OPTIMAL ZONAL PROTOCOL FOR CONTAINING REBROADCAST IN MOBILE AD – HOC NETWORKS

A Thesis by

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I have examined the final copy of this Thesis for form and content and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science, with a major in Electrical Engineering.

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We have read this thesis
And recommend its acceptance:

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Dr. Krishna K. Krishnan, Committer Member

DEDICATION

To my parents and my sister

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ABSTRACT

With the proliferation of inexpensive and widely available wireless devices, the arena of mobile computing has been expanded dramatically in recent years. Mobile ad – hoc networks have been envisioned as the future of wireless networking technology with continuous effort to improve its performance in various areas and one such area is the routing protocols. Various routing protocols are in existence and Self Learning Ad-Hoc Routing protocol is one of them. SARP is a hybrid routing protocol featuring the properties of both vector routing and source routing. It utilizes the usual route discovery and maintenance procedure same as of on-demand routing protocols to discover and maintain routes in the network. During these procedures, a node rebroadcasts excessive numbers of control packet (RREQs, RERRs) in search and maintenance of routes in a network. However, such rebroadcasting is a common and frequent operation in an ad – hoc environment with high host mobility. Because radio signals are likely to overlap with others in a geographic area, a straightforward broadcasting by flooding is usually very costly and will result in serious redundancy, contention, and collision to which we refer as broadcast storm problem. So, the main objective in this thesis is to contain unnecessary rebroadcast thereby performing efficient rebroadcasting which further reduces the total energy consumption in ad hoc networks. To address an issue of excessive rebroadcasting, a novel Optimal Zonal (OZON) Protocol concept has been proposed according to which, each node has its own optimal intra zonal area and the nodes inside this area are refrain from rebroadcasting the control packets. Only those nodes outside and included in the transmission range of source nodes are permitted for rebroadcasting purpose. The performance of proposed OZON concept has been evaluated using Global Mobile Simulation (GloMoSim) software. The simulation has been carried out for AODV, DSR and SARP and their performance has been compared with modified SARP called EE – SARP. The simulation result shows significant reduction in control packets which lead to the reduction of overall energy consumption of the participating nodes in the network. The significant reduction in the energy consumption has been verified *statistically* with the help of t – test. Proposed OZON protocol has been successfully implemented for the SARP with the achievement of the research goal put forth by this thesis.

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LIST OF ABBREVIATIONS

ACK	Acknowledgement
AODV	Ad-hoc On-demand Distance-Vector routing
CBR	Constant Bit Rate
CTS	Clear To Send
DARPA	Defense Advanced Research Projects Agency
DSDV	Destination-Sequenced Distance-Vector routing protocol
DSR	Dynamic Source Routing
FTP	File Transfer Protocol
GloMoSim	Global Mobile Information Systems Simulation Library
HTTP	Hyper Text Transfer Protocol
IP	Internet Protocol
LMR	Lightweight Mobile Routing
LPR	Low-cost Packet Radio
MAC	Medium Access Control
MANET	Mobile Ad-hoc Networks
MMRP	Max-Min Routing Protocol
OLSR	Optimized Link State Routing
OZON	Optimal Zonal
PRNet	Packet Radio Network
RERR	Route Error
RREP	Route Reply

RREQ	Route Request
RSVP	Resource Reservation Protocol
RTCP	Real Time Control Protocol
RTP	Real Time Protocol
RTS	Request To Send
SARP	Self-learning Ad-hoc Routing Protocol
SNR	Signal-to-Noise Ratio
SURAN	Survivable Radio Networks
TCP	Transmission Control Protocol
TTL	Time To Live
UDP	User Datagram Protocol
VC	Virtual Circuit
WRP	Wireless Routing Protocol

Chapter 1

Introduction

1.1 Overview

Within the past few years, the ad hoc networking field has seen a rapid expansion of visibility and work due to the proliferation of inexpensive and widely available wireless devices such as laptops, personal digital assistants (PDAs), cellular phones etc. Wireless networks can be broadly classified into two types, infrasturctured networks and infrastructureless popularly known as Ad-hoc networks. The cellular networks and wireless local area networks can be termed as infrastructure-based wireless networks whereas the infrastructureless wireless networks include mobile ad hoc networks (MANETs) and sensor networks. The concept of MANETs is not a new one and has been around in different forms for over 20 years but with the introduction of recent technologies like Bluetooth, IEEE 802.11 and HiperLAN, commercial deployment of MANETs has started to take place.

A mobile ad hoc networks (MANETs) is a self – configuring network of mobile routers (and associated hosts) connected by wireless links – the union of which form an arbitrary topology (wikipodia). MANETs are widely used in battlefields, disaster recovery areas, intercommunication between islands or in difficult terrains, and conferencing with any infrastructure support. Sensor networks have a wide range of applications ranging from monitoring environments, sensitive installations, and remote data collection and analysis. The major feature of infrastructureless wireless networks is that they do not need any infrastructure support for their deployment. The participating nodes act both as hosts as well as routers and operate in a self-organizing and adapting manner. Though ad hoc networks are attractive, due to the excessive host mobility, they are more difficult to implement than fixed networks. Research and development in the fields of infrastructureless wireless networks have been advancing at a fast pace and more efforts need to be dedicated in this direction for wide-scale adoption and deployment.

1.2 Historical Developments

In the early 70's a pioneering work in packet radio was done at the University of Hawaii which introduced the first system that used radio medium for transmission of information and consisted of a single-hop terminal access network widely known as ALOHA, developed by Abramson and Kuo.

The Work done in Hawaii led to the development of a multi-hop packet switched radio technology called PARNET under the sponsorship of DARPA in 1972 [13]. DARPA Packet Radio Project helped to establish the notion of ad – hoc wireless networking technology. PARNET permits the direct communications among mobile users over wide geographical areas, coexistence with existing users of the frequency band in which it is to operate, protection against multi-path effects, and protection against jamming, ease of deployment, unattended operation, and reconfiguration ability.

Rapid advances of radio technology in the 70's simulated the development of mobile communication system; as a result we encountered the explosion of wireless products and systems. Cordless and cellular telephones, paging systems, mobile data networks, and mobile satellites have experienced tremendous growth in the last decade.

Later DARPA developed Survivable Radio Networks (SURAN) in 1983. This project was primarily inspired by the efficiency of packet switching technology, which had key advantages such as bandwidth-sharing and store-and-forward routing. PRNET has an issues with network scalability, security, processing capabilities and energy management where were addressed by SURAN. Efforts were made to develop small low-cost, low-power radios that could support advanced routing protocols, scale to thousands of nodes and withstand security attacks. This resulted in the development of Low-cost Packet Radio (LPR) technology in 1987.

The third wave of academic activity started in the mid 1990s with the advent of inexpensive 802.11 radio cards for personal computers and notebooks. The idea of an infra structureless collection of mobile hosts was proposed in two conference papers [14] [15], and the IEEE 802.11 subcommittee adopted the term "ad hoc networks." The concept of commercial ad hoc networking had arrived.

At around the same time, the Department of Defense continued from where it left off, funding programs such as the Global Mobile Information Systems (GloMo), and the Near-term Digital Radio (NTDR). The goal of GloMo was to provide office-environment Ethernet-type multimedia connectivity anytime, anywhere, in handheld devices. Channel access approaches were now in the CSMA/CA and TDMA models, and several novel routing and topology control schemes were developed. The NTDR used clustering and link-state routing, and self-organized into a two-tier ad hoc network. Now used by the US Army, NTDR is the only "real" (non-prototypical) ad hoc network in use today.

Spurred by the growing interest in ad hoc networking, a number of standards activities and commercial standards evolved in the mid to late '90s. Within the IETF, the

Mobile Ad Hoc Networking (MANET) working group was born. The purpose of the MANET working group is to standardize IP routing protocol functionality suitable for wireless routing application within both static and dynamic topologies with increased dynamics due to node motion and other factors.

1.3 Characteristics of Ad – Hoc Networks

This section describes the typical characteristics of mobile ad – hoc networks.

Mobility:

In ad – hoc networks, the nodes can be rapidly repositioned causing excessive host mobility. Rapid deployment in areas with no infrastructure often implies that the users must explore an area and perhaps form teams/swarms that in turn coordinate among themselves to create a taskforce or a mission. We can have individual random mobility, group mobility, motion along preplanned routes, etc. The mobility model can have major impact on the selection of a routing scheme and can thus influence performance.

Self – organization:

The ad hoc network must autonomously determine its own configuration parameters including: addressing, routing, clustering, position identification, power control, etc. In some cases, special nodes (e.g., mobile backbone nodes) can coordinate their motion and dynamically distribute in the geographic area to provide coverage of disconnected islands.

Bandwidth – constrained, variable capacity link:

Wireless links will continue to have significantly lower capacity than their hardwired counterparts. In addition, the realized throughput of wireless communications, after accounting for the effects of multiple access, fading, noise, and interference conditions, etc. is often much less than a radio's maximum transmission rate. The effect is the occurrence of congestion which is typically the norm rather than the exception.

Energy Conservation:

Some or all of the participating nodes in an ad hoc network may rely on limited power supply or other exhaustible means for their energy and has no capability to generate their own power. For these nodes, the most important system design criteria for optimization may be energy conservation. *Energy efficient protocol design* (e.g., MAC, *routing*, resource discovery, etc) is critical for longevity of the mission.

Scalability:

In some applications (e.g., large environmental sensor fabrics, battlefield deployments, urban vehicle grids, etc) the ad hoc network can grow to several thousand nodes. For wireless “infrastructure” networks scalability is simply handled by a hierarchical construction. The limited mobility of infrastructure networks can also be easily handled using Mobile IP or local handoff techniques. In contrast, because of the more extensive host mobility and the lack of fixed references, pure ad hoc networks do not tolerate mobile IP or a fixed hierarchy structure. Thus, mobility, jointly with large scale is one of the most critical challenges in ad hoc design.

Limited Physical Security:

Mobile ad hoc networks are generally more prone to well known security threats like eavesdropping, spoofing, and denial-of-service attacks. Both active attacks leading to disrupt operation and passive attacks leading to monitoring of data are possible. Existing link security techniques are often applied within wireless networks to reduce security threats.

1.4 Research Overview

The purpose of this research work is to develop, analyze, implement and simulate a protocol to contain excessive rebroadcast of control packets in the mobile ad – hoc networks thereby reducing the precious energy consumption of the participating nodes.

For this thesis, the existing SARP protocol has been modified and renamed EE – SARP to reflect the influence of the developed protocol and its effectiveness is simulated using GloMoSim simulator software developed by University of California, Los Angels.

1.4.1 Problem Identification

The previous research on the on – demand routing protocol shows the following discrepancy in the protocol.

- The on – demand ad hoc routing protocol utilizes the route discovery and maintenance procedure to discover and maintain route in the network. During these procedures, a node rebroadcasts an excessive amount of control packet (RREQs, RERRs) in search and maintenance of routes in a network. However, rebroadcasting such control packets is a common and frequent operation in an ad – hoc environment with high host mobility. Because radio signals are likely to overlap with others in a geographic area, a straightforward broadcasting by flooding is usually very costly and will result in serious redundancy, contention, and collision to which we refer as broadcast storm problem. Thus flooding of control packets creates an unnecessary amount of rebroadcast packets within the network thereby increasing the amount of energy consumption of the participating nodes which is highly undesirable for the networks with limited resources. The dying node makes the whole network inefficient.

1.4.2 Proposed Solution

The problems regarding to the implementation of on – demand routing protocol has been identified in the above sub-section of this thesis. Following is solution and contribution that can be made in the implementation of energy efficient routing protocol.

