

ENERGY CONSERVATION IN MOBILE
AD-HOC NETWORKS USING
RELAY NODES

By

EASHWAR RAO CHITTIMALLA

Master of Science in Computer Science

Oklahoma State University

Stillwater, Oklahoma

2005

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE OR ARTS
December, 2005

ENERGY CONSERVATION IN MOBILE
AD-HOC NETWORKS USING
RELAY NODES

Thesis Approved:

Dr. Venkatesh Sarangan

Dr. Johnson Thomas

Dr. N. Park

A. Gordon Emslie

Dean of the Graduate College

TABLE OF CONTENTS

Chapter	Page
I. INTRODUCTION	1
Characteristics of MANET	1
II. BACKGROUND	
Application Nodes	5
Relay Nodes	5
Flow	5
Routing Protocol	6
Position Based Routing	8
III. PROBLEM FORMULATION	9
Problem Statement	11
IV. LITERATURE REVIEW	12
V. PROPOSED SOLUTION	15
Issues in the Development	15
Application Node Functioning.....	16
Relay Node Functioning	18
Preliminary Equations.....	20
Equations for the Relay Node	23
VI. SIMULATION	27
Epoch Interval.....	27
Max vs. Random	28
Single Hop vs. Multi Hop	28
Local View vs. Global View.....	29
Message Types.....	29

Initialization and working of MANET node.....	30
Working of a Relay Node	31
 VII. RESULT	 34
Single Hop	34
Multi Hop.....	35
 CONCLUSION.....	 43

LIST OF FIGURES

List of Figures	Page Number
1. Network scenario with Relay Node	8
2. Network scenario with Relay Node handling multiple Flows	19
3. Power saved single hop with no error in motion prediction	32
4. Power saved multi hop with no error in motion prediction	33
5. Power saved multi hop max flow global view with error in motion prediction	34
6. Power saved multi hop max flow local view with error in motion prediction	35
7. Power saved multi hop random flow local view with error in motion prediction	36
8. Power saved multi hop random flow global view with error in motion prediction	37
9. Power saved single hop max flow local view with error in motion prediction	37
10. Power saved single hop random flow local view with error in motion prediction	38
11. Power saved single hop max flow global view with error in motion prediction	38
12. Power saved single hop random flow global view with error in motion prediction	39

CHAPTER I

INTRODUCTION

MANET (mobile ad-hoc network) is a self organizing and self-configuring multi hop wireless network. Mobile ad-hoc network consists of wireless mobile nodes equipped with computational, storage, communication, sensing and mobility engine subsystems. The network conditions change dynamically due to member mobility. The nodes use the computational power to make decisions. The mobile nodes are normally dedicated to a particular task. Their movement is controlled and dictated by an application which drives the task. There are host of applications that can use these nodes. They are very useful for tactical communication in the military, law enforcement and surveillance of borders. They are also used in civilian fore such as manning forests, oceans, precision agriculture, convention centers, conferences, and electronic class rooms (Christian, 2002). Energy conservation is the most critical issue in MANET since the node has a limited power supply and it has to be taken out of the network area to recharge.

Characteristics of a MANET (Royer, 1999)

- Highly dynamic network: The network is highly dynamic. The conditions of network keep changing due to the movement of the nodes. The neighbor relationship is only for a short time. The movement of the nodes is mostly unpredictable and directed by the application in that node.

- Heavy Equipment Load: The node that is deployed has heavy-weight equipment required for its application. The equipment acts as a payload for the node. Erroneous movement of the nodes would consume a lot more energy, so the node movement has to be accurate; hence a lot of co-ordination is needed among the nodes.
- Limited Battery Power: The nodes run on battery power, hence have a limited supply of energy. Once deployed in the network, to have the power recharged the node would have to lose its active status in the network and has to be taken out of the network area. This limited battery power is the biggest limitation of the node and it has to use energy sparingly.
- Erroneous Transmission Medium: The medium of communication is air. It has a higher error rate and this consumes a lot of energy due to the more number of retransmissions. The medium also is a broadcast medium. Every node can listen to the communication in its range. Some form of encryption is needed to provide security.
- Lack of Central Server: There is no central server to which the nodes are responsible. The nodes are independent and work co-operatively with other nodes to achieve their task. The lack of central server means that nodes will have to do a lot of communication to co-ordinate themselves.

For a sensor based application where the node purpose is doing some sensing and activation job, node needs to be equipped with the heavy sensor equipment. The nodes need to expend a lot of energy to move and hence the movement should be very accurate and as needed. Conserving energy would increase the longevity of the nodes. For this

purpose the nodes need to co-ordinate themselves to move in the right direction. There is no central server directing the activities of each node. Each node is independent and takes its own decision. These nodes have to work co-operatively to achieve a particular task. Hence there is heavy communication between the nodes to co-ordinate themselves. Communications between these nodes take place in a multi-hop manner starting with the source and ending with destination. Each of the nodes functions as a router and hence can act as intermediate relay node for the information. They co-operate with each other to engage in multi hop forwarding.

The routing protocols in the MANET play critical role in their communication. The routing protocols have to adapt quickly to frequent and unpredictable topology changes. The routing protocols in the MANET are mainly classified as proactive and reactive routing protocols. Some of them use the position information to speed up the routing and are called as position based routing protocols. For position based routing there is accuracy needed in position information, hence each of these nodes is equipped with GPS system that would help them determine their global positions. The nodes exchange position information from time to time.

In conserving energy these routing protocols employ different optimization techniques. All the optimization techniques adjust to the evolving scenario in the network due to the movements of the node and try to conserve the energy. Some of techniques put the nodes to sleep periodically effectively removing the node of the network, move to a position not directed by the application to optimize the communication.

We propose an entire new approach in conserving of energy, introduction of new nodes into the network area whose sole purpose is to conserve energy by acting as intermediate

hops. More specifically, we propose the use of dedicated, mobility controllable relay nodes, for providing logistical support by facilitating better connectivity among the MANET nodes. We shall call these the “relay nodes”. The energy consumed in a wireless environment is proportional to exponent of the distance between source and destination. The value of the exponent varies from 2.4 to 3.0 depending on the medium. We can save energy by making these relay nodes act as intermediate nodes in between the source and destination and thus conserve energy. The relay nodes movement unlike the other nodes can be controlled and directed to conserve more energy. We will use an additional layer in the protocol stack operating above the routing layer that would control the operation of the relay node. The layer has protocol principles and algorithms for the operation of the relay node. This layer dictates the effectiveness of the relay node. The relay node should have the same routing protocol as the native routing protocol in the network. We shall be using a position based proactive routing protocol for the application nodes.

CHAPTER II

BACKGROUND

Application Nodes: These are nodes that are dedicated to achieving a particular task. Their movement is dictated by the application. Each node is independent and takes its own decision. All of the application nodes work collectively to achieve their task. There is heavy communication expected among these nodes to co-ordinate themselves and work co-operatively. These nodes have considerable weight since they are equipped with sensing, computational and communication subsystems. The nodes have shorter span of life and the battery needs to be recharged frequently.

Relay Nodes: These are dedicated, mobility controllable nodes, for providing logistical support by facilitating better connectivity among the Application nodes. These nodes act as intermediate nodes decreasing the total power consumed in the communication. The movement of the relay node is directed by a layer operating above the routing protocol which dictates the movement of the relay node. It has all the principles and algorithms for the operation of the relay node. The relay node is a light weight node equipped only with the basic communication and computational subsystems. Thus the relay node is expected to consume far less energy in its operation and nodes have a longer life than compared with application nodes.

Flow: A flow is characterized by the bit rate, source and destination, duration. A flow also includes all the intermediate nodes which form the links of the communication between the source and destination. It includes the information as to how long the

communication is going to last, the total number of bits to be transmitted, the time the communication has been going on and number of bits already transferred.

Routing Protocol: It is the protocol that governs the communication between the nodes. It is responsible for finding the destination and for delivering the message. Depending on the way they find the destination and operate routing protocols in MANET are broadly classified Proactive (Table-driven) and Reactive (on-demand) (Royer, 1999).

Proactive Routing Protocol: These are routing protocols where in the information about destination is always known. The node always maintains a routing table and updates it periodically to reflect the changing network. Each node exchanges information with other nodes periodically. Since the nodes gather information from all nodes one at a time, they do not have a synchronous global view of the network but have an asynchronous global view. The nodes need to exchange information very frequently. This produces a lot of traffic. This routing protocol is to be used in a scenario where there is heavy communication expected so that the traffic generated by the routing protocol is a small percentage of the entire traffic generated. Once the node decides to communicate with another node the node looks up the routing table and sees the next hop for that destination. It then sends the packet to the next hop with the final destination in the packet. The intermediate node then looks up its table and then forwards it to the next hop and this goes on until the packet reaches the destination. Since the routing table plays a critical role in the communication keeping it updated is critical to its functioning of the network. The frequency of the information exchange between the nodes thus needs to be high.

Reactive Routing Protocols: These are the class of protocols which do not have any prior knowledge about the destination. Once a node decides to communicate with another node, the node starts a search process. In this process the node broadcasts a search packet which is received by its immediate neighbors and they in turn broadcast the search packet until it reaches the destination. Once it reaches the destination the search packet travels back to the source providing the source a route to reach the destination. Thus the channel is established for communication. The protocol needs to be adaptive to changing dynamic conditions of the network. The intermediate nodes use handshake protocol in case they move out of range. Reactive routing is used in situations where in the communication between nodes is not very frequent. Since in reactive routing, for each flow the destination needs to be found, it is very effective if the message is short and can be in one packet so that in the search phase itself the information can be put in the packet. The reactive routing protocols are not that prevalent in their native form. In most scenarios a mixture of both reactive and proactive routing protocols are used.

