not only exchanges routing information but also handles the data traffic.

3.3 HWMP

Hybrid Wireless Mesh Protocol is the basic mesh routing protocol which is standard in IEEE802.11s. IEEE802.11s is a task group formed by IEEE to develop an integrated mesh networking solution. Hybrid Wireless Mesh Protocol is set as a default routing protocol by the task group. Many simulations and few test bed studies to evaluate the performance of the HWMP protocol.

3.4 BABEL

Babel is a distance vector routing protocol which heals twice as fast as BATMAN. In wireless mesh routing protocols, babel is one of the newest. It implements in Linux and OpenWRT. Many route cost metric of HWMP are used by babel but like HWMP it does not require specific routing strategy. Babel determines which routing update should be taken and which are not. It is possible for its metrics which is smaller than the routing updates. It also discovers its neighborhood by exchanging message.

3.5 DD-WRT

DD-WRT is an open source firmware project which developed to enhance the performance and features of wireless internet routers. It can make the network more controllable and versatile. But its functionality is limited and it provides minimal support for mesh routing protocols.

3.6 Open-WRT

OpenWRT is also a Linux based embedded operating system like DD-WRT and may be more stable than the firmware of some routers. It also offers a built-in package manager. Open-WRT can be used in the SSH server for SSH tunneling, set up a VPN, install a BitTorrent Client, run server software, perform traffic-shaping and QoS, create a guest network, capture and analyze network traffic.

3.7 Microsoft Windows

A Microsoft window is an operating system written in C, C++ and assembly language. It is developed by Microsoft. The first windows is the Windows 1.0 released in 20th November, 1985. After that windows 2.0, windows 2.1, windows 3.0, windows 95, windows 98 and so many versions were released. Recently windows 10 is released. Mesh network is explored in Microsoft very early.

3.8 Android

Android platform or operating system is developed by google. It is mainly developed for the touch screen mobile devices based on Linux kernel. Comparing with all kind of operating system, android has the largest installed base.

3.9 Comparative Differences Between Batman-Advanced and Hybrid Wireless Mesh Protocol (HWMP)

This two systems were available for many of the target platforms. That is why Michael A. Decristofaro, Chatwin A. Lansdowne, and Adam M. Schlesinger conducted a research [9] exploring these systems by some criteria.

A. Test Articles

   There was no need to install HWMP in Linux because it was already included by default (as is the case in Linux Kernel). So in a mesh configuration, at first

BATMAN-Advanced was installed on a set of eight Wi-Fi routers and six laptop computers. By auto selecting tools physical layer protocols and channel section were set. For the mesh configuration IPv4 was used. The throughput and packet loss were measured by ‘iperf’ network testing tool. Security was ensured by using WEP. Ping was used to measure the mesh reconvergence times. There were no compatibility issues, as all of the devices were running the same mesh routing protocol at the same time. Laptops and routers were employing different routing protocol software versions for Batman-Advanced system. No significant problems arose as backwards compatibility was contained automatically.

B. Test Techniques

To test the techniques, indoor and outdoor systems were used. In the indoor test, video and audio streaming were assessed using VLC and Ekiga open source software packages and techniques. Four nodes were used in the test structured in a heterogeneous mesh. 1 laptop and 1 router was used as nodes per room, where the laptop was used for shorter hop and the router for communication. After bandwidth test, the mesh re-convergence test started. To get an average re-convergence time, the test was repeated multiple times. In the outdoor system, the additional structure and controlled testing were done on NASA's 750m antenna range with the nodes being separated by 150 meters. By the number of hops, the throughput was measured. By driven down a mobile device on the line, the route switching behavior was observed. By UDP ‘iperf’ connection, the bandwidth was measured.

C. Test Results

There was a defect in the way Ekiga VoIP software adapted to latency changes. In case of changing the route of mesh protocol between two nodes, Ekiga would drop the call. As far as the indoor tests were concerned, the quality of the video was very low. However, the audio quality was significantly high. Dropped packets caused very low frame rates as higher resolution video streams were less tolerant of dropped frames.

Table 3.1: Indoor bandwidth test results

Number of Hops	BATMAN-Adv Bandwidth	HWMP Bandwidth
1	52.8 Mbps	84.2 Mbps
1 (Through Floor)	9.91 Mbps	9.34 Mbps
2 (Through Floor)	9.35 Mbps	9.55 Mbps