- As mentioned, on – demand routing protocol produces excessive amount of Route Request, Route Reply and Route Error packets during route discovery and maintenance process thereby making it energy inefficient. So, in this research work, the Optimal Zonal (OZON) concept has been proposed to restrict the flooding of these rebroadcast control packets. This includes creating the zone of particular radius around the source nodes and restricts those nodes falling within this zone from rebroadcasting the control packets. For the nodes outside this zone and included within the transmission range of the source, route request is forwarded to other nodes similarly as in normal routing.

In this research work the Optimal Zonal Protocol for containing rebroadcast in Mobile Ad-Hoc network has been developed and implemented to the existing SARP (EE – SARP). Also, the mathematical model for the energy consumption for proposed protocol has been formulated and its energy consumption behavior has been compared with three routing protocols; respectively the Ad-hoc On Demand Distance Vector

(AODV) [4], the Direct Source Routing (DSR) [6] and the Self-Learning Ad-Hoc Routing Protocol (SARP) [1].

1.4.3 Thesis Organization

The thesis is organized as follows. Chapter 2 describes the review of surveyed literature related to ad-hoc routing protocols, provides a comparison between them and enumerate the research work that has been carried out in the design and implementation of energy aware ad hoc routing protocols. It also discusses the existing Self Learning Ad – Hoc Routing Protocol. Chapter 3 presents overview of the energy model for radio transmission, the details of the proposed OZON concept, its mathematical model for energy consumption. Chapter 4 describes the GloMoSim, the simulator used to simulate the EE – SARP, the result and analysis obtained from the simulation, compare the performance of EE – SARP with other routing protocol and finally provide a comprehensive simulation result. This chapter also gives the statistical analysis of the result obtained through simulation and validates the significance of proposed protocol *statistically*. Finally, chapter 5 concludes this thesis and presents our conclusion and future work that can be carried out to further improve the performance of EE – SARP.

Chapter 2

Literature Survey

This chapter will discuss the brief overview of proactive and reactive ad-hoc routing protocols, provide a comparison between them and finally enumerate research work that has been carried out in the design, implementation and testing of energy efficient ad hoc routing protocols. It also discusses the brief overview of SARP.

2.1 Introduction

Effective and dynamic routing is one of the key issue in the mobile ad – hoc routing. Various routing protocols have been proposed for ad-hoc network in order to achieve better routing performance [2]. These routing protocols are classified be based on the manner in which route tables are constructed, maintained, and updated. They are classified as follows

- Proactive Routing Protocol (Table – Driven)
- Reactive Routing Protocols (Source initiated or on - demand)

The first method uses a routing table that is maintained via periodic updates from all the other nodes in the network irrespective of the fact that the network may not be active in terms of data traffic. On other hand, on-demand routing protocols, create routes only when needed by the source. Table driven schemes are more expensive in terms of energy consumption as compared to the on-demand schemes because of the large routing overhead incurred in the former [2]. Therefore, in this study, we focus on on-demand routing protocols. Some of the protocols have been studied and their performance have been evaluated in detail focusing on aspects like routing overhead, latency, throughput, route length, packet loss etc. In this work we concentrated on the energy consumption pattern of various routing protocols.

2.2 Proactive Routing Protocols

Proactive routing (table – driven) protocols maintain unicast routes between all pairs of nodes regardless of whether all routes are used in the network. Hence, when a traffic source initiates a session with remote destination, the source has readily available routes to the destination and does not have to incur any delay for route discovery. These nodes maintain routing tables and respond to the changes in the network topology by propagating updates throughout the network in order to maintain a consistent view of the network. The different table-driven protocols differ in the number of routing tables and the methods by which changes in the network structure are broadcast. The following sections discuss the different proactive ad hoc routing protocols.

2.2.1 Destination Sequenced Distance Vector Protocol (DSDV)

The Destination-Sequenced Distance-Vector (DSDV) [6] Routing Algorithms is one of the earliest protocols and is based on the idea of the classical Bellman-Ford Routing Algorithm with certain improvements.

Every mobile station maintains a routing table that lists all available destinations, the number of hops to reach the destination and the sequence number assigned by the destination node. The destination sequence numbers is used to achieve loop freedom without any inter-nodal coordination. Every node maintains a monotonically increasing sequence number for itself. It also maintains the highest known sequence number for each destination in the routing table (called “destination sequence numbers”). DSDV also uses triggered update as well as periodic updates. So, the update is both time-driven and event-driven. The routing tables updates are send in two ways: a "full dump" or an incremental update. A full dump sends the full routing table to the neighbors and could span many packets whereas in an incremental update only those entries from the routing table are sent that has a metric change since the last update and it must fit in a packet. If there is space in the incremental update packet then those entries may be included whose sequence number has changed. When the network is relatively stable, incremental updates are sent to avoid extra traffic and full dump are relatively infrequent. In a fast-changing network, incremental packets can grow big so full dumps will be more frequent. Each route update packet, in addition to the routing table information, also contains a unique sequence number assigned by the transmitter. The route labeled with the highest (i.e. most recent) sequence number is used. If two routes have the same sequence number then the route with the best metric (i.e. shortest route) is used.

2.2.2 The Wireless Routing Protocol (WRP)

The Wireless Routing Protocol (WRP) [2] is another table-based distance-vector routing protocol optimized for ad – hoc network. It belongs to the class of distance vector protocols called path finding algorithm. Each node is updated with the shortest path spanning tree of each of its neighbor and uses the cost of its adjacent links along with shortest path trees reported by neighbors to update its own shortest path tree; the node reports changes to its own shortest path tree to all the neighbors in the form of updates containing distance and second-to-last hop information to each destination. This routing protocol suffers from temporary routing loops even though they prevent the counting-to-infinity problem. This happens because these algorithms fail to recognize that updates received from different neighbors may not agree on the second-to-last hop to a destination. WRP improves on the earlier algorithms by verifying the consistency of second-to-last hop reported by all neighbors. With this mechanism, WRP reduces the possibility of temporary routing loops, which in turn results in faster convergence time.

Node exchange routing tables with their neighbors using update messages periodically as well as when link changes. The nodes present on the response list of update message are required to acknowledge the receipt of update message. If there is no change in routing table since last update, the node is required to send an idle Hello message to ensure connectivity. On receiving an update message, the node modifies its distance table and looks for better paths using new information. Any new path so found is relayed back to the original nodes so that they can update their tables. The node also updates its routing table if the new path is better than the existing path. A unique feature of this algorithm is that it checks the consistency of all its neighbors every time it detects a change in link of any of its neighbors. Consistency check in this manner helps eliminate looping situations in a better way and also has fast convergence.

2.2.3 Global State Routing Protocol (GSRP)

Global State Routing (GSR) [2] is similar to DSDV described in section 2.2.1. It is similar to link state routing but improves it by avoiding flooding of routing messages.

In this algorithm, each node maintains a Neighbor list, a Topology table, a Next Hop table and a Distance table. Neighbor list of a node contains the list of its neighbors. For each destination node, the Topology table contains the link state information as reported by the destination and the timestamp of the information. For each destination, the Next Hop table contains the next hop to which the packets for this destination must be forwarded. The Distance table contains the shortest distance to each destination node. The routing messages are generated on a link change as in link state protocols. On receiving a routing message, the node updates its Topology table if the sequence number of the message is newer than the sequence number stored in the table. After this the node reconstructs its routing table and broadcasts the information to its neighbors.

2.3 Reactive Routing Protocols

This type of routing creates routes only when desired by the source node. The source node initiates a process called route discovery when it requires a route to the destination. This process is completed when a route is found or when all the possible routes are examined. The process of route maintenance is carried out to maintain the established routes until either the destination becomes unavailable or when the route is no longer required. This approach is attractive when the network traffic is sporadic, bursty and directed mostly toward a small subset of nodes. However, since routes are created when the need arises, data packets experience queuing delays at the source while the route is being found at session initiation and when route is being repaired later on after a failure.

2.3.1 Ad Hoc On – Demand Distance Vector Routing (AODV)

AODV [4] is an on-demand routing protocol that is dynamic, self-starting, loop-free, and scales to large numbers of mobile nodes. It uses the traditional distance-vector routing approach and tries to find the shortest route possible using a source-initiated route discovery process.

AODV maintains the traditional routing table, one entry per destination. When a source node wishes to send a packet to a destination node, it consults its routing table to see if it has the route to the destination. If a route is present, it forwards the packet to that node, otherwise the source nodes enters into the route discovery procedure. Upon receiving a packet, a node determines if it was the destination node. If so, the process is complete. Otherwise, if the node has a route to the destination in its routing table it forwards the packet to the next hop.

AODV utilizes two distinct procedures to discover and maintain the routes in its routing table. They are route discovery and route maintenance procedure. Route discovery procedure uses two types of control packet, Route Request (RREQ), Route Reply (RREP) packets whereas route maintenance procedure uses Route Error (RERR) packet. When a source node has no route to a destination, it broadcasts a route-request (RREQs) during route discovery process. If any of the neighbors has a route to the destination it will send a route reply (RREP) to the source. Otherwise, it rebroadcast the route request till the route request reaches to destination or until some intermediate node has a fresh route to the destination. When route request reaches the destination it will initiate a route reply to the source. AODV uses a destination generated sequence number to ensure the freshness of each route and to maintain the loop free topology.

When a node detects a link failure, a route maintenance process is used to send route error (RERRs) message to the affected nodes informing about the link breakage. In effect, the source node re-initiates the route discovery process to find out a new route to the destination.

2.3.1.1 Protocol Description

As discussed earlier, AODV utilizes two mechanisms of Route Discovery and Route Maintenance to discover the destination and maintain the up-to-date routing table. If a source wants to initiate the session with the destination and has no route to the destination, the route discovery process is initiated by broadcasting REEQ control packet to its entire neighbor. Every node maintains two separate counters: a node sequence number and a broadcast id. The pair <source address, broadcast id> uniquely identifies a RREQ. If any neighbor has a route to the destination it will send a Route Reply to the source. Otherwise, it re-broadcasts the route request packet after increasing the hop count. If a node receives a route request packet that it has already received from another node, it drops the packet and does not further rebroadcast it. When forwarding the packet, a node learns the route to the neighbor from which it received the copy of the Route Request and will create a reverse route to that node. This process is continued until the route request reaches the destination or some intermediate node that has a fresh route to the destination.

The destination or the intermediate node that has a fresh route will initiate a route reply to the source. If an intermediate node has a route entry for the desired destination, it determines whether the route is current by comparing the destination sequence number in its own route entry to the destination sequence number in the RREQ. Earlier, when processing the route request, all nodes between the source and destination added routes to their upstream neighbors. This routing information is used in order to send the route reply back to the source and each node that forwards the route reply packet sets up the forward pointer to the node from which the RREP was received.

A route maintenance process is used if any link breakage occurs on the route being used. The intermediate node or destination, upon detecting the link breakage, sends a Route Error message to the affected nodes informing them of the link breakage. When the source node receives a route error packet it can re-initiate the route discovery process to find a new route to the destination.

2.3.2 Dynamic Source Routing (DSR)

DSR is characterized by the source routing and is described in the Internet-Draft [5]. That is the source knows the hop by hop route to the destination. Each node in the network maintains a routing cache containing the complete path to various destinations. When a source node attempts to send a packet to a destination node, it consults its routing table to see if it contains the path to reach the destination. If the path is present, it copies the complete path onto the data packet header and forwards the packet to the next hop node. Upon receiving a packet, a node determines if it was the destination node. If so, the process is complete. Otherwise, the node processes the header and forwards the packet to the node specified as the next hop in the data packet header.

DSR also uses three kinds of packets for its operation, RREQ, RREP and RERR. When a node attempts to transmit data to another node multiple hops away, it broadcasts a Route Request packet (RREQ) to determine the route to the destination. Each intermediate node that receives the request appends its ID to the request and rebroadcast it. The destination, on receiving the RREQ, replies with a unicast packet called the Route Reply (RREP) containing the route back to the source. When a source receives a reply, it caches the source route and includes it in the header of each data packet to send. In addition to these, a Route Error packet (RERR) is used to inform the affected nodes of a link breakage. In order to support source routing, the Route Request and Route Reply packets contain address fields that are used to record the path a particular packet has taken before reaching a node.