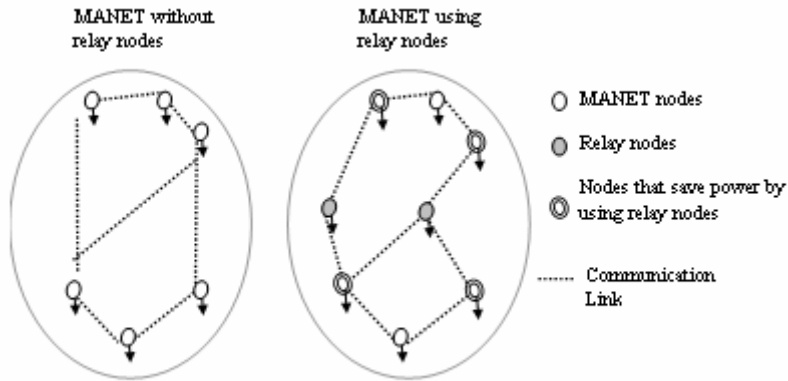
Position Based Routing: Position based routing is used to increase efficiency of the working of routing protocols. In position based routing the position information of the destination is used in delivery of the packet to the destination. The position information is best used if the native routing protocol is a proactive one since the position information in a proactive routing protocol is most up to date. Position is determined by the Global Positioning System (GPS) and the information is used to limit the propagation region of the route requests. The nodes can synchronize their clocks using the GPS system. In a position based proactive routing protocol the position information is maintained in the

routing table. The position information is maintained in terms of the co-ordinates of x , y and z if it is a 3-dimensional network and x and y if it is a 2-dimensional network. The nodes need to be equipped with GPS in order to keep track of their position accurately. The next hop to the destination is maintained against the node along with its current position and the time the node was at that position. The position information can be used even in a reactive routing protocol. It is used to optimize the flooding of the search packets to find the destination, by sending the search packets only in the last known direction of the destination. In our scenario we consider a network where the native routing protocol is a position based proactive routing protocol. In absence of position based routing protocol the optimization of the routing protocol operations based on the location information of the nodes is not possible. This is would lead to increase energy spending by the node to its operations when compared to energy used when location based optimization was used.

CHAPTER III

PROBLEM FORMULATION

While the network can use these relay nodes for achieving many objectives such as maintaining connectivity in the network, act as substitute for MANET nodes in case a MANET node goes down and for saving power in the network. In the following paragraphs we formulate the problem of using relay nodes for conserving power in the MANET nodes. The problem here is to position and move the relay nodes, so that the total power required in the network for communication is minimized. We shall define a few terms before we do the problem formulation.



Let Φ be the set of application nodes in the MANET. Let $N(i)$ be the communicating neighborhood of node i , i.e., $N(i)$ is the set of node to/from which node i is transmitting or receiving data. Let r_{ij} be the number of data flows from node i to node j . Let λ_{ijr} be the rate of the r^{th} flow between the nodes i and j . Let d_{ij} be the distance between the nodes i

and j . Let \mathbf{X}_M be a vector denoting the locations of the MANET nodes at a given instant t . In a two-dimensional plane, this vector will be of size $|\Phi| \times 2$. The power required by a MANET node to transmit over distance d at a unit rate is given by Kd^α watts, where K is a constant and α is the transmission attenuation factor. With these definitions, the total power required in the network for communication is given by:

$$P(\mathbf{X}_M) = \sum_{i \in \Phi} \sum_{j \in N(i)} \sum_{q \in r_{ij}} K \lambda_{ijq} d_{ij}^\alpha = K \sum_{i \in \Phi} \sum_{j \in N(i)} d_{ij}^\alpha \cdot \left(\sum_{q \in r_{ij}} \lambda_{ijq} \right) \dots\dots\dots (1)$$

In the above MANET, let R be the set of network controllable nodes introduced for relaying purposes. Some of the MANET nodes may employ these relay nodes as intermediate hops, and the rest may not. Also, a single relay node may act as an intermediate hop for several MANET node pairs. Let ζ be the set of MANET nodes that use the relay nodes for communication. Let \mathbf{X}_R be a vector of size $|R| \times 2$, denoting the locations of the relay nodes at time t . Now, the total power required in the network for communication in the presence of relay nodes is given by:

$$P(\mathbf{X}_M, \mathbf{X}_R, \zeta) = K \sum_{i \in \zeta} \sum_{j \in N(i)} d_{ij}^\alpha \cdot \left(\sum_{q \in r_{ij}} \lambda_{ijq} \right) + K \sum_{u \in R} \sum_{i, j \in \{N(u) \cap \Phi\}} (d_{iu}^\alpha + d_{uj}^\alpha) \cdot \left(\sum_{q \in r_{ij}} \lambda_{ijq} \right) \dots\dots\dots (2)$$

The set $\{N(u) \cap \Phi\}$ denotes the group of MANET nodes that are using a relay node u as an intermediate hop. It is clear from the above equation that the total power expended for communication in a relay-enabled MANET is dependent on \mathbf{X}_R – the location of the relay nodes at time t , \mathbf{X}_M – the location of the MANET nodes at time t , ζ – the set of MANET nodes using relays for communication, and the data rate of the flows using the relay node. Out of these, the controllable quantities are \mathbf{X}_R , and ζ . Thus, the relay positioning problem for power conservation in MANETs can be stated as:

Problem Statement: Given a MANET with Φ traditional nodes and R relay nodes, for each t , find \mathbf{X}_R^* and ζ^* such that $P(\mathbf{X}_M, \mathbf{X}_R^*, \zeta^*) \leq P(\mathbf{X}_M, \mathbf{X}_R, \zeta)$ for all \mathbf{X}_R and ζ .

Optimization problems such as the above are challenging due to their high dimensionality. We will actively pursue closed form solutions for these problems. When such solutions are not possible, we will turn our attention towards algorithms such as distributed simulated annealing for obtaining the solutions. We will investigate the convergence of these distributed algorithms under fast changing environments, and if necessary, propose modifications for the same. *As the parameters \mathbf{X}_M and λ_{ijr} continuously change with time, solution methodologies that give quick, approximate solutions are preferred over slow accurate solutions.*

CHAPTER IV

LITERATURE REVIEW

PARO (Gomez, 2003) is a presents a routing protocol power that saves energy in the long run in a MANET. In PARO one or more intermediate node chooses to forward the packet on behalf of the source and destination. It uses data packets for route discovery. It has three phases listening, redirecting and route maintenance. First the source uses a proactive routing protocol to find the destination. The source communicates with the destination according to the route returned. The intermediate nodes which are in the range of communication listen to the communication and make a judgment using equations if placing itself as next hop would save energy. If so, then a handshake signal is initiated and the node acts as a relay node. To compensate for mobility the intermediate nodes do route maintenance where in the hand shaking and message exchanges are down between a nodes upstream and downstream neighbor which then decide the next course of action i.e. finding he next hop. PARO optimizes one route at a time and thus requires a lot of iterations to get to the optimal stage. A node always has to listen to its surroundings and calculate if it can act as intermediate node. It thus interferes in the normal operation of the node which if devoted to a particular application might produce a sub-optimal performance for the application. All the decisions are taken locally by the node. QOS metrics of time may have to be compromised in this approach. This protocol functions

below the routing layer and thus cannot effectively use the information collected by the routing layer.

Location Aided Routing (Young, 2001) discusses how location information can be used by the reactive routing protocols. It presents one such where in the location information is used in the every stage of communication. In route discovery location information is used to contain the packet flooding in the network caused by a reactive routing protocol. The last location information of the destination is used and an expected and request zone are formed for the node. It presents two schemes where in this information is used to determine the zones for of the node with a probability for each position. It interferes in the normal working of the nodes. The protocol can be used only in some nodes.

Rodoplu and Meng (Rodoplu, 1999) uses a position based routing protocol where in a bellman-ford algorithm is used. An energy efficient route to the destination is found and that route is used to send the data packets. It uses deployment region, enclosure graph to find the shortest route. The nodes are assumed to be equipped with GPS system and it is used to track the nodes. The decisions are made locally and the connectivity in the network is always maintained. We get a local minima in terms of energy savings. A lot messages are exchanged for this purpose and the protocol interferes in the normal working of the nodes.

Message ferrying (Zaho, 2004) takes about an approach in message communication in a wide and sparse network. Since the network is wide the chances of one node coming in contact with another is slim and the network being sparse does not facilitate the use of intermediate nodes. In this approach the node sends the message to its immediate neighbors who store the message. If they come in contact to any node they pass along the

message to that node until it reaches the destination. The message has to be a non-critical since delivery is not guaranteed and the time of delivery can never be predicted. The neighbors act as storage and delivery point for the message. It helped in understanding the principle of message relaying using an intermediate node as receiver. Message ferrying has different scenario of application than relay node.

Fleetnet project (Hartenstein, 2001) describes a project for the development of wireless network for inter-vehicle communication on the road ways, and for providing internet services to the vehicles. It uses position based routing where in the position information is used to forward the packet to the destination. It assumes that all vehicles would be installed with GPS system and hence would accurately know their position. There would communication stations at various points which broadcast the message in their region. It is inspired from the cellular phone architecture. It helped in understanding the principle of message relaying using an intermediate node as receiver.

The proposed approach to the problem of conserving the energy in a MANET is a lot different from the above approaches. In our solution we would be introducing into the network autonomous nodes which would save the energy consumed in communication by acting as an intermediate hop for the flow. Unlike these approaches, we have a separate layer that operates above the routing protocol. The layer has entire control of the node operations. The solution is explained in detail in the following chapters.

CHAPTER V

PROPOSED SOLUTION

The solution that we propose for the problem is explained in this chapter. The relay node movement is to be governed by the algorithm in the layer operating above the routing layer. This layer contains the decision modules for the relay node to decide the flows for which it would act as the intermediate next hop. Let us consider some of issues that we need to consider in developing the algorithms.

The Issues in the development of the protocol are

- Global view vs. Local view: The relay nodes have the responsibility of appropriately positioning themselves, and picking up the MANET nodes/flows that they will service. The relay nodes can arrive at these decisions using either the global or local information about the network. Having a global view of the network will certainly enable the relay nodes to arrive at a globally optimum solution. However, if the network is fast changing, the relay nodes might consider just using the local information to arrive at local optima. The decision to aim for global vs. local optimality depends on the information available to a relay node. In our implementation we would be using the asynchronous global view of the network and take a decision locally.
- Optimal number of relay nodes: We have assumed until now was that the number of relay nodes in the network is pre-determined. The relay node should be able to decide how many other relay needs should be there in the network in order for the

power consumption of the network to be optimal. In calculating this, the relay node needs the information on number of application nodes, flows and traffic pattern in the network.