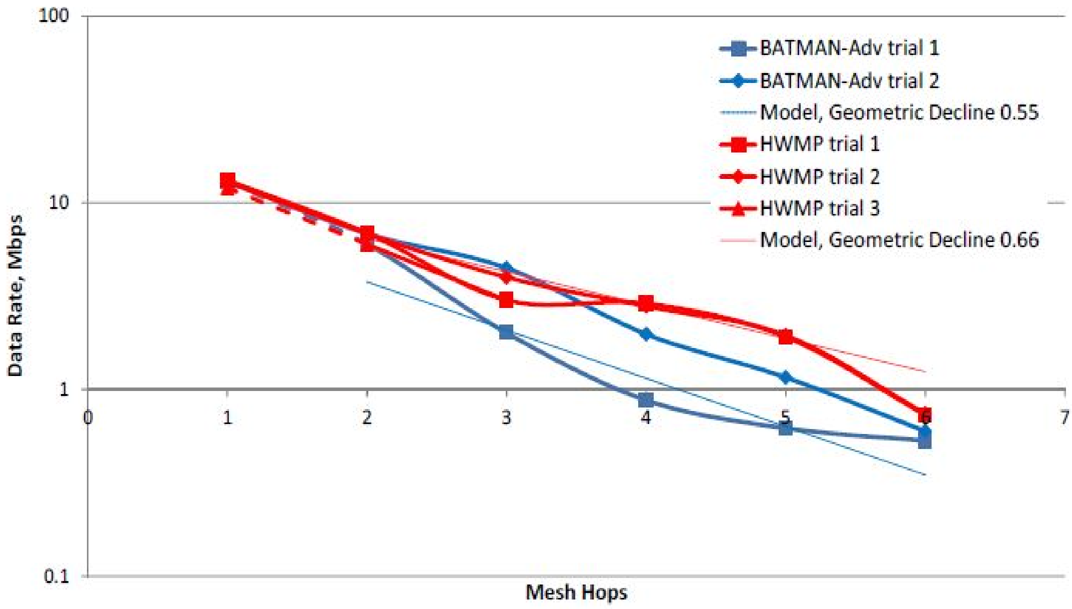

Figure 3.1: Mesh bandwidth vs Separation, 150m spacing, Single packet stream

Table 3.2: Indoor reconvergence test results

BATMAN-Adv	HWMP
Low: 120ms	Low: 140ms
Average: 743ms	Average: 443ms
High: 2120ms	High: 2660ms

3.10 Analysis of the Results

The performance of the bandwidth can be noticed from figure 3.1. As hops were increased, the amount of throughput dropped more for BATMAN-Adv than for HWMP. BATMAN-Adv shows 45% bandwidth decrease per hop at the performance rate of 1% packet loss whereas the HWMP shows 34% bandwidth decrease per hop at the performance rate of 1% packet loss. In case of an instantaneous failure of a node from loss of power, reconfiguration time of both BATMAN-Adv and HWMP were considerably within an acceptable range. Moving in a direction, that reduced the number of hops, BATMAN-Adv shows a 3.2s average hold off. While moving in a direction that would increase the number of hops, BATMAN-Adv shows a 75s average hold off. In stark contrast though, HWMP shows a 9.5s average hold off when moving in a direction that increased number of hops. However, that falls to 9.3s while moving in a direction that reduces the number of hops.

After analyzing the test results, it was evident that wireless mesh network works best in the HWMP. HWMP is also Radio Aware (RA) which BATMAN is not. Wireless mesh network works finely for RA protocol. That makes HWMP best suitable for wireless mesh network.

Chapter 4

The Proposed Method

4.1 System Model

In this section, we first define the system model of an interconnection between MANET and the internet and an example is shown in figure 4.1. The load balancing routing problem is researched under such an environment. We assume that the interconnection architecture is mainly used to support internet access. A mobile node without a direct internet link can access the internet through the gateway. Therefore, the service area of the internet is extended by the ad hoc links. From the system model, we can achieve the interconnection network model. We assume a communication graph,

$$G = (V, E)$$

Where, $V = \{v_1, v_2, \ldots\ldots, v_m, \ldots\ldots, v_n\}$ is the set of mobile nodes $(n \geq m \geq 1)$, n is the number of mobile nodes and m is the number of gateways. Mobile nodes from v_1 to v_m are gateways. Also E is the set of links. $l_{ij} = (V_i, V_j)$, if they have direct link.

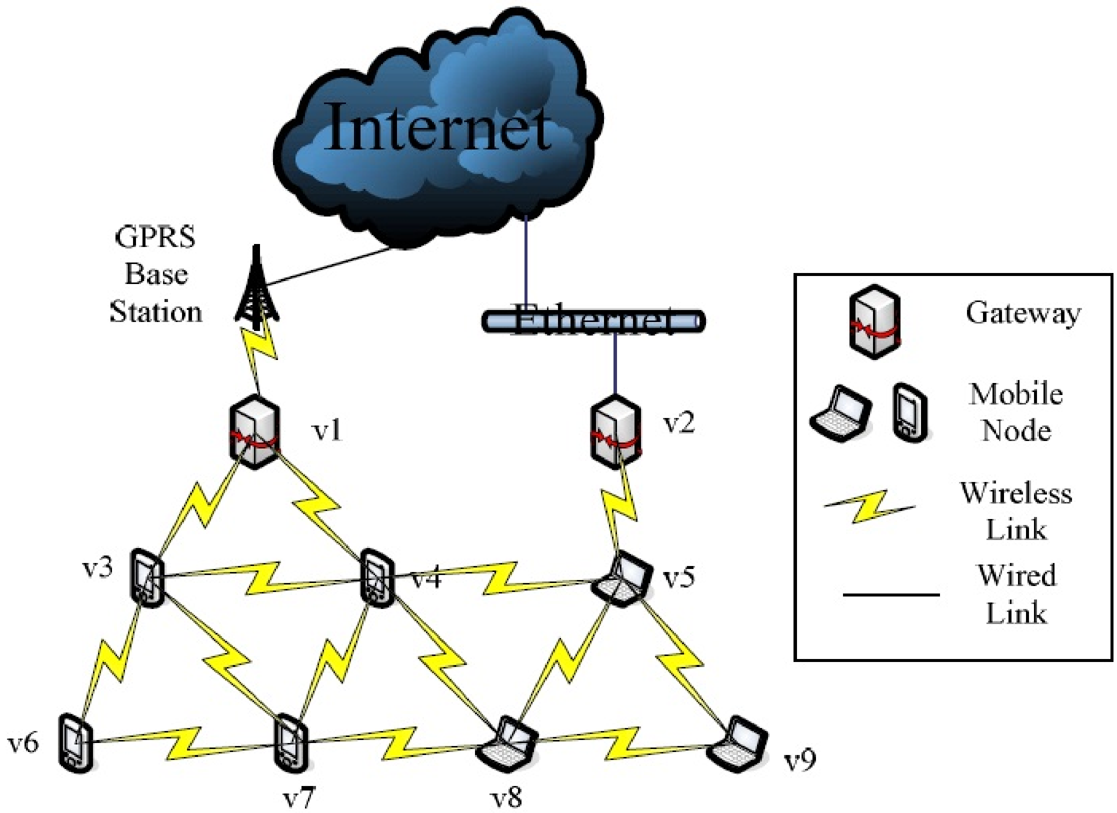

Figure 4.1: An example of the interconnection between MANET and the Internet

To solve the load balancing routing problem, we model the interconnection network architecture by a node-weighted graph as follows.