2.3.2.1 Protocol Description

Like AODV, DSR also consists of two procedures; Route Discovery and Route Maintenance for discovering the destination and maintaining the routes. When a source wants to transmit the data to the destination and has no route in its route cache, then it initiates the procedure of route discovery by sending the route request message. During this process, the source node broadcasts a Route Request packet that is received by all nodes that are currently in its transmission range. In addition to source address and target address, the route request packet also contains a route record which lists the address of each intermediate node through which this particular copy of route request packet has been forwarded. The source of the route request packet initializes the route record to an empty list before broadcasting the packet. There is also a request id, which when coupled with the sender’s address, helps in the detection of duplicate route requests. If any link on a source route is detected broken by the failure of transmission of data over a link, a route error packet is generated. Route error is sent back toward the source which erases all entries in the route caches along the path that contains the broken link. A new route discovery must be initiated by the source, if this route is still needed and no alternate route is found in the cache.

2.4 Proactive vs. Reactive Routing Protocols

Proactive protocols have the overhead of route updates with no regard to the frequency of forwarding packets that take place in the ad hoc network. The routing information is constantly propagated within the network. This is not the case with on-demand protocols where routing information is exchanged only when the source wishes to send some information to the destination and has no information about the destination in its route cache. On the other hand, since routing information is constantly propagated and updated in table-driven protocols, information about a particular source-destination route is always available regardless of whether or not this information is required. This feature leads to significant signaling overhead and power consumption. Since both battery and bandwidth are scarce resources in ad hoc networks, this becomes a serious limitation.

From the discussion of table-based protocols provided in Section 2.2 and on-demand protocols presented in Section 2.3, we conclude that table-based protocols incur significantly high routing overhead and hence lead to increase amount of energy consumption compared to the on-demand protocols. However, on – demand routing protocol is efficient compared to table – driven routing protocols, due to its flooding nature of rebroadcast packets while locating and maintaining the destination causes excessive consumption of precious energy of participating nodes.

2.5 SARP – An Overview

SARP is an on-demand routing protocol developed at Wichita State University [1]. It combines the concepts of source routing and distance vector routing. It uses a vector routing approach similar to that of AODV, but modifies the route discovery process to behave more closely to DSR thus minimizing the need for further requests, resulting in less amount of routing overhead. For route discover and maintenance procedure, SARP uses the Route Request, Route Reply and Route Error packets. The Route Request and Route Reply packets contain all the fields that AODV packets have and also the address fields from DSR. These address fields are used to record the path that a particular packet had traversed before reaching a node. In DSR, this route record contains the complete path from the initiator to that node since it employs source routing. SARP doesn't need the complete path, so the route record can be set to contain a specific number of hops. If a specific number is set, a node that receives a route record will learn about only those previous hops and not all the nodes from the initiator to that node. The route request and reply packets also include the sequence number of each address. The sequence numbers are used to ensure the freshness of a route as in AODV.

The route error packet of SARP is used to maintain the integrity of the routing table and contains all the fields that AODV packet. The address and sequence number (corresponding to that address) fields which are used to record the path that a particular packet had taken are also included in the route error packet. SARP uses the address and sequence number fields to learn routes to the nodes specified in these fields. DSR route error packet doesn’t contain any address fields. SARP route error packet also contains an “Error Type” field which specifies whether the error is caused due to link failure, absence of default route, incorrect default route, or absence of reverse route to the source.

2.5.1 Packet Format for SARP

- **Router Request (RREQ)**

<table>
<tr><td>Type</td><td>J</td><td>R</td><td>G</td><td>D</td><td>U</td><td>URREQ</td><td>Reserved</td><td>Hop Count</td></tr>
<tr><td colspan="9">RREQ ID</td></tr>
<tr><td colspan="9">Destination IP Address</td></tr>
<tr><td colspan="9">Destination Sequence Number</td></tr>
<tr><td colspan="9">Originator IP Address</td></tr>
<tr><td colspan="9">Originator Sequence Number</td></tr>
<tr><td colspan="9">Address[0]</td></tr>
<tr><td colspan="9">Address[0] Sequence Number</td></tr>
<tr><td colspan="9">……...</td></tr>
<tr><td colspan="9">……...</td></tr>
<tr><td colspan="9">Address[n]</td></tr>
<tr><td colspan="9">Address[n] Sequence Number</td></tr>
</table>

Figure 2.1 SARP route request packet format

- **Route Reply Packet (RREP) Format**

Type	R	A	Reserved	Prefix Size	Hop Count
Destination IP Address					
Destination Sequence Number					
Originator IP Address					
Lifetime					
Address[0]					
Address[0] Sequence Number					
………					
………					
Address[n]					
Address[n] Sequence Number					

Figure 2.2 SARP route reply packet format

- **Route Error Packet (RERR) Format for SARP**

Type	N	Reserved	Error Type	DestCount
Unreachable Destination IP Address (1)				
Unreachable Destination Sequence Number (1)				
Additional Unreachable Destination IP Address (if needed)				
Additional Unreachable Destination Sequence Number (if needed)				
Address[0]				
Address[0] Sequence Number				
………				
………				
Address[n]				
Address[n] Sequence Number				

Figure 2.3 SARP route error packet format

2.5.2 Protocol Description

Like other on demand routing protocol, SARP also uses the two main mechanisms of route discovery and route maintenance to discover and maintain routes. When a source attempts to transfer a data packet to the destination and has no route in its routing table, then the source node goes into the route initiation process. During this process, a source node broadcasts a route request packet to all its neighbors. If any neighbor has a route to the destination it will send a route reply to the source. Otherwise, it re-broadcasts the route request packet. When a node receives a route request packet it will learn the route to the source of the route request and will create a reverse route for itself back to the source. However, to increase the number of routes learned per route request, the address and sequence number fields in the route request packet are used. As each node forwards the packet, it appends its own address and its current sequence number to the packet. Upon receiving the packet, nodes learn routes to any node that has seen the packet. This process is continued until the route request reaches the destination or some intermediate node that has a fresh route to the destination. As in all ad-hoc routing protocols, if a node receives a route request packet that it has already received from another node, SARP drops the packet and does not broadcast it to any of its neighbors.

The route reply packet in SARP also contains the address and sequence number fields which are used to record the path the route reply packet has traversed before reaching a node. As each node along the path forwards the route reply packet, it adds its own address into the packet. Upon receiving a route reply, a node adds routes pertaining to all nodes listed in the packet into its routing table. This route discovery process enables intermediate nodes to learn more routes but in an expense of increased overhead.

However, the more routes known by each node, the fewer number of route requests required. This relationship keeps a balance in the amount of overhead produced by SARP.

A route maintenance process is used if any link breakage occurs on the route being used. The intermediate node or destination upon detecting the link breakage sends a route error message to the source node informing it of the link breakage. When the source node receives the route error packet it can re-initiate the route discovery process to find a new source route to the destination. In SARP, however, the route error packets also contain the address and sequence number fields and as each node along the path forwards the route error packet it adds its own address into the packet. Upon receiving a route error, a node adds routes pertaining to all nodes listed in the packet into its routing table. To understand the working of SARP, let us consider the network scenario of Figure 2.4.

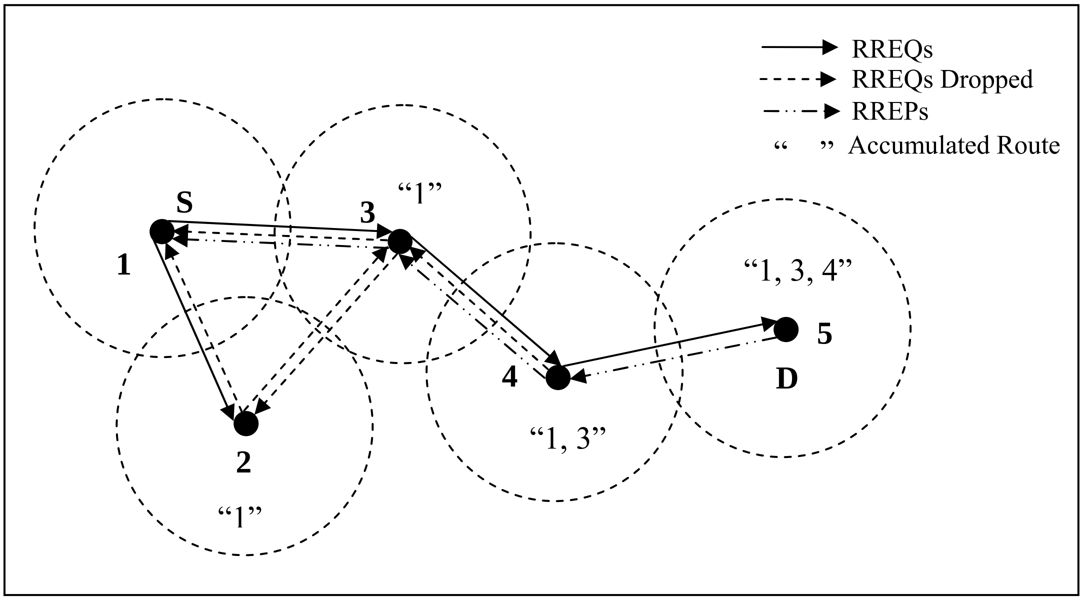

Figure 2.4 SARP Operation

In the above figure, node 1 wants to communicate with node 5 and has no route in its own routing table thereby requiring it to go into the route discovery process. It accomplishes this by broadcasting RREQ to all its neighboring nodes 2 and 3. Node 2 and Node 3 will set up a reverse route to Node 1 in their routing table and then rebroadcast the route request packet. All the rebroadcasted control packets are dropped by nodes if found duplicate and was initiated by own. By the virtue of this argument, node 1 and 3 will drop this rebroadcasted control packets. The route request packet that is broadcasted by node 3 is only processed by node 4. Node 4 sets up the reverse route to Node 3, stores the route to Node 1 and rebroadcasts the route request packet which is again processed by node 5 only which finally sets a reverse route to node 1. Since it is the destination of the route request packet, it sends a route reply back to the source.

In the next section, we will discuss the research work that has been carried out to reduce energy consumption in ad hoc networks.

2.6 Prior Research in Energy Optimization in AD – Hoc Networks

Research has been carried out at each layer of the OSI stack to minimize energy consumption. At the physical layer, research is carried out addressing the energy problem considering two views (i) an increase in battery capacity, and (ii) a decrease in the amount of energy consumed at the wireless terminal. L.M. Feeney has presented a detail analysis of energy consumption model in ad – hoc networks [12]. According to [12], the three prominent factors that cause increased energy consumption in ad – hoc networks are transmission, reception and processing of the signals. In case of AODV, the frequent route discovery process triggers transmission and reception of control packets thereby increasing energy expenditure in the network. It is suggested that if these broadcast are prevented from flooding in the network, then there could be significant energy conservation. DSR employs the aggressive route caching and has less number of route requests, but since the nodes are always in promiscuous mode, the reception and processing of every signal give rise to higher energy consumption. SARP, which is the combination of AODV and DSR, also employs the promiscuous mode and result in less number of route request but higher reception and processing thereby increasing energy consumption. S. Jain classifies the current research efforts for energy aware communication in ad – hoc networks into three categories based on the different aspects they address: power control, routing and sleep mode control [14] and presents the details of each aspects. The author advocates the implementation of integrated approach to reduce the energy consumption in the networks.

In Chapter 3, the details of proposed OZON protocol for containing rebroadcast in Mobile Ad – Hoc networks has been discussed and its mathematical model for energy consumption has been formulated.