- Dynamism in node behavior: We have assumed so far that the behavior of a node in the network is fixed, i.e., a node is designated as either a MANET node or a relay node, and this designation does not change. However, it is possible that at times, some MANET nodes may not be used by the application. During such intervals, these MANET nodes can volunteer to act as relay nodes. When the application requires the nodes again, they revert back to the MANET node status. Thus the number of relay nodes in the network need not remain constant, but can vary with time. Though these dynamisms in node behavior offer greater flexibility, they also increase the complexity of the system.
- Effect on bandwidth availability: The use of network controlled relay nodes offer a range of opportunities for enhancing the quality of communication in MANETs. However, they might also have associated drawbacks. For example, by acting as intermediate hops, the relay nodes can decrease the net bandwidth available for the MANET nodes, and increase the latency of data transfer.

The application node is dedicated to a particular task and is directed in its movement by the application. Let us consider the operation of the application node in detail. By operation, we mean the functioning of the routing protocol in the application node.

Application node functioning:

The details of the routing protocol operation in a MANET node are:

As soon as the application node boots up, it first determines its position using the GPS system. Once it determines its position, it then broadcasts search packet to establish neighbor relationship with other application nodes within its range. All the nodes, both application and relay nodes, that receive this packet would send neighbor reply to this new node with their positions and the time in the packet.

The application node would then update its routing table entries and add the node that sent the reply as its neighbor and send it as reply a packet having its position information and the time in it. Once the neighbor receives this information, it updates its routing table and then sends its updated routing table to the relay node.

All the other neighbors also receive this routing table and update their table with the new routing table information. In the routing table there would be fields for a node, its position co-ordinates, the time it was at that position and the next hop to reach that node. In calculating of the next hop the position information of the node is used. All the nodes that lie in the direction of the destination node would be considered first. Then the nodes that would consume optimal energy in the communication would be the next hop node. Once this process is done with all other nodes, the MANET node has established neighbor relation with all the nodes in its vicinity. All the MANET nodes would periodically exchange their routing tables with its neighbors as dictated by the native routing protocol in the network. The nodes would then move about their application task. Once the node goes out of range its routing update information would not be available to its neighbors and their node entry would be modified to reflect that it is not within range with the next hop column against this node having an entry (Jones, 2001).

Handshaking would be needed in case the node which is the next hop node of a flow is going out of range. The native routing protocol has all the features to handle such situations. The node has knowledge of being an intermediate node for a flow and if it is going out of range would inform the upstream neighbor of that flow. The upstream neighbor would then find another node to be next hop and inform this information to its upstream neighbor and the information reaches until it reaches the source of the information.

The source and destination of the information has knowledge of all the nodes that are intermediate for that flow and the intermediate nodes have knowledge of the information of source, destination, upstream and downstream neighbor. The intermediate node broadcasts a “low battery” message when its available power falls below a certain level and initiates the handshake procedure.

These constitute the important principles governing the operation of the routing protocol of the application node.

Relay node functioning:

Let us consider the operation of the relay node in detail. The relay node is governed in its operation by a layer operating above the routing layer. This layer has principles which determine what flows should a relay node handle and the path that the relay node should be following. These are determined by using equations and flow information gathered by the relay node. The operation of the relay node is as follows:

As soon as the relay node boots up it enters the listening phase. It first establishes neighbor relationship with all the MANET nodes in its vicinity. It then starts collecting

the information about the flows and decides the position that it should move to, the position where maximum energy would be saved. The region of the network that is the most active is often the place where more energy can be saved.

The relay node moves itself to that region and establishes neighbor relation with the MANET nodes in that region. It collects the updated information about the flows either originating or traveling through that region. The relay node does its operations in cycles. It decides its action from cycle to cycle.

Once all the flows information is collected, the relay node decides the flows that it would be handling. For this purpose it uses equations that are explained in the later section. It then informs the immediate upstream and downstream nodes of the flow that it would act as an intermediate node of the flow and the handshake procedure is carried out. The relay node does this for all the flows that it decides to handle.

The relay node calculates based on the flows that it would be handling the path that it would be moving. In calculating the path the relay node uses the position information of the nodes, its own position and the direction the nodes would be traveling in the clock cycle.

The application nodes would be able to predict their path for the short cycle. The movement can be certain or with some probability. The relay node would be able to calculate its motion either way. When choosing a flow, the relay node chooses the flow if it is able to stay in contact with the sender and the destination or sender and the receiver through out the clock cycle. We can attach priorities to the flow other than the amount of communication which decides the priority of the nodes in a default manner. Say some node is very low on its energy level, and then we could increase its priority and

thus save more energy in that node. At the end of clock cycle the relay node would again calculate its path based on flows and position of the nodes. The relay node operation spans in cycles, whose length is to be investigated. The length of the cycle should not be long because predicting the application node over a long time would not be possible. The cycle should not be too short to avoid the relay node spending most of its time in calculation rather than saving energy. The optimal cycle time should be same as the cycle of routing table updates. We presume so because the tables are exchanged at the end of cycle. Having the relay nodes operation cycle have the same time would save energy because the additional information needed for the relay node could be send as piggy back in the packets. We would test the cycle time for various values during the simulation and based on the result we should be able to conclude the optimal length of time for the cycle.

Preliminary Equations:

Let us consider the equations governing the relay node when handling a single flow.

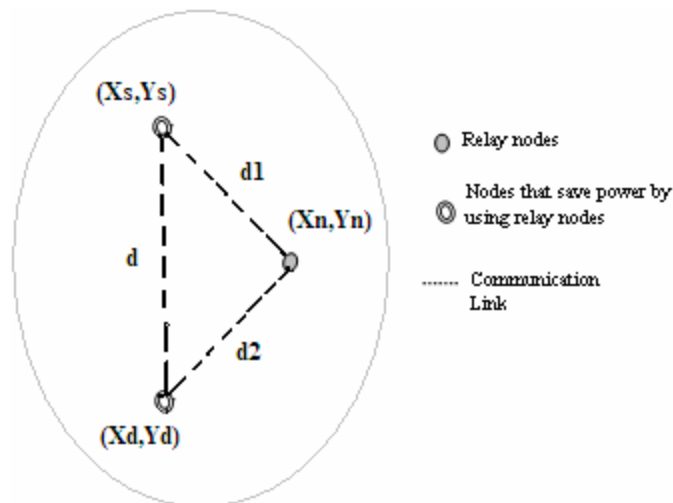


Figure II : Network Scenario with Relay Node

Consider the Figure II shown below. The relay node N located at (X_r, Y_r) is acting as intermediate node to the source of the transmission S, located at position (X_s, Y_s) and

destination D located at (X_d, Y_d) . Let α be the coefficient to which the distance is to be raised, which is proportional to the energy consumed. Let P_r be the power consumed when the relay node R located at (X_r, Y_r) is used.

$$P_r = (d_1^\alpha + d_2^\alpha) \\ = ((\sqrt{(X_s - X_r)^2 + (Y_s - Y_r)^2})^\alpha + (\sqrt{(X_d - X_r)^2 + (Y_d - Y_r)^2})^\alpha) \text{ ----- (3)}$$

Usually value of α is between 2.4 to 3.0. For simplification let us for now assume that value of α is 2.

Then the power consumption equation is:

$$P_n = ((X_s - X_r)^2 + (Y_s - Y_r)^2) + ((X_d - X_r)^2 + (Y_d - Y_r)^2) \text{ ----- (4)}$$

To obtain the minimum point for this equation we use differential calculus and partially differentiate the equation with X_r and Y_r , the position at which the relay node should be present so that the energy consumption is minimum. This is assuming that the X and Y co-ordinates are independent in the power equation. The motion in direction of one co-ordinate is independent of the motion in the other co-ordinate. We then equate it to zero to find the minimum of the equation.

$$\frac{\partial P_r}{\partial X_r} = 2(2 * X_r - X_s - X_d)$$

Equating it to zero to we get the value of X_r for which the power equation would have minimal value.

$$X_r = \frac{(X_s + X_d)}{2} \text{ ----- (5)}$$

This is the value of X_r for which we get the lowest value of P_r . Similarly the value of Y_r for which we get the lowest value of P_r is

$$Y_r = \frac{(Y_s + Y_d)}{2} \text{ ----- (6)}$$

(X_r, Y_r) is the point that the node should be at given time if it is handling one flow only. Once the motion of the source and the destination in the cycle is known the node can calculate the path that it should be traveling by tracing the positions that it should be for the positions of the relay node. Now let us consider the scenario where in the relay node is handling multiple flows. The relay node has to find the flows that it would be handling first. For this we add two constraints on relay node that it should take into consideration when deciding the flows that it would be handling.

Constraints on choosing a flow:

The first constraint is that when the relay node decides to handle a flow in a multiple flow situation, the minimum energy saved for the flow should be certain percentage of energy that would be saved when the node is handling only that flow. This constraint is to ensure that justice is done to the flow in terms of saving energy.

The second constraint is that the energy saved should be at certain minimum level in terms of watts. This is to ensure that the relay node does not spend time in saving energy that is insignificant. The minimum level constraint ensures that relay node does not spend its energy in handling flow where the energy savings are not significant.

For any flow if any of these constraint is not met then the flow is not handled by the relay node.

Equations for the relay node:

Let us now consider the equations that govern the multiple flows handling scenario by the relay node to obtain the position and the direction that it should be moving. Let P_r be the power consumed in the network when the flows are handled by the relay node. The relay node is handling N flows at a time. The Power equation P_r is

$$P_r = PF_1 + PF_2 + \dots + PF_N \text{ ----- (7)}$$

Where PF_I is the power consumed by handling the flow “ I ”. The equation for this would be on the similar lines of the equations obtained in the above case of handling a single flow. There are a total of N flows that the relay node is handling and we have a power equation similar to that of (4) for each of the flows.

Let the relay node be at position (X_r, Y_r) . The nomenclature for the positions of the nodes for the flow 1 is (X_{1s}, Y_{1s}) and (X_{1d}, Y_{1d}) for the sender and receiver of the flow for which the relay node acts as intermediate node. The “ I ” represents the flow number and the “ s ” and “ d ” represents the upstream and downstream neighbor of the relay node for the flow 1.