Each mobile node V_i is translated into a pair (V_i, T_i), where T_i is the traffic load of V_i and it represents the traffic load between V_i and the internet. Note that, we mainly consider the interconnection architecture as an internet access environment and therefore we did not consider inter-node (mobile node) traffics. For each gateway $V_j (m \geq j \geq 1)$ with the capacity of C_j, it is translated into (V_j, C_j). An example is shown in figure 4.2.

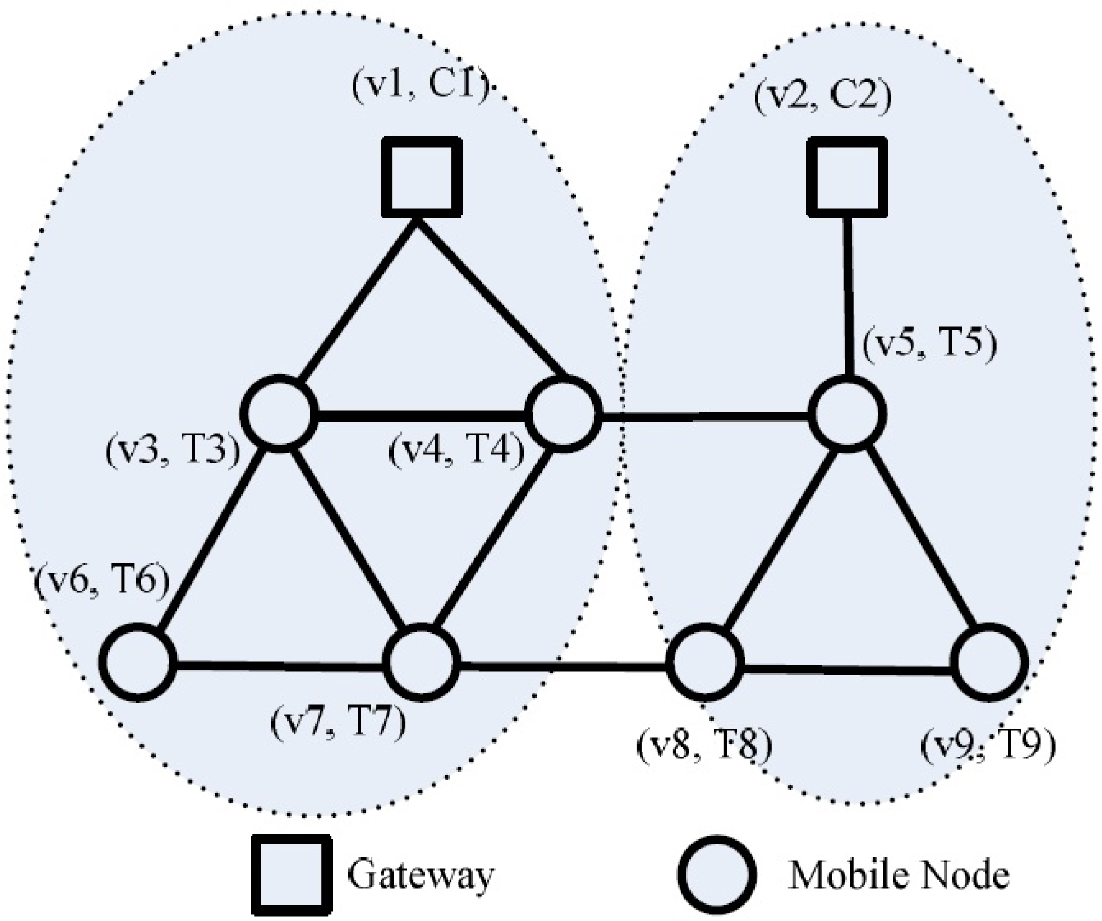

Figure 4.2: The graph model of the interconnection architecture between MANET and the Internet in figure 4.1

In figure 4.2, gateways and mobile nodes are represented by squares and circles, respectively. Gateways are sinks in the network, while the other nodes traffic loads need to be drained out to proper sinks with considering load balance. One possible solution is shown in figure 4.2; where mobile nodes are divided, based on shortest path routing algorithm, into two groups of sizes 4 and 3 to be served by gateways v_1 and v_2 respectively.

Considering the gateways having different capacities, such arrangement is obviously imbalanced in most of the cases. If we assume the capacity of gateways v_1 and v_2 are 256 Kbps and 11 Mbps respectively, then gateway v_2, which has the largest bandwidth, is responsible for 3 mobile nodes.

So it is possible that gateway v_1 may run out all its bandwidth while gateway v_2 still has unused bandwidth.

4.2 Routing Algorithm

In this section, we first define all gateways load balance factor (GLBF) and then present the load balancing routing algorithm among multiple gateways.

4.2.1 Calculating All Gateways Load Balance Factor

To make the mobile nodes find out an optimal routing path to the gateway to distribute the traffic load evenly among multiple gateways. we define the concept of all gateways load balance factor (GLBF) as follows.

Without loss of generality, we assume that the network is connected. Otherwise, either some mobile nodes are not connected to any gateway or the problem can be divided into some sub-problems which can be resolved independently.

Let, $V_j\,(m \geq j \geq 1)$ be any gateway node. Let S_j be the set of mobile nodes which are connected to the gateway V_j. Then the remaining available bandwidth of gateway V_j, denoted by θ_j, is defined to be C_j subtracted by the sum of the traffic load from the mobile nodes which are connected to this gateway, as is shown in equation 4.1.

$$\theta_j = max\{(C_j - \textstyle\sum_{i \in S_j} T_i),0\} \quad \text{..................... (4.1)}$$

The 'max' function is to ensure that θ_j is always non negative.