Chapter 3

Optimal Zonal Protocol

This chapter discusses the brief overview of energy model for radio transmission and explains the details of the proposed Optimal Zonal (OZON) Protocol for containing rebroadcast in mobile ad – hoc networks which has been implemented in the existing SARP to create EE – SARP. Finally, the mathematical model for energy consumption in the EE – SARP model has been formulated.

3.1 The Energy Model

Energy is the limiting factor in the successful deployment of the wireless networks. This is a particular concern for mobile ad hoc networks where devices are expected to be deployed for long time with limited potential for recharging batteries. Such expectations demand conservation of energy in the participating nodes. In ad hoc network, there is a trade – off between the amount of data an application sends and the amount of energy consumed by sending that data. Hence, to support the energy efficient communication in ad hoc networks, it is imperative to consider the energy consumption at the multiple layers in the network protocol stack. In network layer, the intelligent routing can reduce the energy consumption which is the main goal of this thesis.

The network interface has four possible energy consumption states: transmit, receive, ideal and sleep. Transmit and receive states are for transmitting and receiving data when the node is active. In the idle mode, the interface is in transmitting and receiving phase. This is the default mode of Ad Hoc network. The sleep mode has extremely low power consumption and the interface can neither transmit nor receive until it is awaken. Unlike in the base station based mobile network where the mobile node can spend their most time in sleep state, in ad hoc network environment, there are no base stations and therefore the default state is the idle state rather than the sleep state.

First Order Radio Model:

Here we consider the First order radio model as discussed in [7]. The equation used to calculate transmission cost and receiving cost for r_0*-bit* message and at a distance *d* are shown below:

Energy expended during message transmission

$$E_{Tx}(r_0,d) = E_{Tx-elec}(r_0) + E_{Tx-amp}(r_0,d)$$

$$E_{Tr}(r_0,d) = (E_{elec} + \varepsilon d^n)r_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.1$$

where E_{elec} = energy require to run transmitter or receiver circuitry (50 nJ/bit)

ε = Amplification factor for tx amplifier (*100 pJ/bit/*m^2)

d = distance between two nodes

n = Path loss component *(*$2 \le n \le 4$*), 4* for Ad Hoc network

Similarly,

Energy expended during receiving of message is

$$E_{Rx}(r_0) = E_{elec} * r_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.2$$

3.2 Geometric Random Graph Model for EE – SARP

A wireless ad hoc network can be modeled as an undirected geometric random graph denoted by $G_{P(r_{ij})}(n)$ [12] where $P(r_{ij})$ is the probability of having a link between two nodes i and j (or j and i) at a distance r_{ij} from each other.

In $G_{P(r_{ij})}(n)$, the total number of edges or links between nodes is defined as

$$L = \sum_{i=1}^{n} \sum_{j=i+1}^{n} P(r_{ij}) \qquad \ldots\ldots\ldots\ldots \qquad 3.3$$

Assuming that n nodes are uniformly distributed over a certain two dimensional area with size ω covered by small squares *Δω* (placeholders) containing at most one node, the expected number of links *E[L]* is given by

$$E(L) = \frac{n(n-1)}{m(m-1)} \sum_{i=1}^{n} \sum_{j=i+1}^{m} P(r_{ij}) \qquad \ldots\ldots\ldots\ldots \qquad 3.4$$

where r_{ij} is the distance between the place holder *i* and *j*.

Also the link density *η* is defined as the ratio of *E[L]* and $E_{max} = n(n-1)/2$, the maximum number of links in full mesh network.

$$\eta = \frac{E(L)}{E_{\max}} = \frac{2}{m(m-1)} \sum_{i=1}^{n} \sum_{j=i+1}^{m} P(r_{ij}) \qquad \ldots\ldots\ldots\ldots \qquad 3.5$$

This formula shows that the link density is independent of number of nodes in the network and depends only on strength of connectivity.

Knowing the expected number of links in the network, the mean degree of node can be written as

$$E[d] = \frac{2E[L]}{n} = (n-1)\eta \qquad \ldots\ldots\ldots\ldots \qquad 3.6$$

3.3 Proposed Optimal Zonal (OZON) Protocol

3.3.1 Introduction

As mentioned in the problem identification section of this thesis, SARP produces excessive number of route request messages during route discovery process thereby making it energy inefficient. However broadcasting such control packets is a common operation in ad hoc environment [8]. In ad hoc network, due to host mobility, such operations are expected to be executed more frequently. Because radio signals are likely to overlap with others in a geographic area, a straightforward broadcasting by flooding is usually very costly and will result in serious redundancy, contention, and collision to which we refer as broadcast storm problem. The broadcast session is the process of one node exploring a part of the network. Within the broadcast session, many nodes may rebroadcast packets to support the particular broadcast session. So, our goal is to contain unnecessary broadcast thereby performing efficient broadcast which further reduces the total energy consumption in an ad hoc networks.

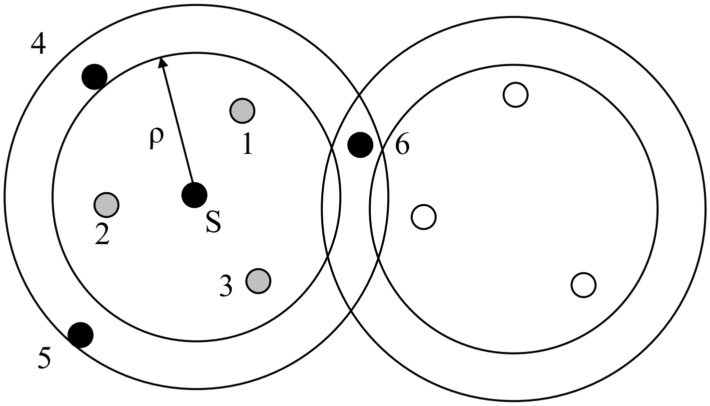

Figure 3.1 Optimal Zone of radius *ρ* for determining the rebroadcast nodes

Consider the figure 3.1 where we estimate and use the optimal distances between the nodes to improve the efficiency of single broadcast session. While doing this, we will create an optimal zone of radius ρ and contain the broadcast message by not allowing some of the nodes to rebroadcast it.

Assume that the node '*s*' is the source node that initiates route request to discover the destination node. This initiates a single broadcast domain from source node '*s*'. If the peripheral node 4, 5 and 6 rebroadcast then we can maximize the number of new nodes we can reach. Intra zonal nodes 1, 2 and 3 do no yield much if the aforementioned nodes rebroadcasts. Thus we do not want intra zonal nodes 1, 2 and 3 to rebroadcast.

Here we can use the signal strength to estimate the zonal radius ρ. Let E_{tx} and E_{rx} be the power level on which a message is transmitted and received respectively. Then according to [11],

$$E_{rx} = cE_{tx}\left(\frac{1}{\rho}\right)^{n} \qquad \text{……………………………………………………….. } 3.7$$

where n and c are constants related to physical environment and antenna properties respectively. For mobile ad – hoc networks, $n = 4$. As E_{tx} and E_{rx} can be measured, the radius ρ can be estimated from this formula.

3.3.2 Working Principle of OZON Concept

Assume S is transmitting a Route Request message in the search of destination D. All nodes are assumed to be identical and have equal transmission range. The node S will

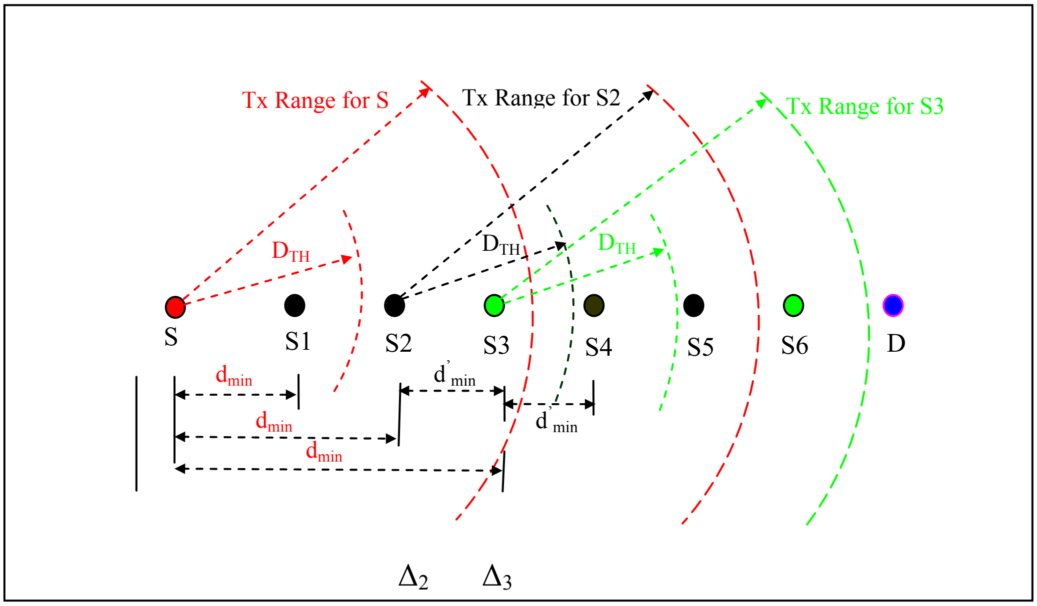

Figure 3.2 Working principle of OZON concept

transmit a RREQ message that will be heard by all nodes within the transmission range of *S* including *S1, S2* and *S3*. When a broadcast message RREQ is heard for the first time, all broadcast hearing nodes including *S1, S2* and *S3* will initialize d_{min} to the distance to the broadcasting host, '*S*'. If $d_{min} < D_{TH}$, then the host is inhibited from rebroadcasting. For example in the above figure, S1 will not rebroadcast by the virtue of above discussion. Then *S2* and *S3* for which $d_{min} > D_{TH}$, are eligible for rebroadcasting. However, we want each node to wait for Δ time proportional to the signal strength to maximize the coverage area and decrease the number of rebroadcast. One possibility of estimating the signal strength of the received message is given by the equation (3.7).

In functional form,

$$waitingtime = f(SignalStrength)$$

Since, the signal strength can be approximated according to the equation (3.7), the above function can be rewritten in a linear form as,

$$\Delta = \alpha E_{Rx} \qquad \text{3.8}$$

where α is the constant called waiting coefficient.

Since signal strength of message received by *S2* is stronger than *S3*, $\Delta_2 > \Delta_3$. With this waiting mechanism, *S3* will timeout first in comparison to *S2* and rebroadcast the message. This rebroadcast is heard by *S2* and *S4*. Again *S4* will not rebroadcast because $d'_{min} < D_{TH}$ and *S2* will calculate d'_{min}. If this d'_{min} is less than d_{min} and d'_{min} is less than D_{TH}, then *S2* will not rebroadcast. In this way, *S1* and *S2* will refrain from rebroadcasting the message, and *S3* will rebroadcast. In this manner, only *S3* and *S6* will rebroadcast RREQ to reach destination *D*. This procedure of rebroadcasting will help reducing the number of rebroadcast message to reach the destination thereby conserving the precious energy in the mobile ad hoc environment.

3.3.3 Determination of Threshold Broadcasting Range

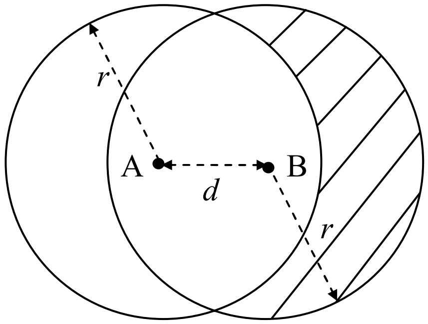

Figure 3.3 Determination of optimal broadcast range.