Using the equations (3) and (4) derived in the case of single flow handling, substitute value of the distance and power in the equation. Let us for the moment consider the value of α to be 2.

$$P_r = ((X_{1s} - X_r)^2 + (Y_{1s} - Y_r)^2) + ((X_{1d} - X_r)^2 + (Y_{1d} - Y_r)^2) \\ + \\ ((X_{2s} - X_r)^2 + (Y_{2s} - Y_r)^2) + ((X_{2d} - X_r)^2 + (Y_{2d} - Y_r)^2)$$

$$\begin{aligned}
& + \\
& \dots \\
& \dots \\
& + \\
& ((X_{Ns} - X_r)^2 + (Y_{Ns} - Y_r)^2) + ((X_{Nd} - X_r)^2 + (Y_{Nd} - Y_r)^2) .
\end{aligned}$$

The Power equation is

$$P_r = \sum_{i=1}^{i=N} ((X_{is} - X_r)^2 + (Y_{id} - Y_r)^2) + ((X_{id} - X_r)^2 + (Y_{id} - Y_r)^2) \text{ ----- (8)}$$

To obtain the minimal value for this power equation we partially differentiate this equation with X_r and Y_r and equate the result to zero. We assume that X and Y are independent, the motion of the relay node is independent in X and Y co-ordinates. The result of differential with X_r is

$$\frac{\partial P_r}{\partial X_r} = (N * X_r - (X_{1s} + X_{1d} + X_{2s} + X_{2d} + \dots + X_{Ns} + X_{Nd})) \text{ ----- (9)}$$

Equating (9) to zero to find the value of X_r for which (8) has minimal value we get

$$X_r = (X_{1s} + X_{1d} + X_{2s} + X_{2d} + \dots + X_{Ns} + X_{Nd}) / N$$

Similarly differentiating P_r with respect to Y_r , the value of the differential is

$$\frac{\partial P_r}{\partial Y_r} = (N * Y_r - (Y_{1s} + Y_{1d} + Y_{2s} + Y_{2d} + \dots + Y_{Ns} + Y_{Nd})) \text{ ----- (10)}$$

Equating (10) to zero to find the value of Y_r for which (8) has minimal value we get

$$Y_r = (Y_{1s} + Y_{1d} + Y_{2s} + Y_{2d} + \dots + Y_{Ns} + Y_{Nd}) / N$$

(X_r, Y_r) is the point that the node should be at given time. The result shows that the relay node should place itself in the geometric center of the nodes whose flows it is handling.

Once it knows the path of each node, the relay node obtains the points that it should be for points the nodes in their paths, and thus the relay node traces its path. The relay node then calculates the energy savings in each flow and discards the flows that do not meet the constraints, and it then calculates its position again with out those flows until there are no more flows that can be discarded.

We can add priority to each flow. By prioritizing a flow, we would be saving more energy on that flow. If a node is low on power then all the flows emanating from that node can be given higher priority and the node thus would have to expend less energy and have a longer operating time. The equations that we obtain are similar lines on the equations we have developed for the multiple flow handling.

$$P_r = W_1 * PF_1 + W_2 * PF_2 + \dots + W_n * PF_n \quad \text{-----} (11)$$

Differentiating with X_r , Y_r and equating the result to zero, we get the values of X_r and Y_r for which (11) would have minimal value. They are

$$X_r = \frac{((W_1 * X_{1s}) + (W_1 * X_{1d}) + \dots + (W_n * X_{ns}) + (W_n * Y_{ns}))}{2(W_1 + \dots + W_n)} \quad \text{-----} (12)$$

$$Y_r = \frac{((W_1 * Y_{1s}) + (W_1 * Y_{1d}) + \dots + (W_n * Y_{ns}) + (W_n * X_{ns}))}{2(W_1 + \dots + W_n)} \quad \text{-----} (13)$$

As we increase the weight of one flow, the relay node would be moving to a position where the energy saving is optimal for that flow. The optimal energy saving for any flow is obtained when only that single flow is handled.

When we consider the network in 3-dimension the additional would be represented by “Z” and the equations for those would be on similar lines to those that we have developed.

Even if the value of α is not a perfect 2, the equations obtained still are the same. These equations are the decision modules for the relay node. The results of these equations determine the flows that the relay node is going to handle.

Our proposed solution is a new approach to the problem. The approach is much cleaner than other approaches since it does not interfere with the working of the relay node. Unlike other protocols our approach leaves the application node free to do its task and not interfere with its movement to optimize the energy. This solution can be deployed and used very effectively with out any change to the infrastructure and much investment.

We need to find the cycle time for the operation of the relay node. If the relay node cycle time has the frequency as the application nodes routing table exchange then we could optimize the energy, by saving the energy that would have otherwise been needed in sending the additional information needed by the relay node for its operations. If the relay node cycle time is same as that of the application table exchange time then the relay node information can be piggy backed in the packets send for the table exchange.

CHAPTER VI

SIMULATION

The simulation of the protocol was done very extensively and under various conditions. The source code for the simulation program was written C++. The program contains implementation of CSMA / CA, Position based routing protocol and the relay node layer. The source code of the program runs to about 2000 lines of code. Mac layer has collision detection, binary exponential back off and uses NAV (network allocation vector) to determine when the network is busy. In case of a collision the nodes go into binary exponential back-off. The output parameter of the simulation was percentage of power saved when using relay node, number of packets handled by the relay node. The input parameters for the simulation are the Epoch clock interval, error in motion prediction, sending range, reception range, single hop, multi hop, Max vs. Random flow, Local view vs. Global view.

Epoch Interval:

The Epoch time interval is the frequency of the routing tables being exchanged. The power saved was tested for various Epoch intervals. There was error introduced into the predicted motion of the MANET node to test the protocol for various conditions. Testing was done for various percentages of the error in motion prediction. The nodes movement area was restricted to ensure that the node position was within the error percentage from

its original predicted position. Testing was done for error percentages of 0, 20, 30, 40, 50, and 60. Each of the error percentage was tested for both single hop and multi-hop.

Max vs. Random:

When choosing a flow the simulation tested the power saved when the flows were chosen in a random fashion and when the flows were chosen in accordance with the equations developed for the relay node. In random fashion the flows were chosen randomly and not governed by the equations. Flows were selected with a probability of 0.5. We shall call the scenario in which the random flows are chosen as “random flow” and the scenario in which flows are chosen using equations as “max flow”. Each of the scenarios was again tested for both Local view and Global view of the network for a relay node. When using max flows the relay node has to compute the flows to be selected using the developed equations.

Single hop and Multi hop

A single hop network is formed when all the nodes in the network are at a single hop distance. In a single hop network each node can directly contact the other node. The number of hops for a packet is 1. In a multi hop network the number of hops for a flow can be more than 1. The nodes may be out of range of each other and hence to reach a destination the source may have to use an intermediate receiver. The intermediate node receives the packet and stores the packet in its sendq. The intermediate receiver forwards the packet to the destination. The intermediate receiver is obtained using the look up into the routing table. The routing tables are exchanged at the beginning of the Epoch interval. The routing table of a node is updated when it receives the routing table from its

neighbor. The routing tables are updated and maintained using the distributed Bellman Ford algorithm.

Local View vs. Global View:

The view of the network is formed depending on how the relay node collects information. When the relay node collects information only about the local nodes, i.e. its one hop neighbor, the relay node gets a Local view. When the relay node collects the information of all the nodes in the network it is said to have obtained a Global view. The Global view and Local view is same for a single hop network. Global view of the enables the relay node to decide the active part of the network. Relay node calculates the most active area by taking into consideration the flows in that area. The relay node checks for the sum of flows of a node and its neighbors. The highest sum area is the most active part of the network. The relay node moves to this area. In simulation we had two relay nodes and one of them moved to the highest sum area and the other moves to the second highest sum area. The relay node would be handling more flows using the Global view than Local view. The relay node thus saves more power by moving to the active part of the network.

Message Types:

The message types that are used in the simulation and their purposes in the simulation:

Type 0: This is the individual message being sent by the sender and meant for the receiver.

Type 1: It is the update table message. The message is meant for everyone and the receiver is marked as unknown. Once this message is got the routing table is updated in the node with the received routing table.

Type 2: It is the position prediction information of the node. The relay node uses this information in selecting the flows.

Type 3: It is the flow information in a node. The relay node uses this information in selecting the flows.

Type 4: It is the message sent by the relay node to the sender that it is ready to act as intermediate node for a flow from that sender. The sender marks the flow so as to use the relay node.

Type 5: It is the message sent by the relay node informing the sender that it no longer acts as the intermediate node for an already servicing flow. This happens when the receiver is out of range of the relay node.

Type 6: It is the message by the sender informing the relay node that it would be not be using its service.

Initialization and working of MANET node

The program starts by initializing the MANET nodes, relay nodes and setting up the requisite parameters. The MANET nodes have a flow generation and motion prediction functions. The mobility pattern for the mobile nodes is the random mobility model. The motion prediction function predicts the motion based on the speed of the node. The protocol was tested for both walking speed, and driving speed. The motion prediction generates the motion for the entire Epoch interval. The flow generation function chooses a neighbor from its routing table to be the destination of the flow. Each flow has certain number of packets to be transmitted, and the flow is active until the packets are transmitted. The flow information is maintained in flow structure and transmitted at the beginning of the Epoch interval. The MANET node has a receiving queue and a sending

queue. All the packets that MAC layer receives would be added to the receiving queue. The node checks to see if it is the receiver or destination for the packet. In case it is neither the packet is discarded. In case it is receiver and not the destination, the packet is meant to be forwarded to the destination and hence the packet is stored in the sending queue. For each and every packet received the node updates the position information of the sender of the packet and the NAV value sent in the packet. When choosing a packet to transmit, the MANET node checks to see if there is any packet to be forwarded, if so that packet is transmitted else a packet is taken from the flow and transmitted. If all the packets in the flow have been transmitted then the node does not transmit any packet. In transmitting a packet the node first checks for the NAV value. If the network is determined to be free, the node waits for the binary back off time and then transmits the packet.

If the receiver is out of range the node would make four attempts to send the packet, if despite those attempts the node is unable to send it marks the receiver as out of range in its routing table. When the node comes back into range again or there is change in the routing table status and the receiver node becomes reachable the sender node sends the packet to that receiver again.