The load factor LF_j of gateway V_j is defined by equation 4.2.

$$LF_j = \frac{\sum_{i \in S_j} T_i}{C_j} \quad \text{... (4.2)}$$

Note that, the value of LF_j could be greater than 1, in case that the gateway is loaded. Then we can define all gateways load balance factor GLBF, as shown in equation 4.3.

$$GLBF = \begin{cases} \frac{max\{\theta_j\} - min\{\theta_j\}}{max\{\theta_j\}}; & if\ max\{\theta_j\} > 0 \\ \frac{max\{LF_j\} - min\{LF_j\}}{max\{LF_j\}}; & if\ max\{\theta_j\} = 0 \end{cases} \quad \text{.........................} (4.3)$$

In equation 4.3, $j(m \geq j \geq 1)$ represents all the gateways. The former is the applied when at least one gateway has remaining available bandwidth, while the latter is applied when all the gateways are fully loaded. In both cases, a load balancing routing scheme's goal is to minimize the GLBF value possibly.

4.2.2 Load Balancing Routing Algorithm Among Multiple Gateways

In the process of calculating the routing path to the gateway to achieve load balancing among multiple gateways, the length of the routing path calculated by our algorithm may be very long compared to the one calculated by the shortest path routing algorithm. A research paper titled as "Load-balanced mesh router migration for wireless mesh networks" by Xiea, B., Yub, Y., Kumarc, A., Agrawala, D. p. [10] shows that throughput performance of wireless multi-hop session is seriously degraded with increase of the number of hops. So, when our algorithm calculates a routing path to a further gateway, throughput performance may yet not be improved. In extreme case of finding out a routing path to a far further gateway, throughput performance through this gateway may be degraded seriously and our algorithm may bring worse throughput. So, we use the shortest path routing algorithm as a baseline algorithm and introduce a routing path increment threshold to restrict the length of routing path calculated by our algorithm in a reasonable range. Table 4.1 shows the load balancing routing algorithm among multiple gateways (LBRA). We show the overview of this algorithm as follows.

- Step 1: For all $V_i(n \geq i \geq m+1)$, we calculate the shortest path from V_i to its nearest gateway using shortest path routing algorithm. Then we store V_i in V_s and record the routing path in P_i, g_i and compute its length in vector $length_i$. The remaining available bandwidth of each gateway are computed using equation 4.1 and gateway load factors are computed using equation 4.2. Then all gateways load balance factor are computed and stored by LBF_0 using equation 4.3.
- Step 2: For all $V_i \in V_s$, the following steps are repeated.
- Step 3: We find all V_j such that $l_{i,j} \in E$ and push V_j into stack.

- Step 4: If the stack is empty, then it all returns to step 2. Otherwise, the top element of the stack pops up and assigns this element to V_k. If $k \leq m$, then we go to step 4-1. Otherwise, we go to step 4-2.
- Step 4-1: The current value of the gateway is saved at g_i and g_k. Then we recalculate the remaining available capacity of the gateway $g_i$andg_k and all the gateways load balance factor stored by LBF_k. After that we determine whether the following two conditions are satisfied at the same time: (1) $LBF_k < LBF_0$, (2) $1 + |P_k g_k| \leq Length_i + h_{thres}$. If they are satisfied, then we replace P_i, g_i with $\{l_{i,k}\} \cup P_k g_k$ and assign LBF_k to LBF_0 and go to step 4. Otherwise restore the value of the gateway g_i and g_k and go to step 4.
- Step 4-2: Find all the link $l_{k,l} \in E$ and push V_l in the stack and then go to step 4.

Table 4.1: Load Balancing Routing Algorithm Among Multiple Gateways

Load Balancing Routing Algorithm Among Multiple Gateways (LBRA)

```
Input: Graph G, h_thres
Output: P_i, g_i: m + 1 ≤ i ≤ n
Shortest Path Algorithm;
Store the corresponding information in V_s, P_i, g_i, length_i,
for (all v_g (m ≥ g ≥ 1)){
    Calculate_Remaining_Bandwidth(v_g);
    Calculate_Load_Factor(LF_g);
    Calculate_GLBF(LBF_0);
}
For (all v_i ∈ V_s){
     Push v_j into Stack such that l_i,j ∈ E;
     while(!IsEmpty(Stack)){
v_k = Get_top(); Pop_up();
        if(k ≤ m){
           Save(v_gi; v_gk);
           Recalculate(v_gi; v_gk);
           Calculate(LBF_k);
           if((LBF_k < LBF_0)&&(1 + |P_k g_k| ≤ Length_i + h_thres)){
LBF_0 = LBF_k;
P_i, g_i = {l_i,k} ∪ P_k g_k;
           }
           else{
              Restore(v_gi; v_gk);
           }
        }
        else{
          Push v_l into the Stack such that the link l_k,l ∈ E;
        }
     }//while
}//for
```

LBRA exhaustively searches for all the possible routing paths from v_i to v_{gi}. So, the worst-case time complexity of this algorithm occurs with a full connected network topology. In this case, each mobile node has m links between the gateways and $(n - m - 1)$ links between the other mobile nodes, therefore, $(n - m)$ mobile nodes search for $((n - m)m + (n - m - 1)!)$ paths. The shortest path routing (SPR) uses Dijkstra's algorithm for calculating the shortest path, the time complexity of obtaining the path between a mobile node and the gateway is $O(n^2)$. In SPR, each mobile node repeats this operation m times. Then it determines the path to the gateway within $O(n)$. So, the time complexity of SPR is $O(n^2)$. Then the time complexity of LBRA is the sum of $((n - m)m + (n - m - 1)!)$ and $O(n^2)$. In the end, the time complexity of LBRA is $O((n - m)!)$.