Consider the scenario where a host *A* broadcast a message and host *B* decides to rebroadcast. Let S_A and S_B be the circle area covered by the A's and B's transmission range. The additional area that can be benefited from B's rebroadcast is the shaded area in the above figure and is denoted by $S_{B\text{-}A}$. Let *r* be the radii and *d* be the distance between the two host then,

$$|S_{B-A}| = |S_B| - |S_{A\cap B}| = \pi r^2 - f(x)$$

where

$$f(x) = 4\int_{d/2}^{r} \sqrt{r^2 - x^2}\,dx$$

Supposing the B can randomly locate in any of A's transmission range, the average value can be obtained by integrating above value over the circle of radius *x* centered at *A* for *x* in *[0,r]* as

$$\int_0^r \frac{2\pi r[\pi r^2 - f(x)}{\pi r^2} dx \approx 0.41\pi r^2 \qquad \text{3.9}$$

This shows that a rebroadcasting can only, in average, can provide additional 41 % coverage.

Sze – Yao Ni and et. al. [8] have derived a standard graph that depicted an Expected Additional Coverage *EAK(k)* after a host heard a broadcast message *k* times.

Figure 3.4 Number of rebroadcasting vs. average expected additional coverage.

As shown in the graph, when $k \geq 4$, the expected additional coverage is below 0.05%. Now the value of D_{TH} can be chosen purposely in a way so as to make a reasonable coverage. When $k = 2$, then $EAC(k) = 0.187$. So, we should choose the value of D_{TH} to match the value of additional coverage i.e.

$$\frac{[\pi r^2 - f(D_{TH})]}{\pi r^2} \approx 0.187 \qquad \text{3.10}$$

This equation reduces to the following non-linear equation:

$$D_{TH}\sqrt{4r^2 - D^2{}_{TH}} + 4r^2 \sin^{-1}\frac{D_{TH}}{2r} - 0.4\pi r^2 = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.11$$

In our simulation, the node is assumed to have the transmission range of 250m. Using r = *250m*, the above equation has been solved using Newton – Raphson method and the value of D_{TH} has been approximately found to be *127m*.

3.3.4 Energy Consumption Model of Proposed OZON Concept

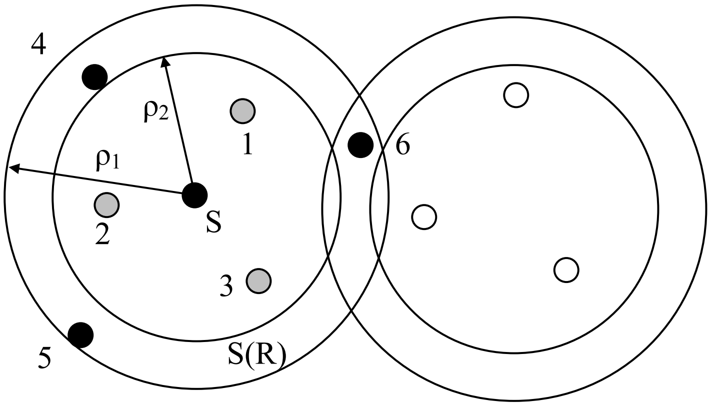

Figure 3.5 Calculation of expected number of nodes for rebroadcasting

Let us consider a multi hop network model as shown in figure 3.5. The node distribution within the topology is a two dimensional Poisson point process with parameter λ and also assume the average number of nodes within S's transmission is *N*.

P_r = *P(k nodes within Tx region of radius* ρ_1*)*

$$= e^{-\lambda\pi\rho^2}\frac{(\lambda\pi\rho_1{}^2)^k}{k!} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.12$$

Then the number of nodes in the region *S(R)* is given by

$$N_\Delta = \frac{S(R)}{\pi \rho_1^2} \times \overline{N_s} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad 3.13$$

where $\overline{N_s}$ is the expected number of nodes within the radius ρ_1 and is equal to P_rN.

In terms of the radius, the equation 3.13 can be rewritten as follows:

$$N_\Delta = \frac{(\rho_1^2 - \rho_2^2)}{\rho_1^2} P_r N \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.14$$

Now the expected number of nodes in the region *S(R)* is given by

$$E[N_\Delta] = \int_0^{2\pi} \int_{\rho_2}^{\rho_1} N_\Delta \frac{1}{\pi \rho_1^2} r dr d\theta \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad 3.15$$

This is the number of expected nodes that can rebroadcast the message initiated by the source node 'S'.

Energy Consumed During RREQs Processing:

As mentioned in the overview of SARP, the node generates the RREQs message to discover the destination. In case of EE-SARP, only the permitted nodes beyond the optimal zone and included within the transmission range of source node are allowed to rebroadcast. So, assume *E[N_Δ]* be the expected number of nodes between the source and destination those rebroadcast the RREQs.

Then, the total number of route request generated by overall nodes in a single broadcast session is given by

$$nRR_{tx} = 1 + E[N_\Delta] + E[N_\Delta]^2 + E[N_\Delta]^3 + \ldots\ldots\ldots\ldots\ldots + E[N_\Delta]^H$$

$$= 1 + E[N_\Delta]\left[\frac{E[N_\Delta]^{H-1} - 1}{E[N_\Delta] - 1}\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.16$$

Let r_0 be the total number of bits in each route request message and A is the number of bits appended by each node during rebroadcast then, the total number of bits transmitted in a single broadcast session is

$$\left[1+\frac{E[N_\Delta]\left\{E[N_\Delta]^{H-1}-1\right\}}{E[N_\Delta]-1}\right]\left[r_0+\sum_{i=0}^{E[h]} iA\right]$$

Hence, the total energy consumed during transmission of a single session route request message is

$$E_{Tx}^{RREQ}=K_e\left[\left[1+\frac{E[N_\Delta]\left\{E[N_\Delta]^{H-1}-1\right\}}{E[N_\Delta]-1}\right]\left[r_0+\sum_{i=0}^{E[h]} iA\right]\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.17$$

where

$$K_e=E_{elec}+\varepsilon d^4$$

The route request received by nodes in a single broadcast session is

$$nRR_{Rx}=E[N_\Delta]+E[N_\Delta]^2+E[N_\Delta]^3+\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots+E[N_\Delta]^H$$

$$=E[N_\Delta]\frac{\left[E[N_\Delta]^{H-1}-1\right]}{E[N_\Delta]-1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.18$$

Hence the total energy consumption due to the route request processing in a single broadcast session is

$$E_{Rx}^{RREQ}=E[N_\Delta]\frac{\left[E[N_\Delta]^{H-1}-1\right]}{E[N_\Delta]-1}\times\left[r_0+\sum_{i=0}^{E[h]} iA\right]E_{relec} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad 3.19$$

Energy Consumed During RREPs Processing:

The route reply is the unicast message from destination to source. Let *E[h]* is the expected number of hops between destination and source. In the case of RERP also, the intermediate nodes appends its address and sequence number in the transmitted route replies.

The total energy consumption by nodes to transmit the single session of unicast reply is

$$E_{Tx}^{RREP} = [E[h]+1][r_0 + AE[h]]K_e \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 3.20$$

The total energy consumed by nodes to receive route reply is

$$E_{Rx}^{RREP} = [E[h]+1][r_0 + AE[h]]E_{relec} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 3.21$$

where A is the number of bits appended by each node to the RREP packets.

Energy Consumed During RERRs Processing:

The RERR message is sent whenever a link break causes one or more destinations to become unreachable from some of the nodes neighbor. Generally, route error and link breakage processing requires invalidating existing routes, listing affected destinations, determining which, if any, neighbors may be affected, and delivering an appropriate RERR to such neighbors.

Let's assume the RERR is unicast from source to destination (1 precursor condition), *E[h]* is the expected number of hops that a route error message have to transverse from its origination to the source node. The total number of bits transmitted during RERRs processing procedure is

$$\left[\left(E[h]+1\right)\left(r_0 + mB\right) + \sum_{i=1}^{E[h]} iB \right]$$

where r_0 = Constant no. of bits attributed to header of RERR packet

m = No. of unreachable routes in the routing table of RERR generating node

B = No. of bits of address and sequence number in one unreachable route

The above express is true for AODV only. But in SARP, each node when transmits RERR packets, adds its own address and sequence number to the RERR packet. If A is the number of bits attributed to the address and sequence number, then the extra bits that need to be transmitted along with RERR packet is

$$\sum_{i=1}^{E[h]} iA$$

Since the RERR packet format in SARP combines the feature of AODV and address and sequence number appending as explained above, the total number of bits that need to be transmitted in a single session is

$$\left[\left(E[h]+1\right)\left(r_0+mB\right)+\sum_{i=1}^{E[h]} iB+\sum_{i=1}^{E[h]} iA\right]$$

Since B (unreachable address and seq. number) and A (appended address and seq. no.) both are of the same length, then above expression can be rewritten as

$$\left[\left(E[h]+1\right)\left(r_0+mB\right)+2\sum_{i=1}^{E[h]} iB\right]$$

Hence, the total energy expended during transmission of RERR for a single session is

$$E_{Tx}^{RERR}=K_e\left[\left(E[h]+1\right)\left(r_0+mB\right)+2\sum_{i=1}^{E[h]} iB\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 3.22$$

Similarly, the total energy expended during reception of RERR for a single session is

$$E_{Rx}^{RERR}=E_{relec}\left[\left(E[h]+1\right)\left(r_0+mB\right)+2\sum_{i=1}^{E[h]} iB\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 3.23$$

Hence, the total energy expended by the participating nodes to process the control packets for a single broadcast session is

E_{TOTAL} = *RREQs processing energy + RREPs processing energy + RERRs processing energy*

$$E_{TOTAL} = (E_{Tx}^{RREQ} + E_{Rx}^{RREQ}) + (E_{Tx}^{RREP} + E_{Rx}^{RREP}) + (E_{Tx}^{RERR} + E_{Rx}^{RERR}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad 3.24$$