Working of a Relay node

The relay node starts by collecting the information on the flows and motion of the nodes. Once it has this information it would be able to decide the flows that it would be servicing. The equations developed in the earlier section, govern the relay nodes decision whether to choose to service a particular flow or not. The relay node has the motion pattern of the nodes and these are substituted in the equations and the path that the relay

node has to travel is obtained. At the end of Epoch cycle the relay node again calculates its motion based on the flow information and position information available. When the relay node determines that a particular flow is to be serviced, it sends a packet to the source of the flow informing that the relay node can act as a receiver for that flow. The MANET node updates its flow information to reflect that the relay node would be the sender for that flow. In case the relay node is no longer able to service an already servicing flow, it sends the source a packet with that information. The source updates the flow information to reflect the same. In case there are more than one relay node competing the source chooses the relay node that first sent the message and lets the other relay nodes know that it would not be using it.

The simulation was done using ten MANET nodes and two relay nodes. The total power savings and the power saved in each Epoch cycle were calculated. In each test run the simulation was done for each setting for a large number of Epoch cycles. Many such test runs were taken to determine the power saved in each case of the input parameters. The simulation was very extensively done to reduce the error in the results.

CHAPTER VII

RESULT

The results of the simulation are presented in graphs. The graphs show the percentage power saved in the network by using the relay node.

The first graph, Figure III shows the power saving obtained in a single hop network when there is no error in motion prediction.

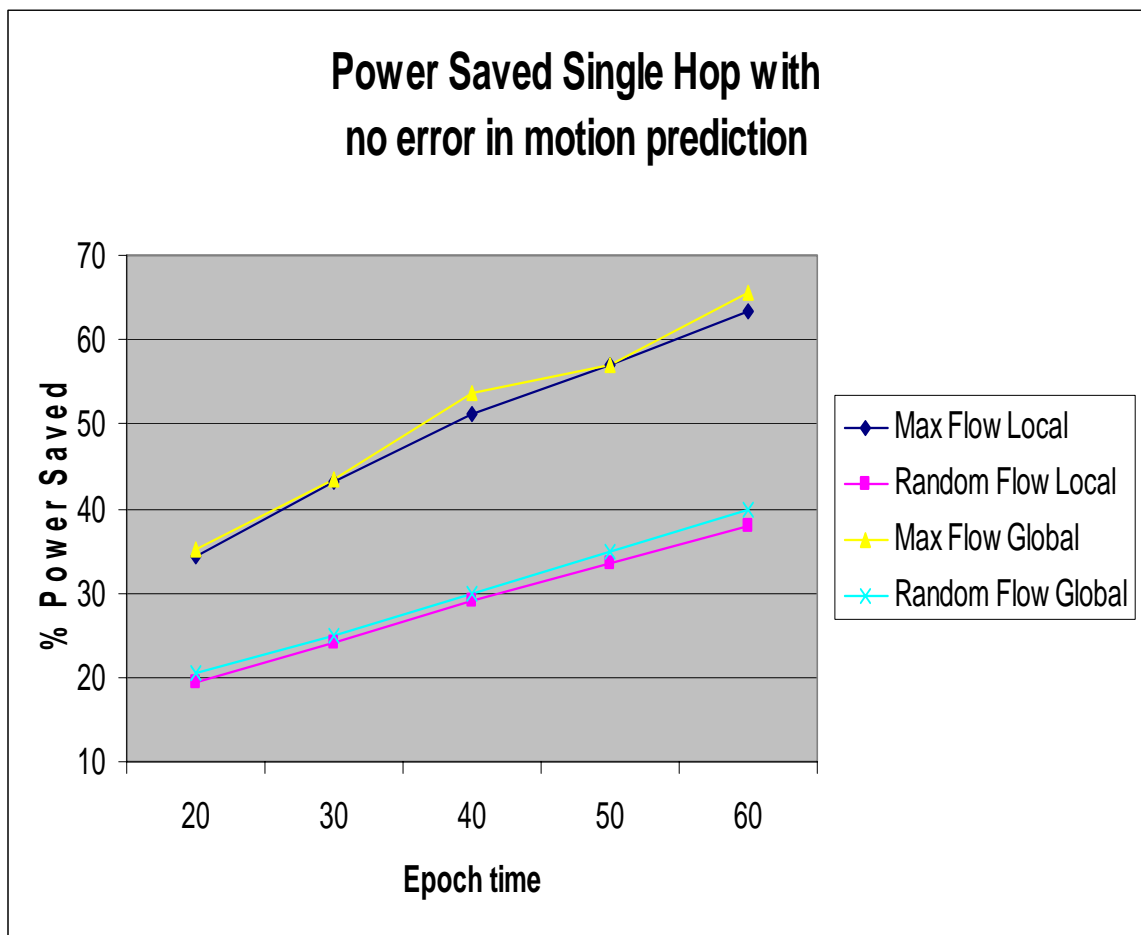


Figure III: Power Saved

In a single hop network there was considerable energy saved when using the relay node. The power saved is shown in Figure I. As the Epoch interval increased the power saved also increased. This is because at the beginning of each Epoch interval a lot control packets are transmitted which are not relayed through the relay node. So as the Epoch interval increases number of data packets sent through the relay node also increased in effect giving more percentage of power saved. There is drastic difference in the power savings when flows where chosen randomly as there were more flows dropped due to the randomness.

The second graph in Figure II shows the power saved in a multi hop network when there is no error in motion prediction.

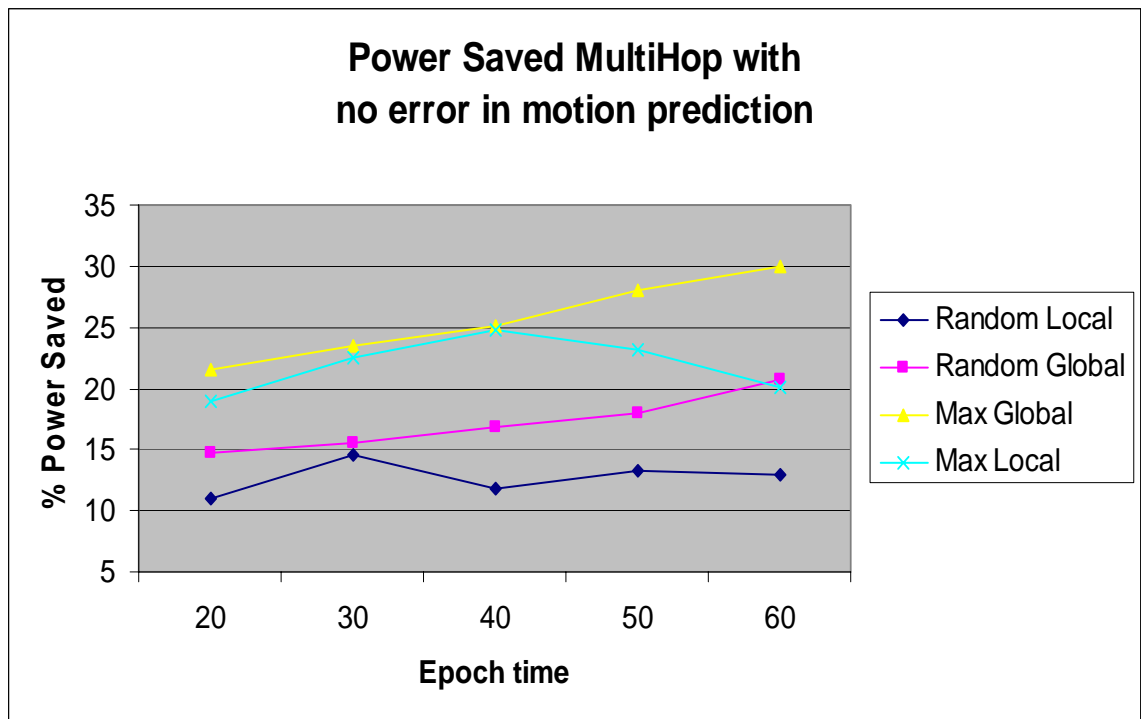


Figure IV: Power Saved

In a multi hop network the power saving when compared to single hop network is less as shown in Figure IV. This is because the number of flows handled by the relay node in a

single hop is much more than the number of flows handled by the relay node in a multi hop scenario. We also observe that there is a sharp fall in the power saved after an Epoch of 40 when “Max Local” is considered. This is because as the relay node services a flow for a longer time it moves in a direction to handle that flow. At the end of Epoch cycle the neighborhood of the relay node is less compared to that of the neighborhood at 40 as the node has moved out of range for most nodes due to its dedication to the flow. In a single hop the nodes were always neighbor with each other. Since local information was only used the node had very few flows to handle and thus the low power savings. When global information was taken the node moved to more active part of the network and hence had hence the percentage power saving kept increasing. The power saving in random flows is less as sometime sub-optimal flows were chosen. The power saving difference in random flows is less compared to that single hop.

In the third graph we shall consider the scenario of multi hop, max flow, global view.