Chapter 5

Performance Evaluation

In this section, through simulation using ns-2.34 network simulator with CMU wireless extensions, we demonstrate the effectiveness of the proposed algorithm in terms of the load on the gateways and the path length.

5.1. Simulation Setup

The simulation area is 1200m*1200m. The node mobility speed we have chosen in the simulation varies from 10 to 20 m/s. The random waypoint model is used as the mobility model of the mobile nodes. Constant Bit Rate (CBR) traffic sources with different packet generation rates are used to model different network scenarios. The maximum transmission range of each node is 250 meters. Simulations are run for 6000 s.

In addition, the gateways are deployed as follows. For 2 gateways, they are deployed in the diagonal of the square. For 4 gateways, they are deployed in the vertex of the square. For 8 gateways, they are deployed in the vertex of the square and in the midpoint of the edge of the square. This is because the numbers of gateway nodes and their locations are carefully determined to maximize the throughput between MANET and the Internet. The simulation parameters are given according to table 5.1.

Table 5.1: Simulation Parameters and Values

Parameters	**Values**
Simulation Area	1200m*1200m
Wireless MAC Interface	IEEE 802.11 MAC
Propagation Model	Two Ray Ground
Transmission Range	250m
Gateway Nodes	2,4,8
CBR Packet Size	512 bytes
Mobility Model	Random Waypoint
MANET node Speed	10-20 m/s
Simulation Time	6000s

5.2 Optimal Path Increment Threshold Setting

Under the premise of distributing traffic load evenly among multiple gateways, LBRA suppresses the increase in the hop count caused by adjusting the routing path up to h_{thres}. The optimal routing path increment threshold is investigated from the viewpoint of both the load on the gateways and the path length. Figure 5.1.1 illustrates the relationship between h_{thres} and all gateways load balance factor when the number of mobile nodes varies and the number of gateways is set to 4. As shown in figure 5.1.1, the all gateways load balance factor does not change if h_{thres} is over 1. The case that h_{thres} equals to 30 represents the routing path increment threshold is unlimited. Because of obtaining similar results in other cases with different number of gateways, we set $h_{thres} = 1$ in the following evaluation.

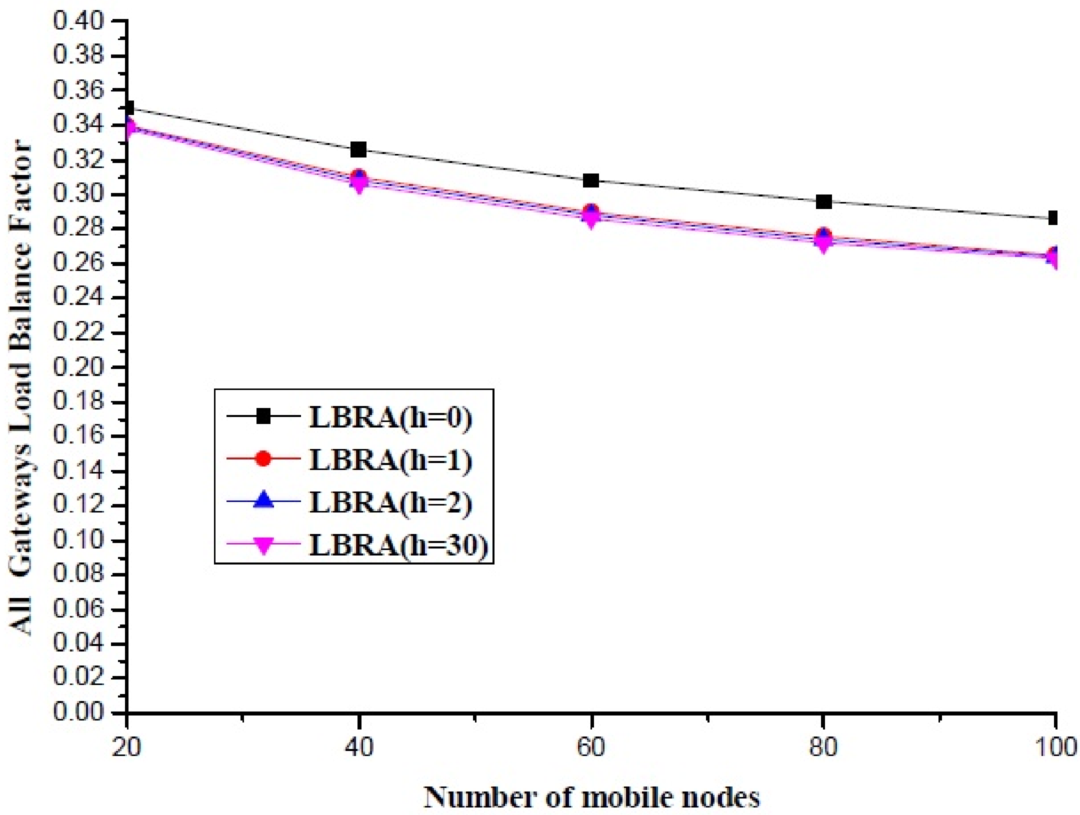

Figure 5.1.1: Relationship between h_{thres} and all gateways load balance factor

5.3 Load balance on gateways

We deploy 2, 4 and 8 gateways respectively in the connected hybrid network to investigate the impact of SPR and our LBRA algorithm on the load balance on gateways when the number of mobile nodes varies. The results are shown in figures 5.1.a, 5.1.b and 5.1.c.

As earlier noted, the locations of the gateways are carefully determined to maximize the throughput between MANET and the internet. From figures 5.1.a, 5.1.b and 5.1.c, we can see that the all gateways load balance factor of the two algorithms become low as the number of mobile nodes increases.