3.3.5 Implementation Flowchart

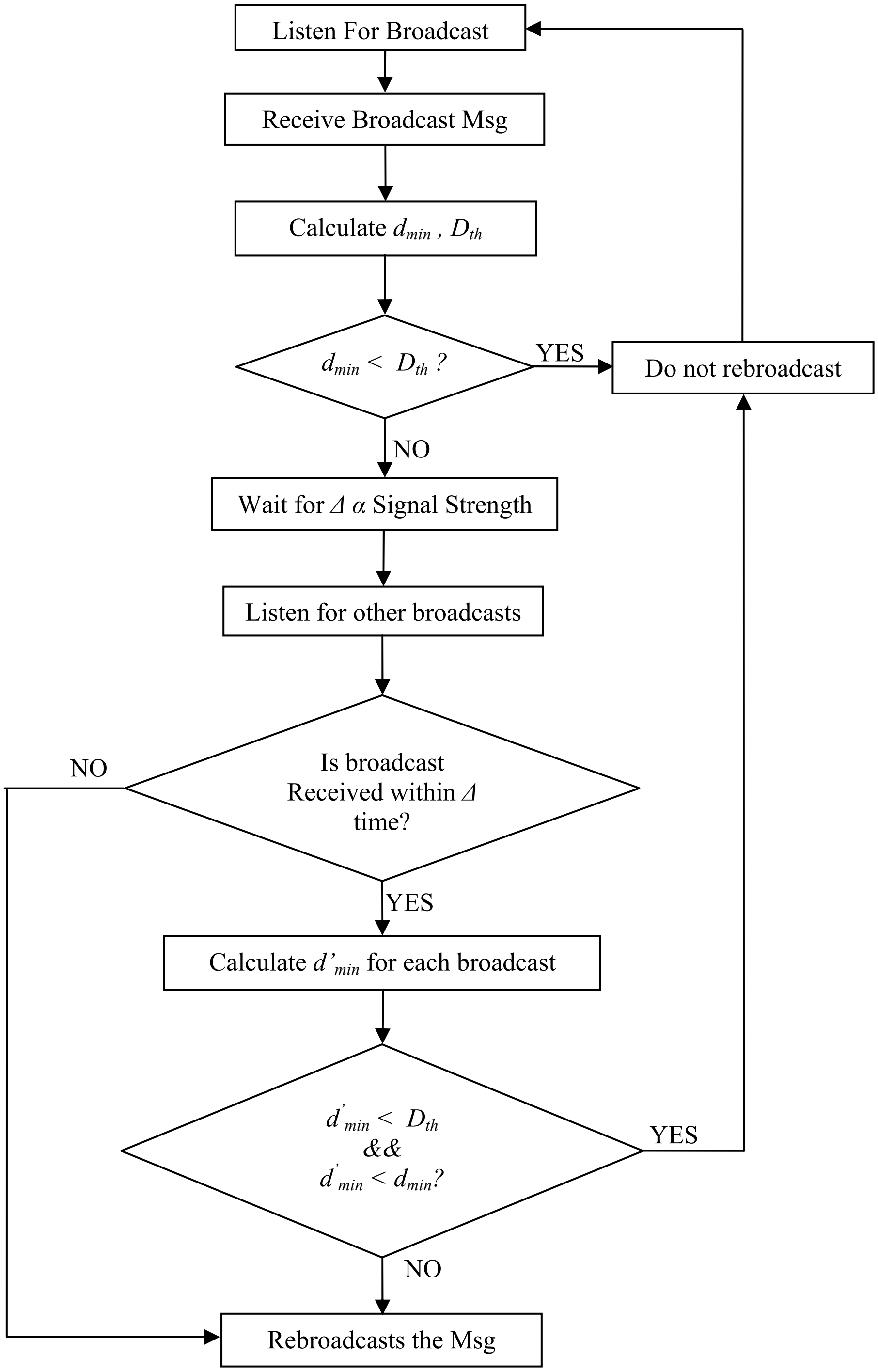

Figure 3.6 Implementation Flowchart of OZON Protocol

Chapter 4

Simulation Results and Analysis

This chapter provides the brief overview of the simulator GloMoSim used to simulate the energy consumption pattern of EE – SARP along with AODV, DSR and SARP. Also, the comparison of energy consumption of these protocols has been provided in the graphical format and the results has been verified statistically using *t – test.*

4.1 Simulation Environment – GloMoSim

Global Mobile Simulator (GloMoSim) [17] is a library-based sequential and parallel simulator for wireless networks developed at University of California, Los Angeles, USA. Its design is based on a set of library modules, each of which simulates a specific wireless communication protocol in the protocol stack. C-based parallel simulation language called PARSEC has been used to develop the library modules that makes easier for new developer to integrate the new protocol and modules.

GloMoSim simulates all layers of a purely wireless network. A number of protocols have been developed in each module and layer such that these modules can be developed at different levels of granularity. This modular nature of implementation enables consistent comparison of multiple protocols at a given layer. The following figure shows the currently available architecture of GloMoSim.

In order to run the required network simulation, GloMoSim requires the two main files:

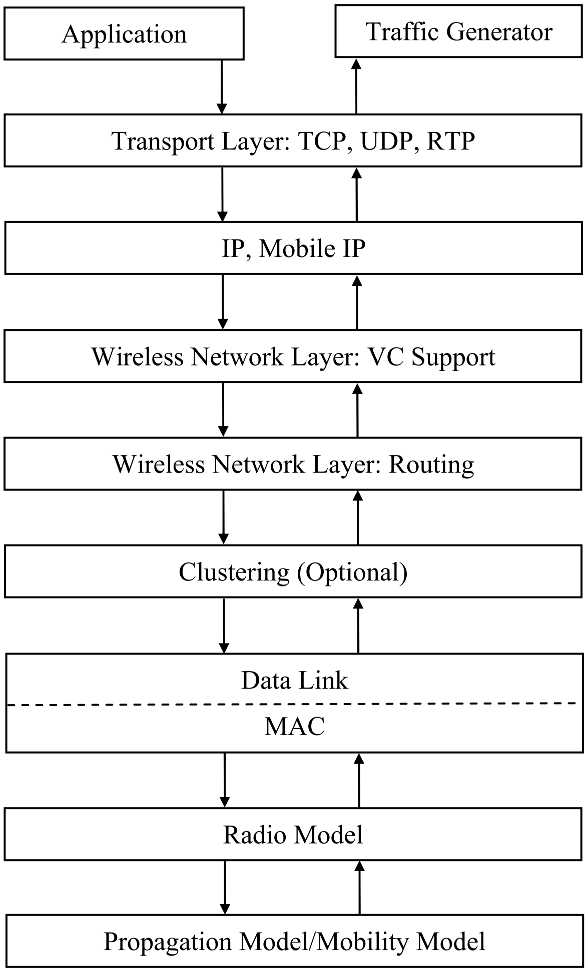

Figure 4.1 GloMoSim architecture

Configuration File:

This file is used to create the specific network scenario and configures the necessary network parameters like simulation time, a random seed to generate random number, parameter related to scenario topology. The placement of the nodes can be done in following ways:

- File: Coordinates of the nodes can be specified in a file
- Grid: Nodes are placed in a grid
- Random: Nodes are placed randomly

- Uniform: Nodes are uniformly spread to grid cells where they are randomly placed.

It enables to configure all the layers of the protocol stack including the radio propagation model, the network routing protocol and the transport layer protocol used.

Application File:

The application file specifies the type of applications that run between different source and destination pairs. It also specifies the number of source and destination pairs communicating, in addition to the type of traffic and the size, number and duration of each traffic flow. In this simulation, Constant Bit Rate (CBR) has been used to simulate the data from source to the destination

CBR simulates a constant bit rate generator. In order to use CBR, the following format is needed:

CBR <src> <dest> <items to send> <item size> <interval> <start time ><end time>

EXAMPLE:

CBR 0 1 10 1460 1S 0S 600S

Node 0 sends node 1 ten items of 1460B each at the start of the simulation up to 600 seconds into the simulation. The inter departure time for each item is 1 second. If the ten items are sent before 600 seconds elapsed, no other items are sent.

Implementation Parameters and Metrics

The goal of this research is to develop an EE-SARP and compare its energy consumption behavior with other routing protocols like SARP, AODV and DSR. Different implementation parameters, metrics and scenarios are considered with different motilities as in [1] to maintain the consistency in simulation.

- The propagation mode was “Free Space”
- The radio model to transmit and receive packets was “Radio –Accoise”.
- The packet reception model was “SNR-Bounded”.
- The MAC layer was 802.11
- *Number of Data Flows:* Set to 20, 40, 60, 80, 100 and 120
- *Area:* Simulations are carried out in a 1 Km * 1 Km Square area
- *Transmission Range:* Transmission ranges of 250 m are used
- *Number of Nodes:* The number of nodes in all the scenarios is 40
- *Total Simulation Time:* The total simulation time of each scenario is 900 seconds
- *Bandwidth:* The bandwidth of each link is 2 Mbps
- *Mobility Model: random waypoint* mobility model. The energy consumption is calculated for four different scenarios with different *pause times*: 0, 300, 600, and 900 seconds.
- *Link Breakage Detection:* To detect link breakages, the nodes employ link layer notification provided by the 802.11 MAC protocol

4.2 Performance Metrics

The performance of the proposed OZON protocol is tested by measuring the following three network parameters:

- Average number of route request (RREQ) generated.
- Average number of route error (RERR) generated.
- Average energy consumption of the participating nodes.

4.3 Simulation Scenarios

4.3.1 Simulation Scenario 1

Figure 4.2 shows the graph for average RREQs for AODV, DSR, SARP and EE - SARP for each number of data flows. The simulation shows that SARP and AODV both generate more number of RREQs than EE – SARP and DSR. These high amounts of RREQs are attributed to the high mobility where the number of link breakage is high. This leads to the increased number of control packet being transmitted to reach to the destination. Since RREQs are the rebroadcast packets, so they are prohibited for rebroadcasting in EE – SARP by certain nodes defined in the Intra Zonal areas thereby reducing their propagation in the network. The simulation shows that EE – SARP

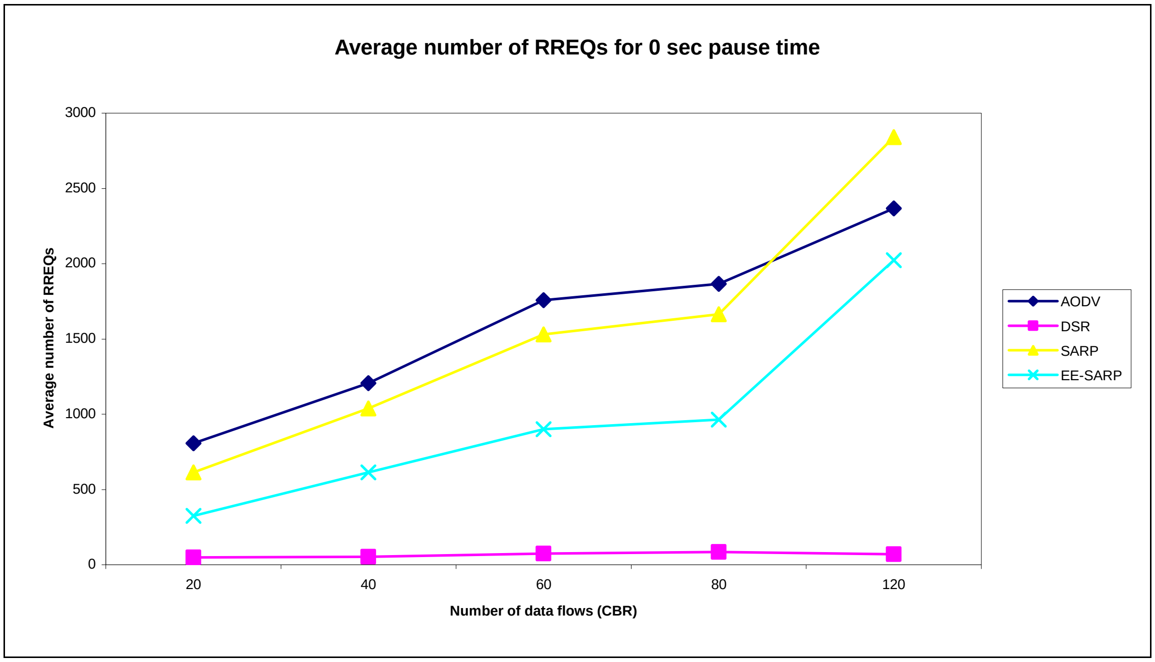

Figure 4.2 Average numbers of RREQs for 0 sec pause time.

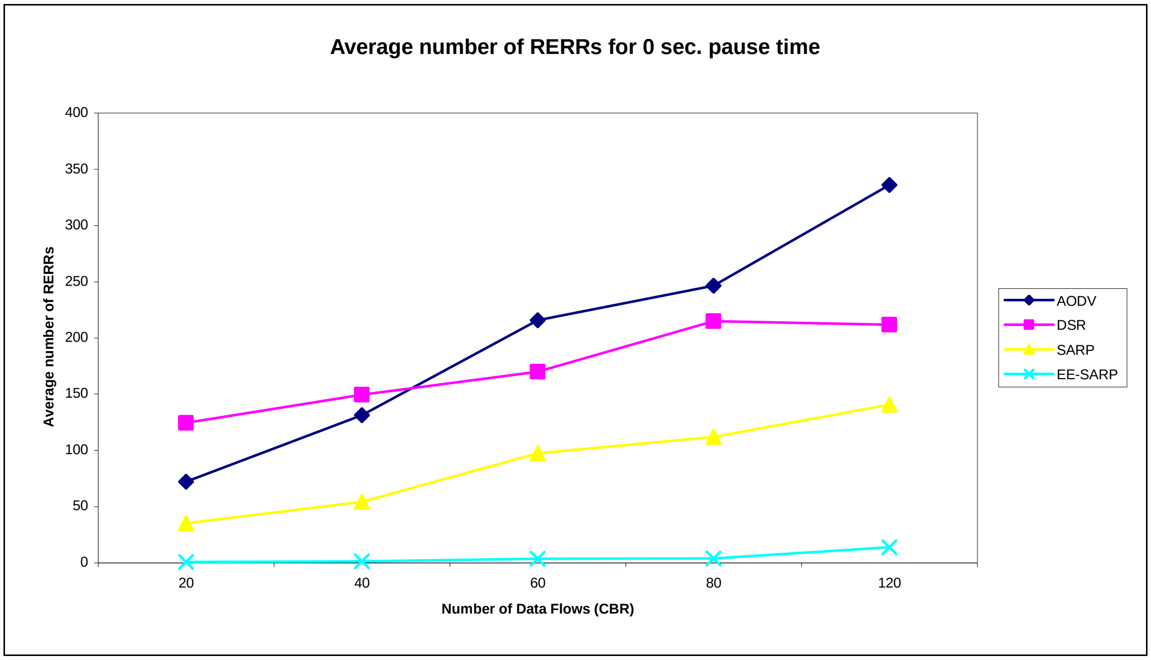

Figure 4.3 Average numbers of RERRs for 0 sec pause time.