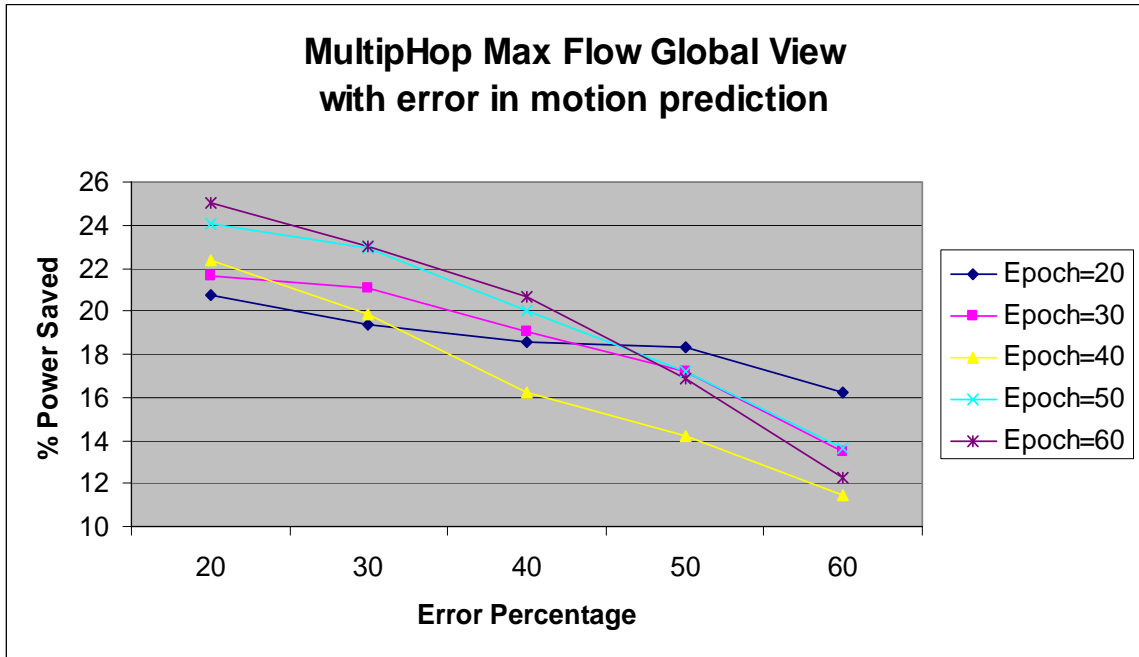


Figure V: Power Saved

We observe in Figure V, that power savings reduce as the error percentage in motion prediction increases. This is because more nodes would go out of range of the relay node since the relay node maps its path based on the predicated motion of the MANET node. We also observe that there is a sharper for fall for scenarios with more Epoch time as the motion prediction error increases. This is because more number of packets dropped as the time increases with the increase in error.

For the fourth graph let us consider the scenario of multi hop, Maximum flow, Local View.

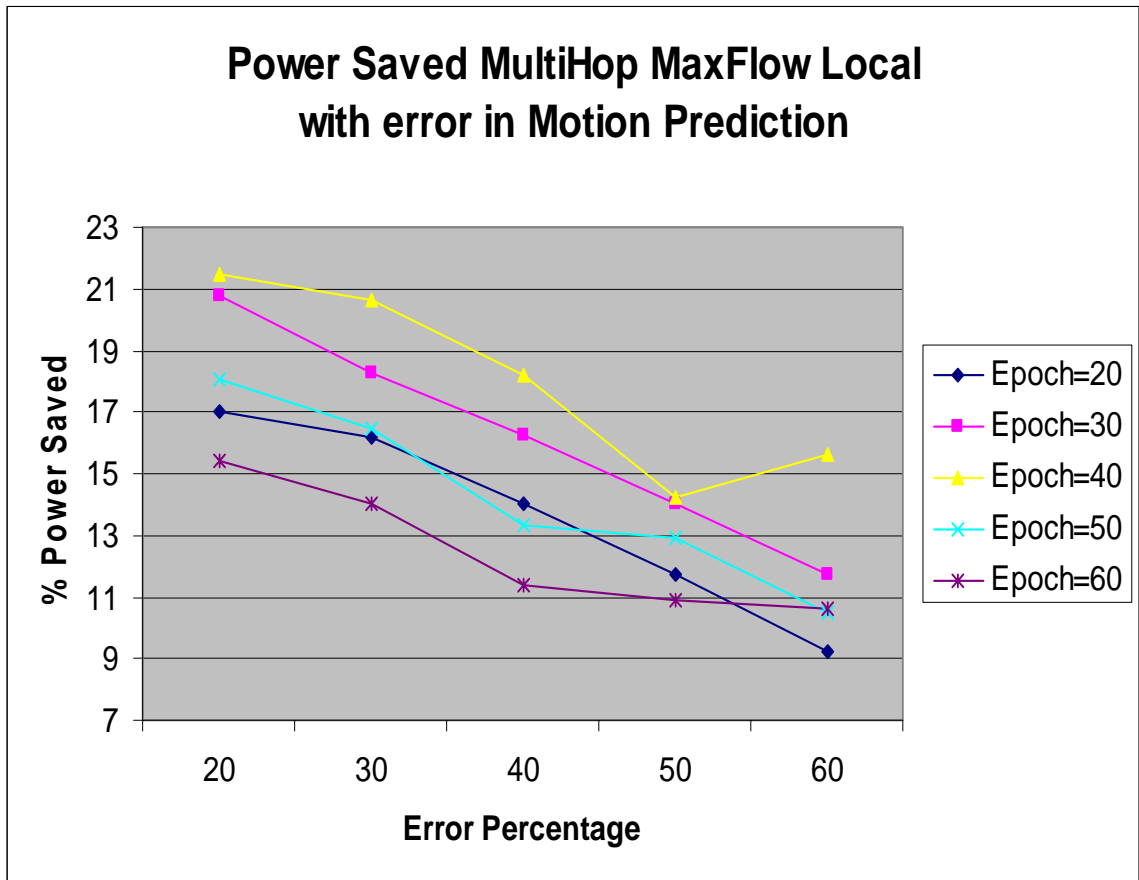


Figure VI: Power Saved

We observe in Figure VI, that the power saved in this scenario is less than the power saved using global view. Global view of the network gives the relay node the ability to choose more active part of the network and thus enabling it to save more power.

The graphs of other simulation results are given below.

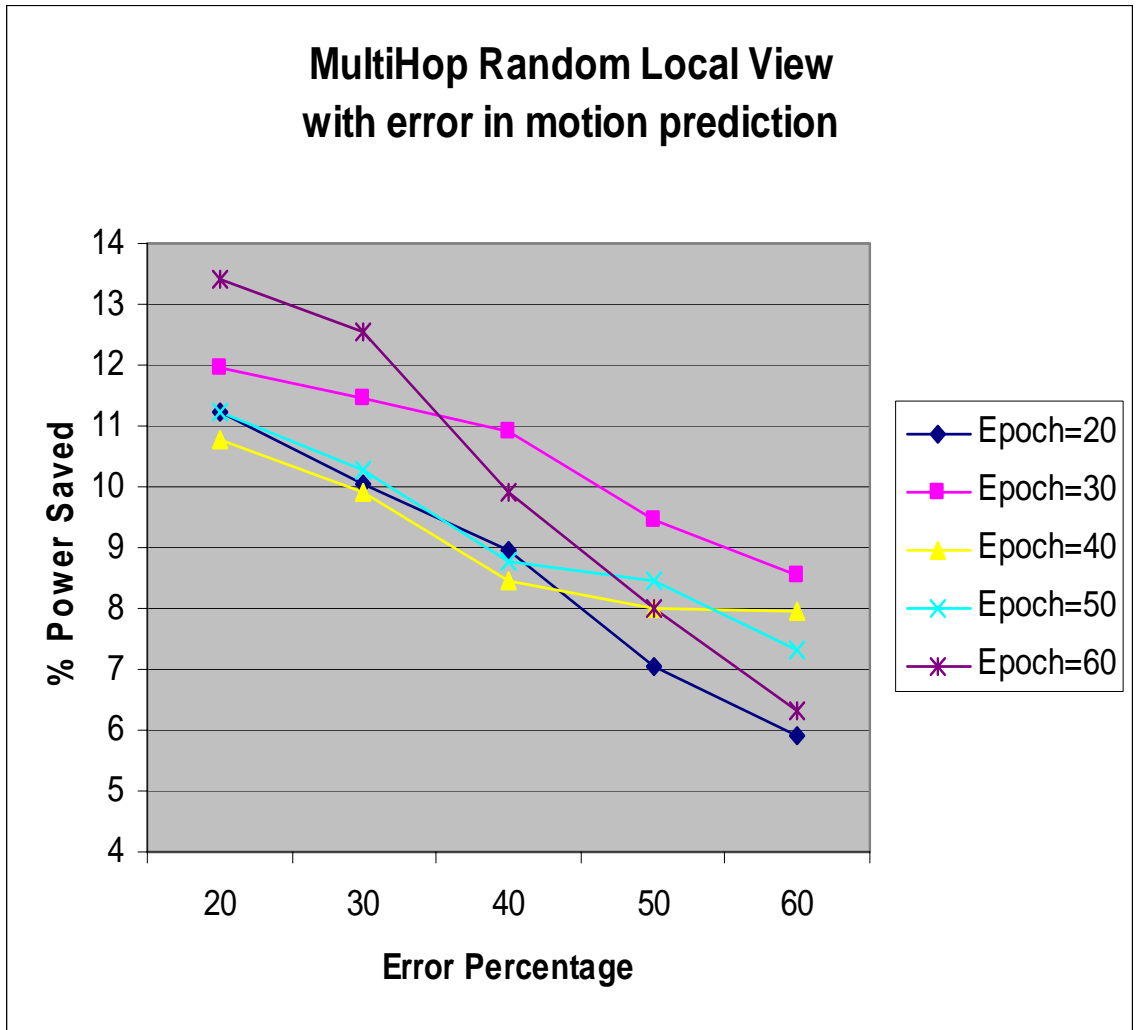


Figure VII: Power Saved

In a random flow the drop in the power savings is not as significant as the drop in max flow as shown in Figure VII. In a random flow the relay node handles fewer flows and thus relays fewer packets. Hence there is no sharp decrease in energy with motion error.