The degree of reducing all gateways load balance factor of LBRA is more obvious.

The LBRA can distribute the load among gateways more uniformly.

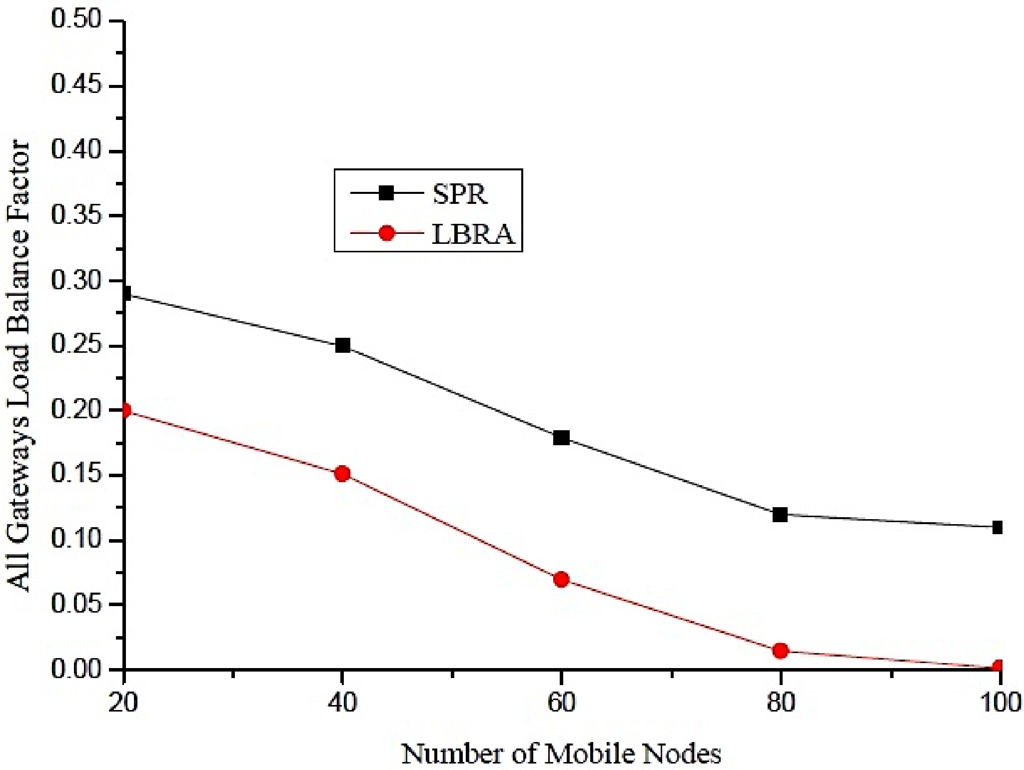

Figure 5.1.a: 2 gateways

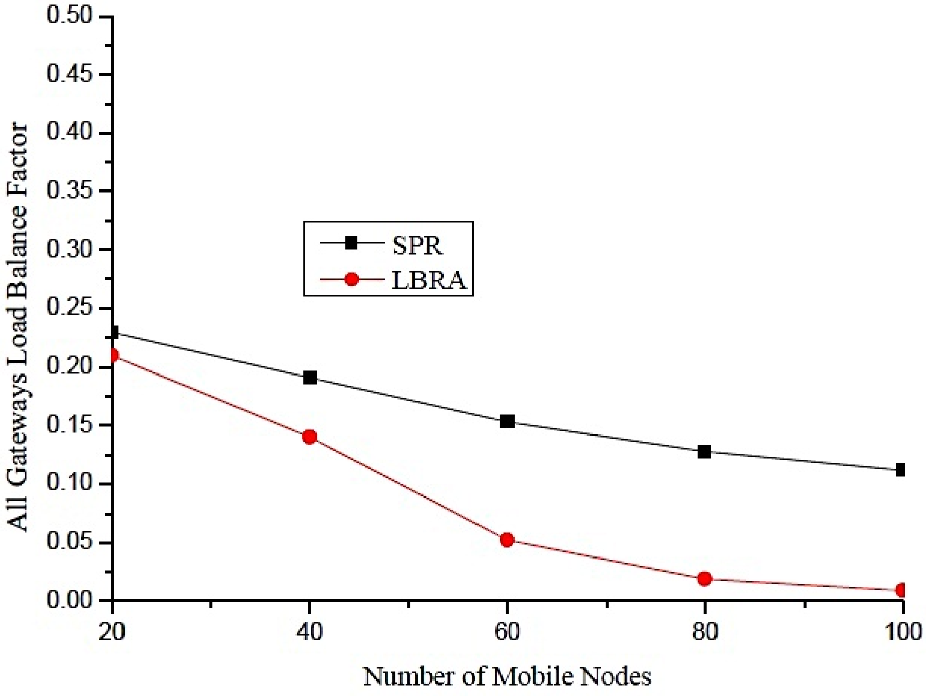

Figure 5.1.b: 4 gateways

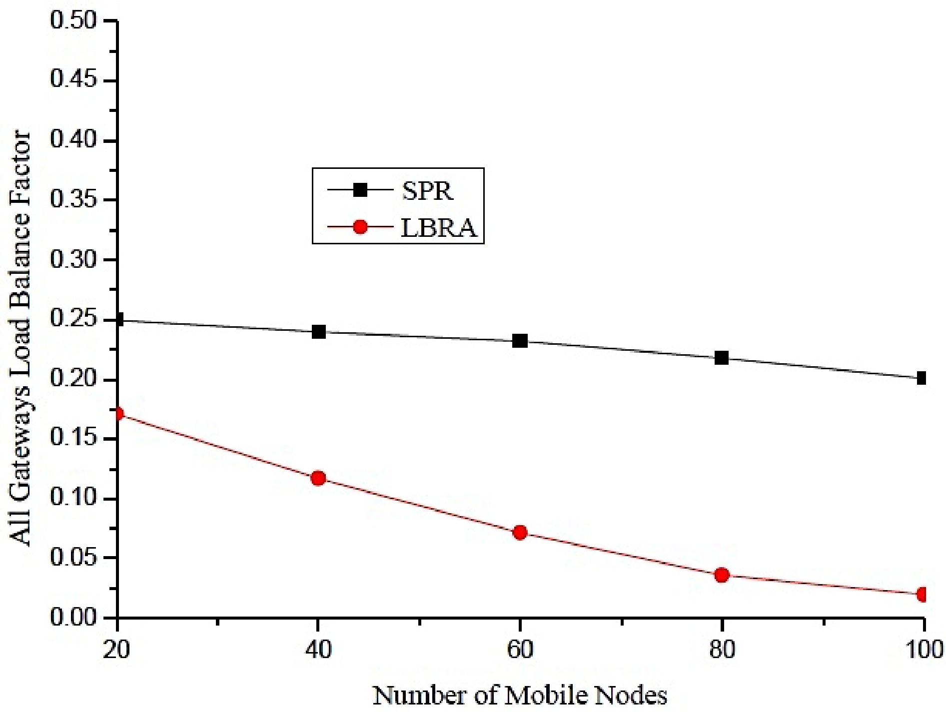

Figure 5.1.c: 8 gateways

Figure 5.1.2: All gateways load balance factor changes with the increment of the number of mobile nodes with 2, 4 and 8 gateways respectively

All gateways load balance factor changes with the increment of the number of mobile nodes with 2,4 and 8 gateways respectively.

Figure 5.2 depicts how the average routing path length between a mobile node and a gateway varies according to the number of gateways when the number of mobile node is 40.