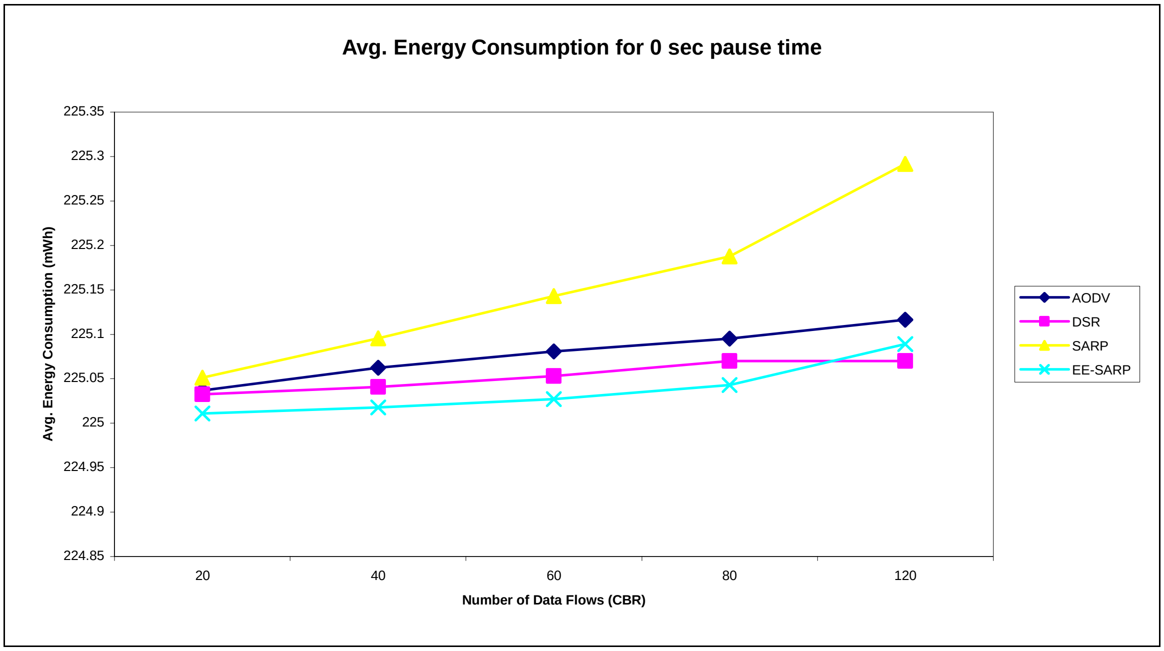

Figure 4.4 Average energy consumption for 0 sec pause time.

produces 39.52 % of less RREQs which is beneficial with the view of conserving precious energy in ad – hoc environment. Figure 4.3 shows the average number of RERRs generated for various protocols among which EE – SARP generated less than other. Also, the energy consumption pattern of various protocols is depicted in figure 4.4. Since the number of route request and errors for EE – SARP are less than other protocols, there is reduction in energy consumption also as depicted by the graph.

4.3.2 Simulation Scenario 2

In scenario 2 all the parameters from previous simulation are kept same except the pause time is increased to 300 sec thereby reducing the mobility of the mobile nodes. The RREQs generation graph for this scenario is shown in fig 4.5. The graph revels that EE -

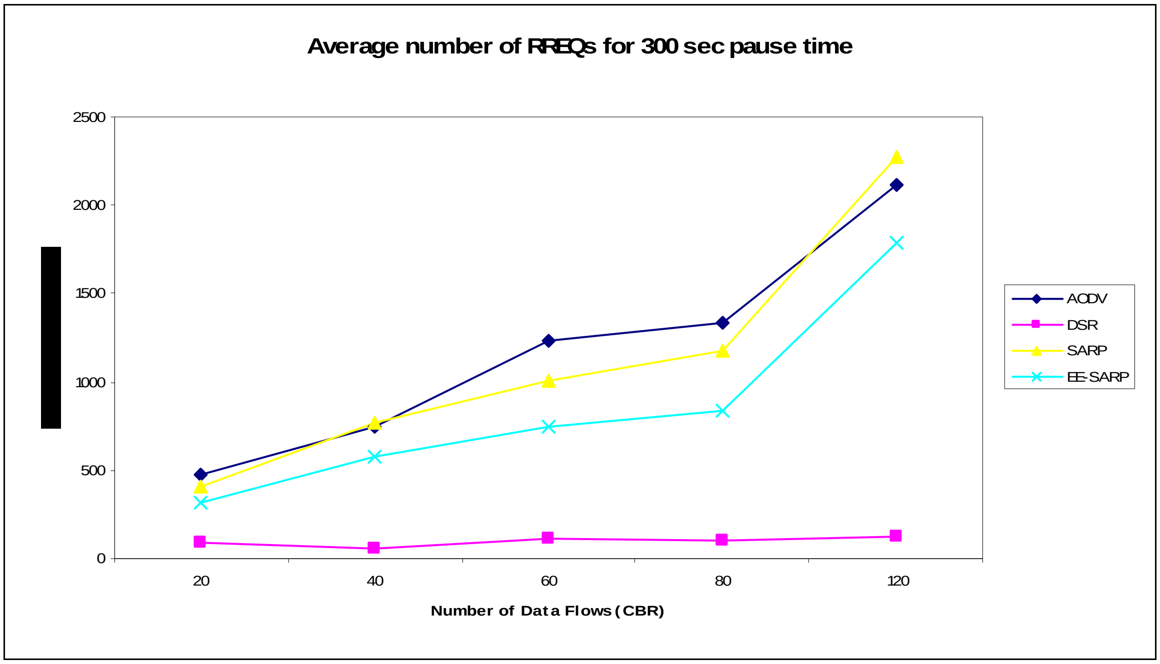

Figure 4.5 Average numbers of RREQs for 300 sec pause time.

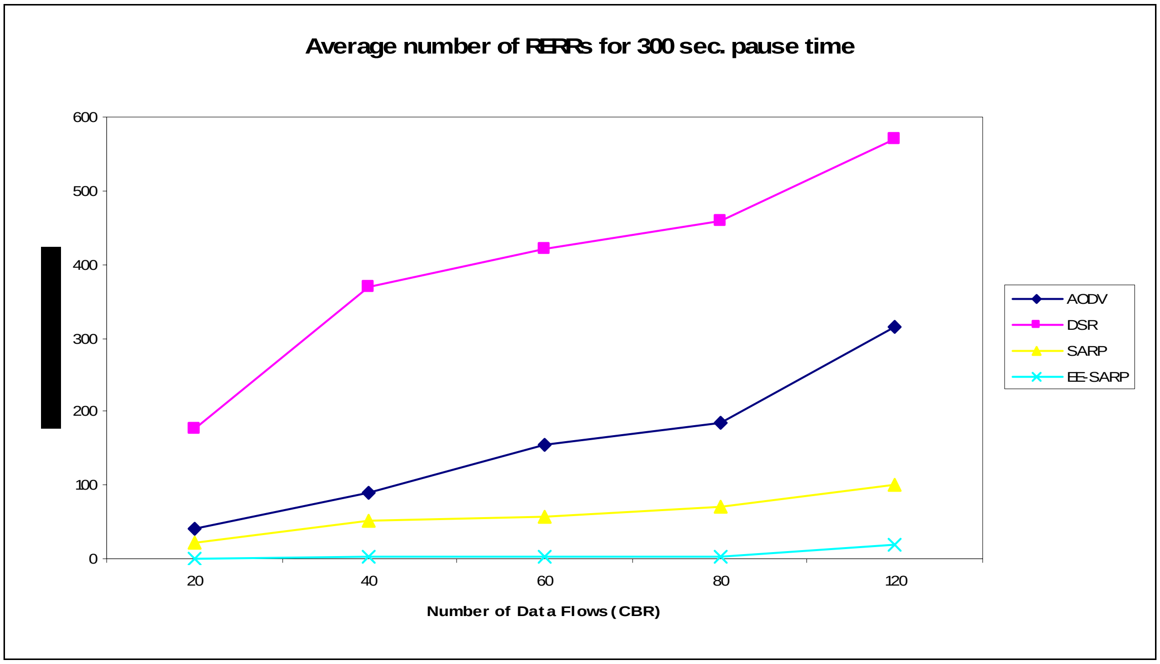

Figure 4.6 Average numbers of RERRs generation for 300 sec pause time.

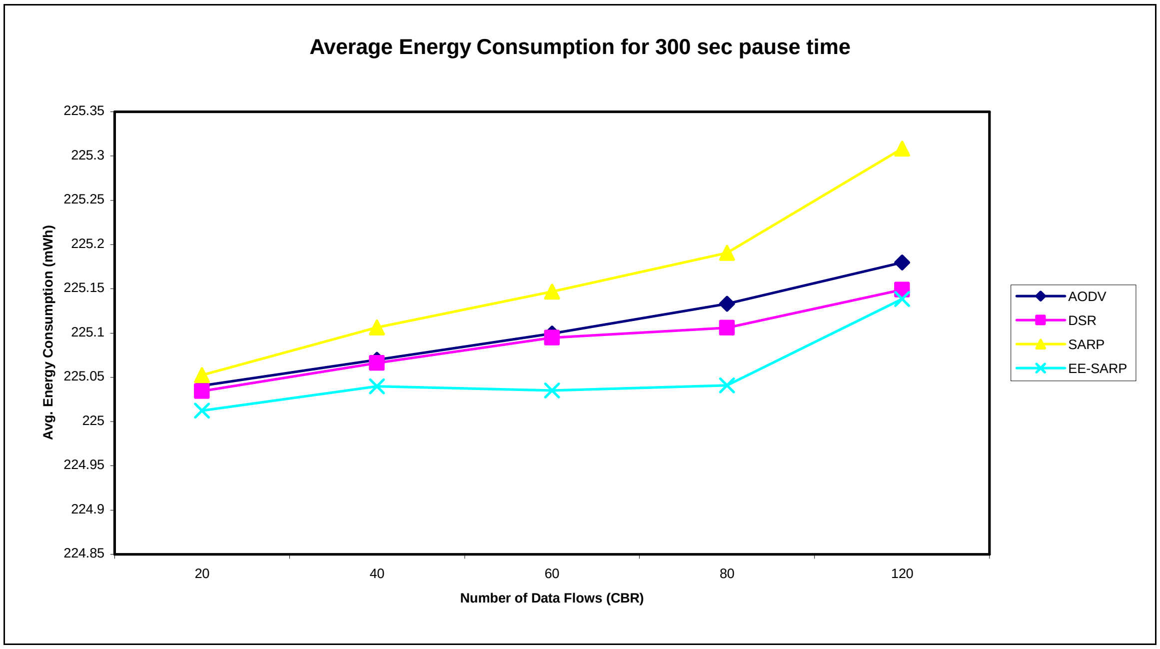

Figure 4.7 Average energy consumption for 300 sec pause time.