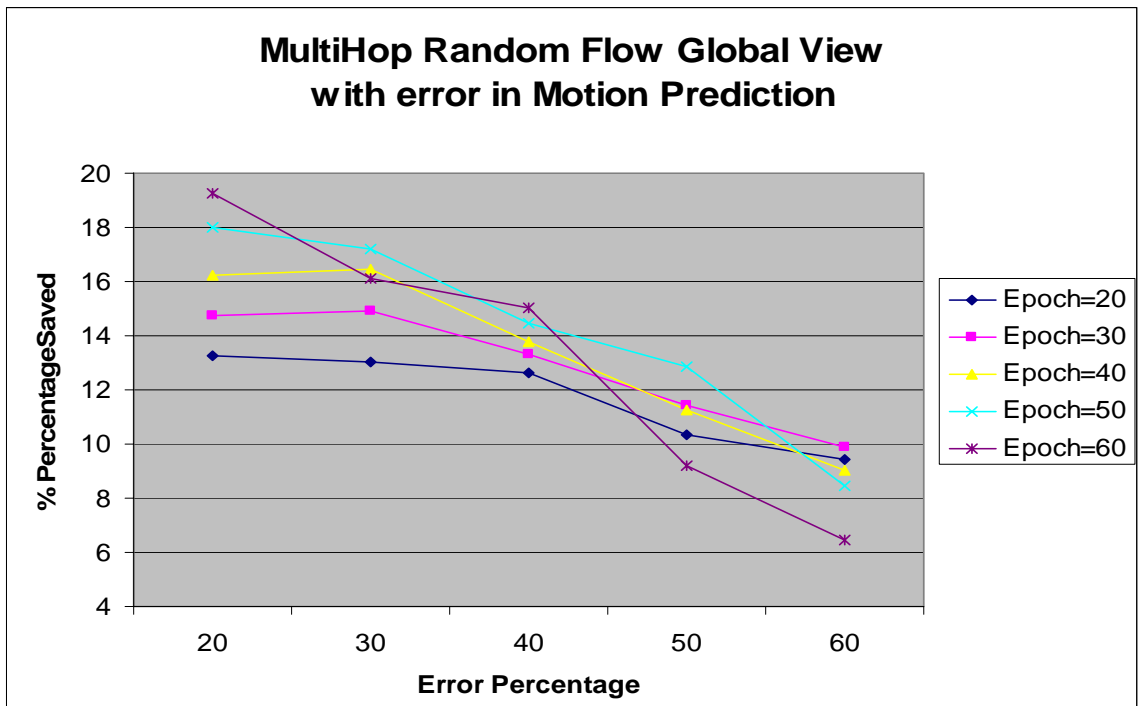


Figure VIII: Power Saved

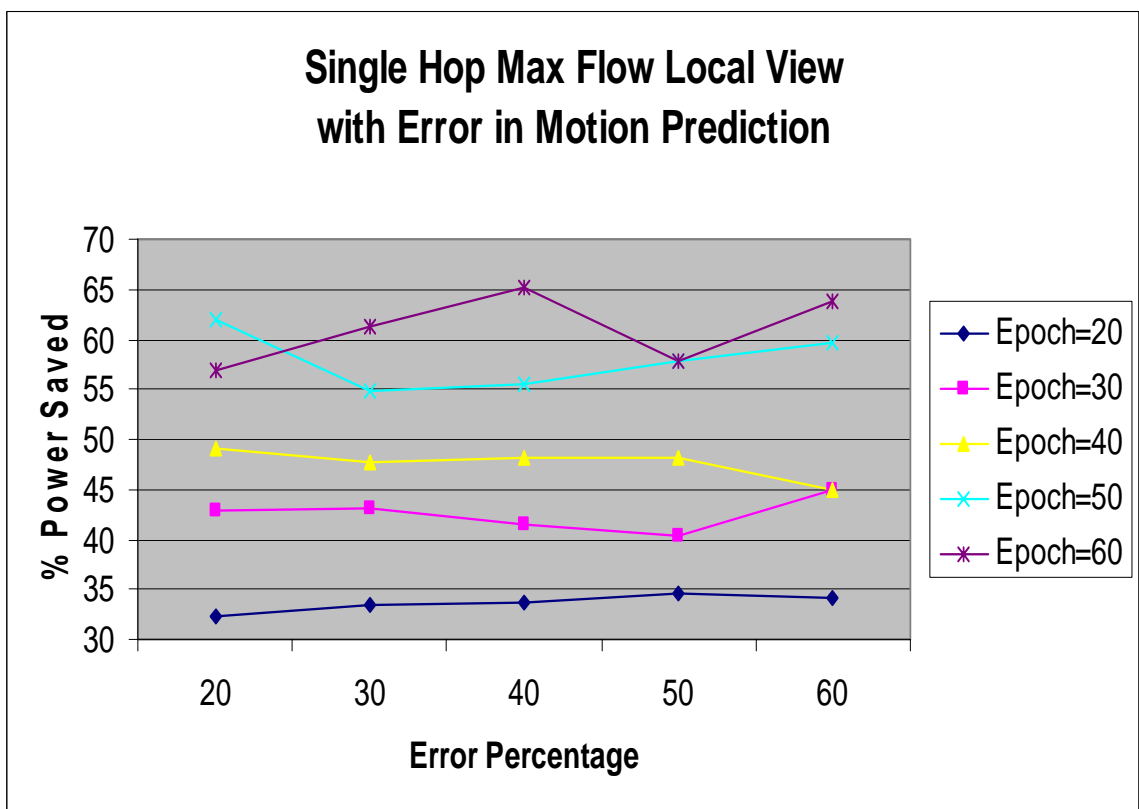


Figure IX: Power Saved

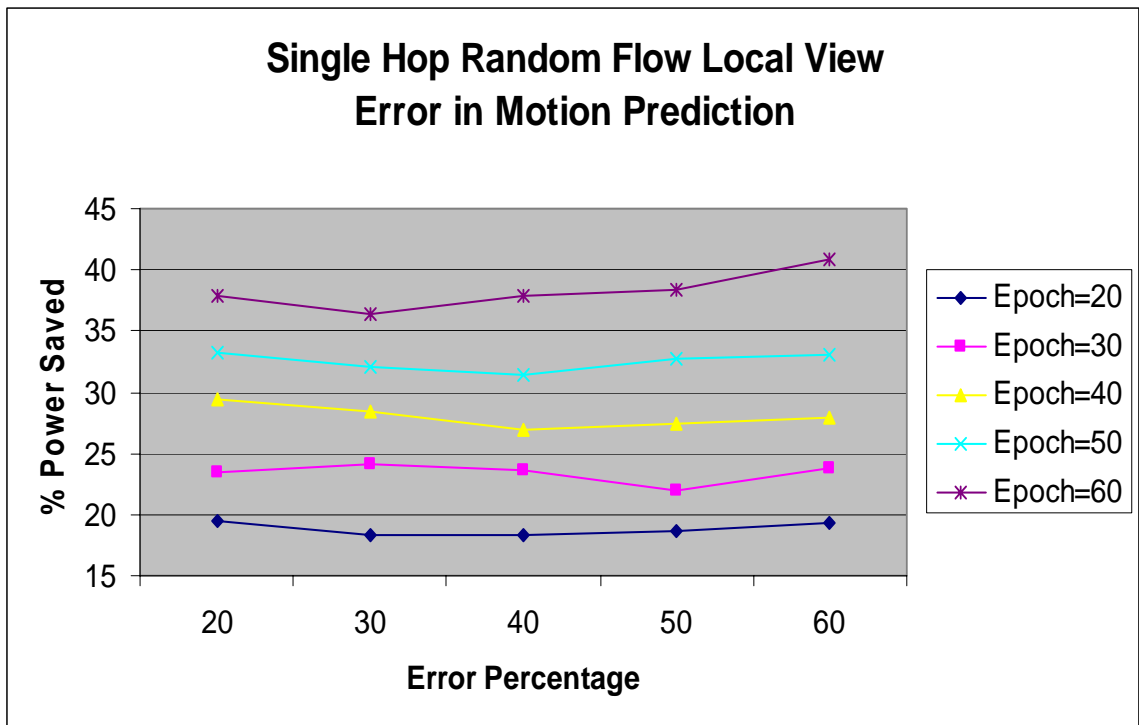


Figure X: Power Saved

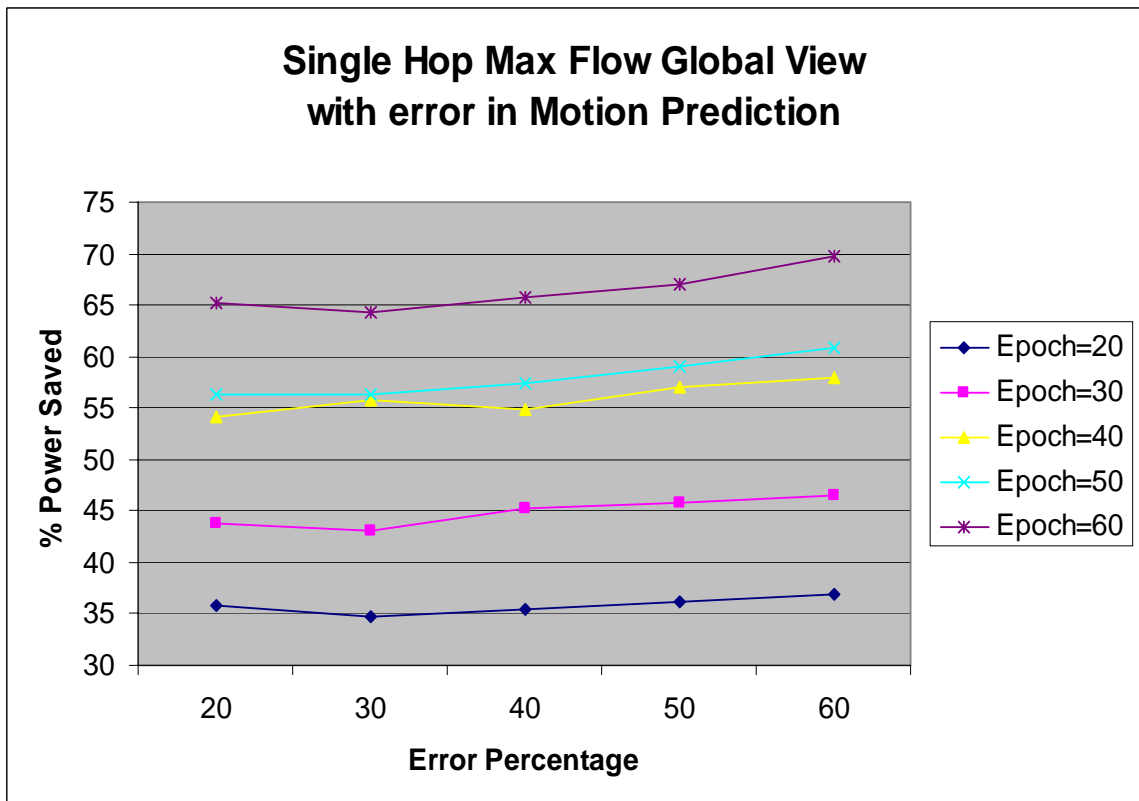


Figure XI: Power Saved

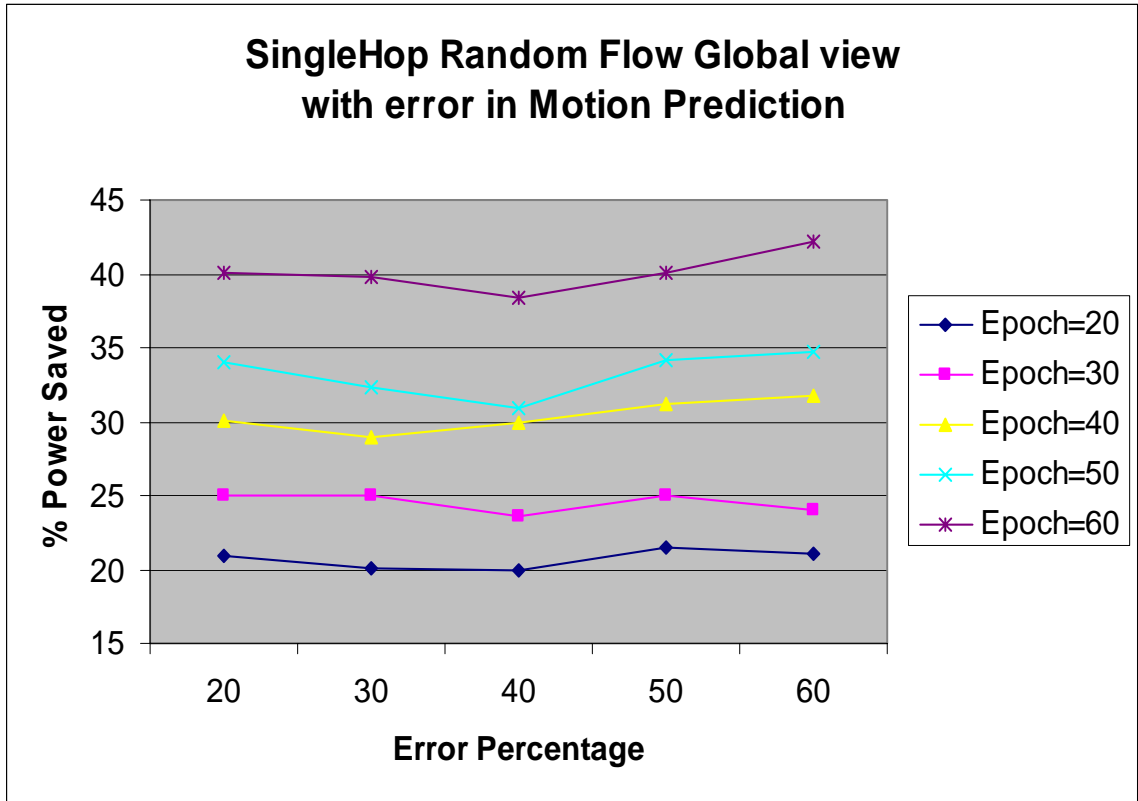


Figure XII: Power Saved

The power savings in a single hop network with error in motion predictions are shown in Figure IX, X, XI, XII. We observe that the energy drop in single hop is not as sharp as energy drop in multi hop. When a sender transmits a packet and the receiver does not receive it in the first attempt, the node then transmits it with the maximum range in the successive attempt. So in a single hop the number of packets lost due to error in motion prediction is less as they are always one hop away from each other. In multi hop once the nodes go out of range, even when the packet is transmitted with highest range it never reaches the receiver, hence more number of packets lost.

The results conclude that a single hop network should have higher Epoch time and for a multi hop should have a in between Epoch time. Global view generates better results than

compared to the Local view though obtaining global view might put an additional burden on the network. Max flow strategy works better than a random flow scenario thus justifying the use of the equations to choose the flows. To obtain Max flow the relay node has to use the equations and calculate the flows it would be servicing using the equations developed.

CHAPTER VIII

CONCLUSION

The graphs of the simulation, shown above conclude that there is considerable amount of energy saved by using the relay node protocol. We also observe that the percentage of energy saved is quite significant in most of the scenarios. In a multi hop network under right conditions the nodes can save substantial amount of energy. The energy saved in a single hop network is much more than the energy saved in a multi hop network. Even with error in motion prediction the protocol succeeds in savings some valuable power in the nodes. The results thus justify the use of the relay node in a network as there is energy savings when using the relay node.

The relay node protocol's energy saving is comparable to that of other protocols, though the network conditions of their optimal performances vary. The relay node approach is much cleaner and equally efficient approach. The relay node protocol does not interfere with the normal working of the MANET node and moulds its working in according with the network situation to conserve power in the MANET node. The MANET node is free from the burden of being concerned with saving of power which could result in sub optimal performance of the application running in the MANET node. The relay node is now responsible for saving power. The MANET nodes can now dedicate themselves completely to the application task.

In conclusion we can say that the relay node the relay node approach can save significant energy and thus prolong the longevity of the MANET node in the network.

Future Work:

The protocol can be expanded to scenario where in multiple relay nodes work with co-operatively with each other to achieve even higher performances. In a multi hop network there can be significant energy savings achieved if co-operative relay nodes were used. Each of the relay nodes could act as intermediate node not only for application nodes but also for other relay node. In the scenario of one relay node using other relay node for the packet to finally reach the destination, the energy consumed in the application node would be very less. The co-operative relay nodes could also be use to provide better connectivity in the network. The protocol for the relay nodes to work co-operatively would be an extension to the current work.

REFERENCES

- Chin, K.W., Judge, J., Williams, A. & Kermode, R. (2002). Implementation Experience with MANET Routing Protocols. ACM SIGCOMM, 32(5), 49-59.
- Christian, S. & Timo, K (2002). Geocast Enhancements of AODV for Vehicular Networks. Mobile Computing and Communication Review, 6(3), 96-97.
- Gerla, M. & Xu, K. (2003). Multimedia Streaming in Large Scale Sensor Networks with Mobile Swarms. SIGMOD Record, 32(4), 72-76
- Gomez, J. & Campbell, A.T. (2003). PARO: Supporting Dynamic Power Controlled Routing in Wireless Ad Hoc Networks. Wireless Networks, 9(5), 443-460.
- Gupta, P. & Kumar, P.R. (2000). The Capacity of Wireless Networks. IEEE Transactions on Information Theory, 46(2), 388-404.