Figure 5.3 shows how the average routing path length between a mobile node and a gateway varies according to the number of mobile nodes when the number of gateway is 4.

We find the average routing path length of LBRA is at most 20% higher than that of SPR (shortest path routing).

So, when using our LBRA to distribute load evenly among multiple gateways, the increase of the routing path length is not large. This effect is achieved by the introduction of the routing path increment threshold h_{thres}.

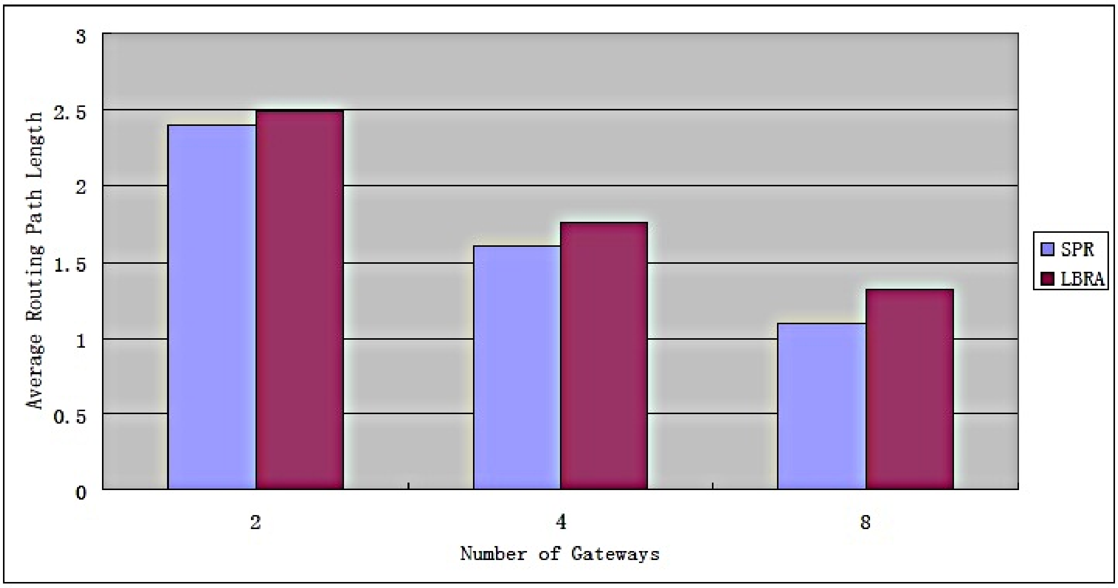

Figure 5.2: The impact of SPR and LBRA on average routing path length with different number of gateways