- Hartenstein, H., Bochow, B. & Ebner, A. (2001). Position-Aware Ad Hoc Wireless Networks for Inter-Vehicle Communications: The Fleetnet Project. Proceedings of the 2nd ACM international symposium on Mobile ad hoc networking & computing, 259-262.
- Hong, X. Xu, K. & Gerla, M. (2002). A Survey on Sensor Networks. IEEE Communications Magazine, 102-114
- Jones, C.E., Sivalingam, K.M. , Agarwal, P. & Cheng, J.C (2001). A survey of Energy Efficient Network Protocols for Wireless Networks. Wireless Networks, 7(4), 343-358.
- Rodoplu, V. & Teresa, H. (1999). Minimum Energy Mobile Wireless Networks. IEEE Journal on selected areas in communications, 17(8), 1333-1344.

- Royer, E.M. & Toh, C.K. (1999). A Review of Current Routing Protocols for Ad-Hoc Mobile Wireless Networks. IEEE Wireless Communications, 6(2), 46 - 55
- Vieira, M. & Junior, D. (2002). Survey on Wireless Sensor Network Devices. IEEE Communications Magazine, 537-544.
- Young, B.K. & Vaidya. (2001). N.H. Location Aided Routing (LAR) in mobile ad hoc networks. Wireless Networks, 6(4), 307-321.
- Zhao, W., Ammar, M.H. (2004). New directions: A message ferrying approach for data delivery in sparse mobile ad hoc networks. Proceedings of the 5th ACM international symposium on Mobile ad hoc networking and computing, 187-198.

VITA

Eashwar Rao Chittimalla

Candidate for the Degree of

Master of Science

Thesis: ENERGY CONSERVATION IN MOBILE AD-HOC NETWORKS USING
RELAY NODES

Major Field: Computer Science

Biographical:

Personal Data

Education: Bachelor of Science, Computer Science, JNTU, India, May 2002

Completed the Requirements for the Master of Science degree at
Oklahoma State University in December, 2005

Experience: Software Engineer, India Aug 2002 – May 2003

Professional Memberships: ACM, AITP

Research Interests: Sensor / Wireless Networks, Routing, QoS, Security.

Name: Eashwar Rao Chittimalla

Date of Degree: December, 2005

Institution: Oklahoma State University

Location: OKC or Stillwater, Oklahoma

Title of Study: ENERGY CONSERVATION IN MOBILE AD-HOC NETWORKS
USING RELAY NODES

Pages in Study: 46

Candidate for the Degree of Master of Science

Major Field: Computer Science

Scope and Method of Study:

MANET (mobile ad-hoc network) is a self organizing and self-configuring multi hop wireless network. The mobile nodes are normally dedicated to a particular task. Energy conservation in the nodes is a critical issue that can affect the performance of the network drastically. The current methods of saving energy tend to interfere in the normal working of the node thus disrupting the application. The work brings in a new scheme of saving the energy in communication by introducing into the network dedicated, mobility controllable nodes called 'relay nodes' whose working protocols was developed in the thesis. The relay node is governed by a set of equations which determine the flows that the relay node would be handling. This layer operates above the routing layer in the protocol stack.

Findings and Conclusions:

The results conclude that the relay node protocol can save significant energy in the MANET. For a maximum energy savings, single hop network should have higher Epoch time and a multi hop should have a in between Epoch time. Global view generates better results than compared to the Local view though obtaining global view might put and additional burden on the network. Max flow strategy works better than a random flow scenario thus justifying the use of the equations to choose the flows. To obtain Max flow the relay node has to use the equations and calculate the flows it would be servicing using the equations developed. In comparison with other protocols, the relay node approach is much cleaner and equally efficient approach. The relay node protocol does not interfere with the normal working of the MANET node and moulds its working in according with the network situation to conserve power in the MANET node. The MANET node is free from the burden of being concerned with saving of power which could result in sub optimal performance of the application running in the MANET node. The relay node is now responsible for saving power. The MANET nodes can now dedicate themselves completely to the application task. In conclusion we can say that the relay node the relay node approach can save significant energy and thus prolong the longevity of the MANET node in the network.

ADVISER'S APPROVAL: Dr. Venkatesh Sarangan