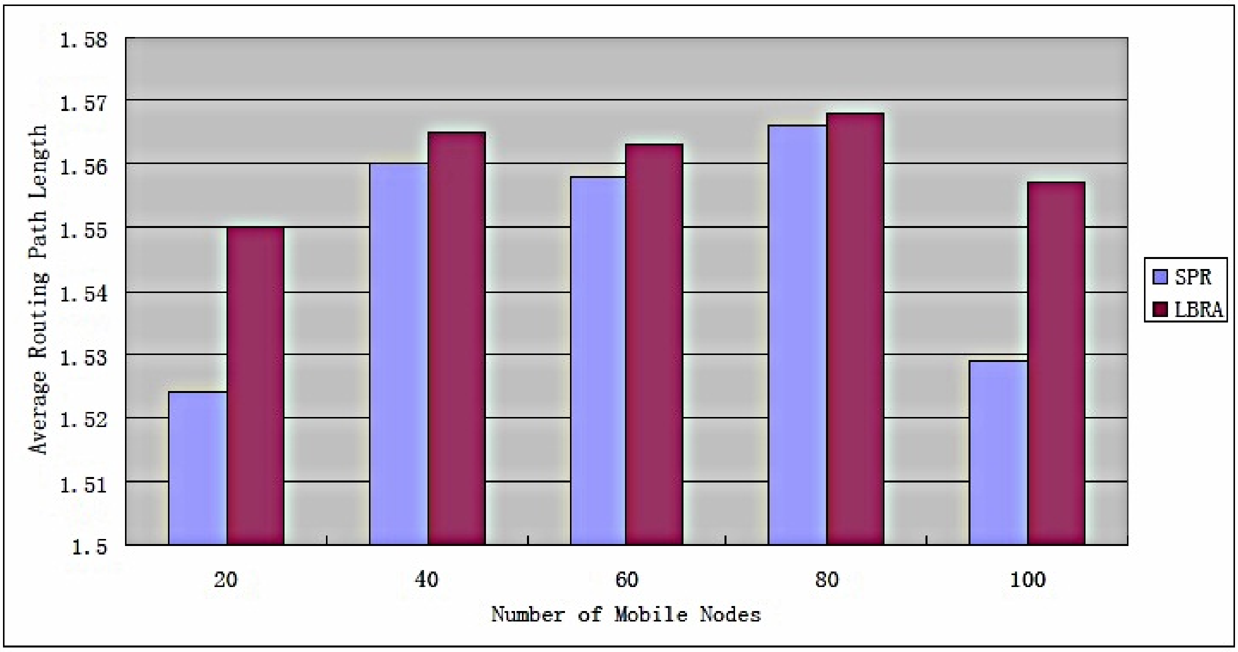

Figure 5.3. The impact of SPR and LBRA on average routing path length with different number of mobile nodes

Chapter 6

Conclusion

In this thesis paper, we have proposed a load balancing routing algorithm, called LBRA, to distribute the traffic load on gateways in MANET with internet connectivity.

To prevent the routing path becoming too long, a routing path increment threshold is introduced to restrict the routing path in a reasonably range.

Through simulations, we showed the proposed algorithm LBRA can distribute the traffic load among multiple gateways uniformly and can restrict the increase of the routing path, at most, 20% compared to SPR (shortest path routing).

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APPENDIX-I (SOURCE CODE)

```
setval(chan)           Channel/WirelessChannel       ;# channel type
setval(prop)           Propagation/TwoRayGround      ;# radio-propagation model
setval(netif)          Phy/WirelessPhy               ;# network interface type
setval(mac)            Mac/802_11                    ;# MAC type
setval(ifq)            Queue/DropTail/PriQueue       ;# interface queue type
setval(ll)             LL                            ;# link layer type
setval(ant)            Antenna/OmniAntenna           ;# antenna model
setval(ifqlen)         50                            ;# max packet in ifq
setval(nn)             2                             ;# number of mobilenodes
setval(rp)             AODV                          ;# routing protocol
setval(stop)           100                           ;# time of simulation end
setval(x)              500                           ;# X dimension of topography
setval(y)              400                           ;# Y dimension of topography
set ns_ [new Simulator]
settracefd [open wireless2node1.tr w]
$ns_ trace-all $tracefd
setnamtrace [open wireless2node1.nam w]
$ns_ namtrace-all-wireless $namtrace $val(x) $val(y)
settopo [new Topography]
$topoload_flatgrid $val(x) $val(y)
#create-god $val(nn)
set god_ [create-god $val(nn)]
# configure the nodes
$ns_ node-config –wirelessmesh routing $val(rp) \
                 -llType $val(ll) \
                 -macType $val(mac) \
                 -ifqType $val(ifq) \
                 -ifqLen $val(ifqlen) \
                 -antType $val(ant) \
                 -propType $val(prop) \
                 -phyType $val(netif) \
                 -channelType [new $val(chan)] \
                 -topoInstance $topo \
                 -agentTrace ON \
                 -routerTrace ON \
                 -macTrace ON \
                 -movementTrace OFF

#############################
for {set i 0} {$i< $val(nn) } {incri} {
set node_($i) [$ns_ node]
         $ns_ initial_node_pos $node_($i) 20.0
         $node_($i) random-motion 0
}
#########################
$node_(0) set X_ 5.0
$node_(0) set Y_ 10.0
$node_(0) set Z_ 0.0
$ns_  at 0.0 "$node_(0) setdest 5.0 10.0 0.0"
$node_(1) set X_ 400.0
$node_(1) set y_ 300.0
$node_(1) set Z_ 0.0

$ns_ at 1.0 "$node_(1) setdest 24.01 20.01 15.1"
$ns_  at 0.0 "$node_(1) setdest 400.0 300.0 0.0"
$ns_ at 2.0 "$node_(0) setdest 155.0 110.0 55.0"
$ns_ at 5.0 "$node_(1) setdest 105.0 110.0 21.0"
$ns_ at 10.0 "$node_(0) setdest 185.0 260.0 45.0"
$ns_ at 40.0 "$node_(0) setdest 105.0 140.0 33.0"
$ns_ at 45.0 "$node_(1) setdest 125.0 210.0 33.0"
$ns_ at 50.0 "$node_(0) setdest 115.0 230.0 60.0"
$ns_ at 100.0 "$node_(1) setdest 200.0 280.0 10.0"
$ns_ at 130.0 "$node_(0) setdest 250.0 380.0 22.0"
proc stop {} {
```

```
        global ns_ tracefdnamtrace
        $ns_ flush-trace
        close $tracefd
        close $namtrace
        exit 0
}
settcp [new Agent/TCP]
$ns_ attach-agent $node_(0) $tcp
set sink [new Agent/TCPSink]
$ns_ attach-agent $node_(1) $sink
set ftp [new Application/FTP]
$ftp attach-agent $tcp
$ns_ connect $tcp $sink
$ns_ at 0.0.050000 "$ftp start"
$ns_ at 150.0.050000 "stop"
puts "Starting Simulation for you.."
$ns_ run
```