SARP generated less number of RREQs (24.60 % less than SARP) than traditional SARP and AODV. However, DSR generates much less RREQs but the simulation shows that the number of router errors in this case is much higher than the other protocols as shown in figure 4.6. The energy consumption for this scenario is depicted in figure 4.7 which shows in this case also EE – SARP consumes less energy than other protocols. This less energy consumption is attributed to the reduced number of control packets in the network.

4.3.3 Simulation Scenario 3

In this scenario, the pause time is further reduced to 600 sec which means less mobility of the mobile nodes. All the other simulation parameters are kept as it is from the previous scenario. The comparison graph in figure 5.7 shows that, for small number of data flows, EE – SARP's RREQs generation pattern closely follows to that of its

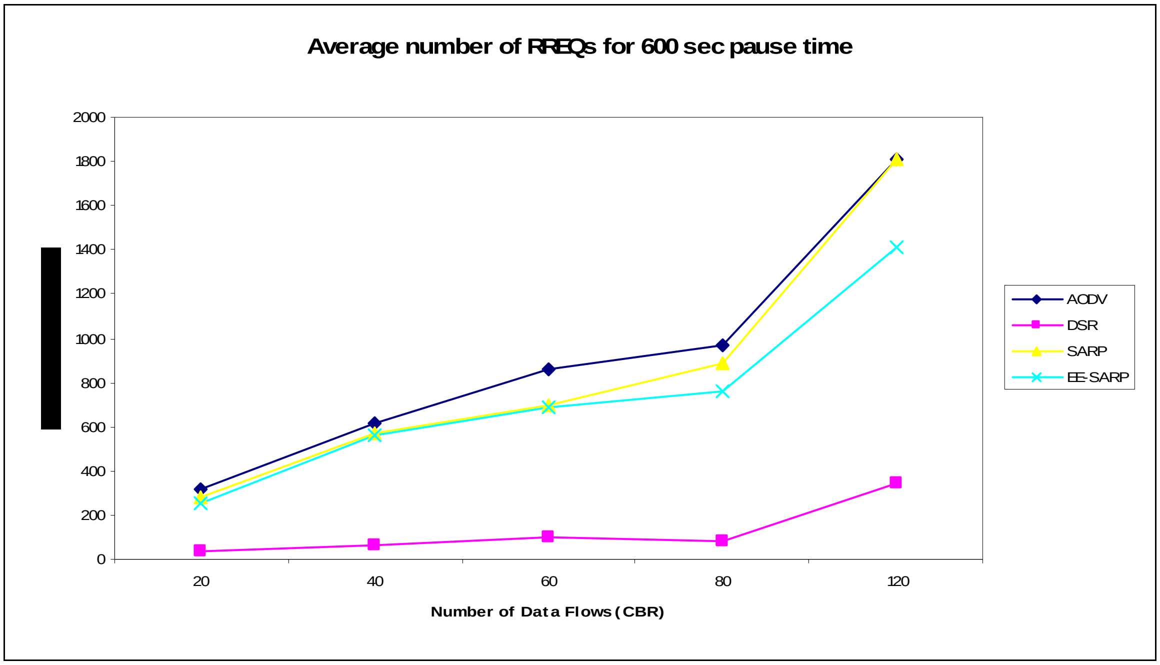

Figure 4.8 Average numbers of RREQs generation for 600 sec pause time.

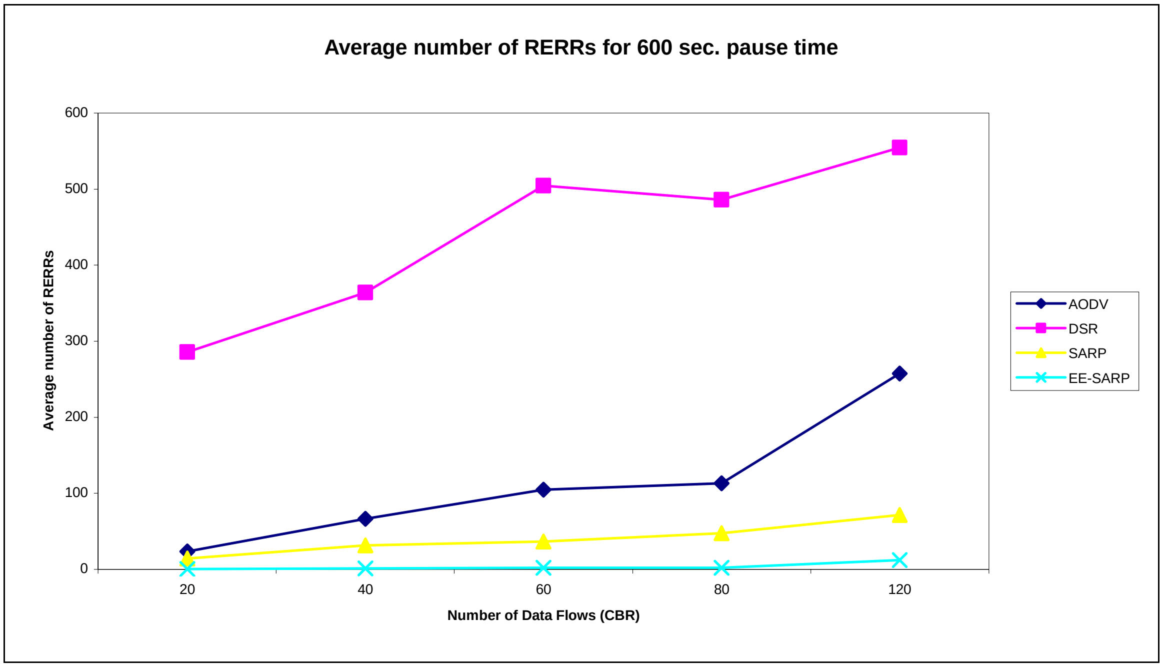

Figure 4.9 Average numbers of RERRs generation for 600 sec pause time.

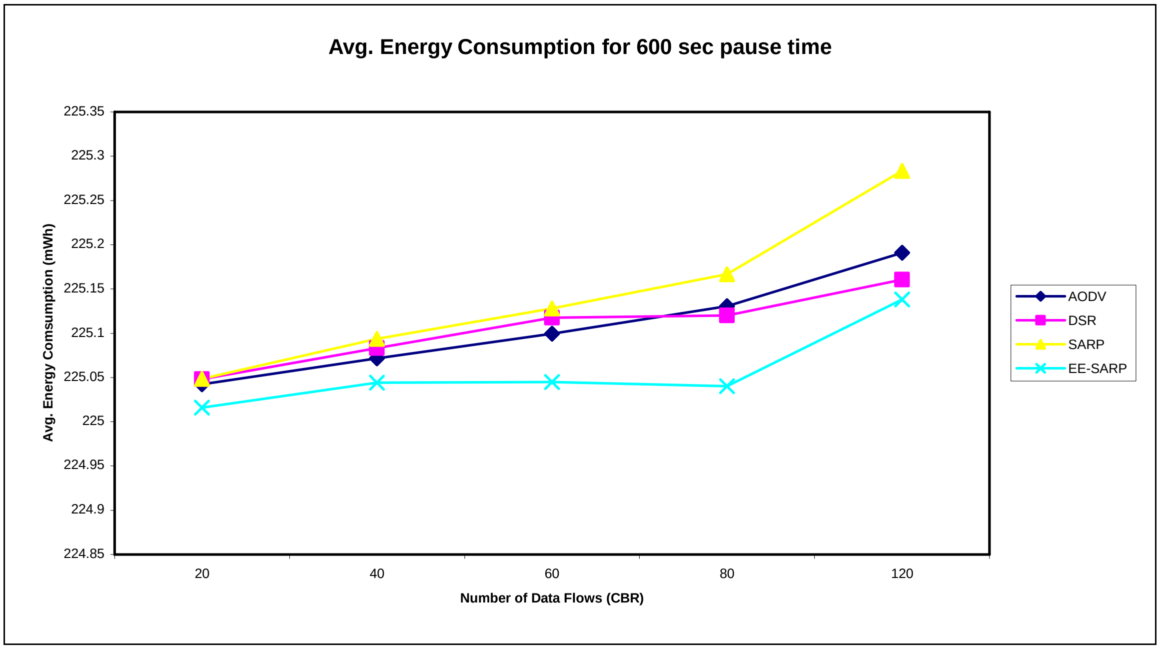

Figure 4.10 Average energy consumption for 600 sec pause time.

counterpart ad hoc protocols SARP but is still less than AODV. But for high number of data flows like CBR source of 120 pairs, the RREQs generated is in EE - SARP is still significantly less than that of SARP. The route error generated in this case is much higher for DSR than other protocols. However, for EE- SARP, RERRs generation is significantly low as compared to other protocols. This reduced number of control packets lead to the reduced energy consumption in the network as depicted by figure 4.10.

4.3.4 Simulation Scenario 4

Again in this scenario, all the parameters from the previous simulation are kept same except the mobility of the nodes are further reduced to 900 sec. In this simulation scenario, 900 sec pause time is equivalent to the no mobility of the nodes. This scenario

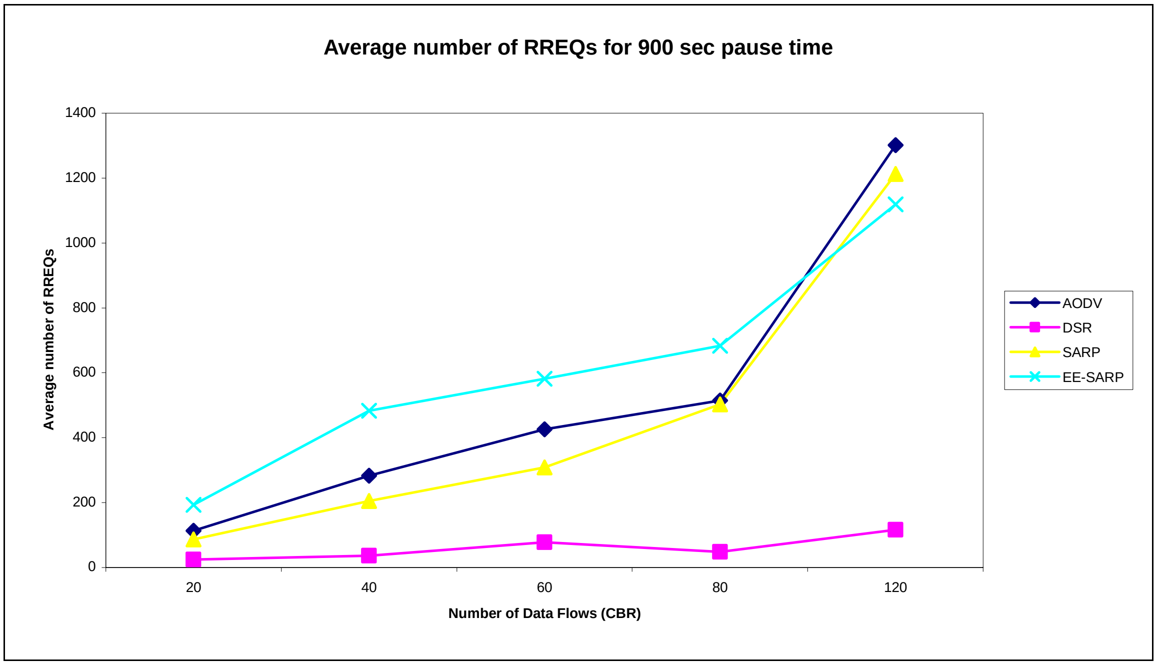

Figure 4.11 Average numbers of RREQs generation for 900 sec pause time.

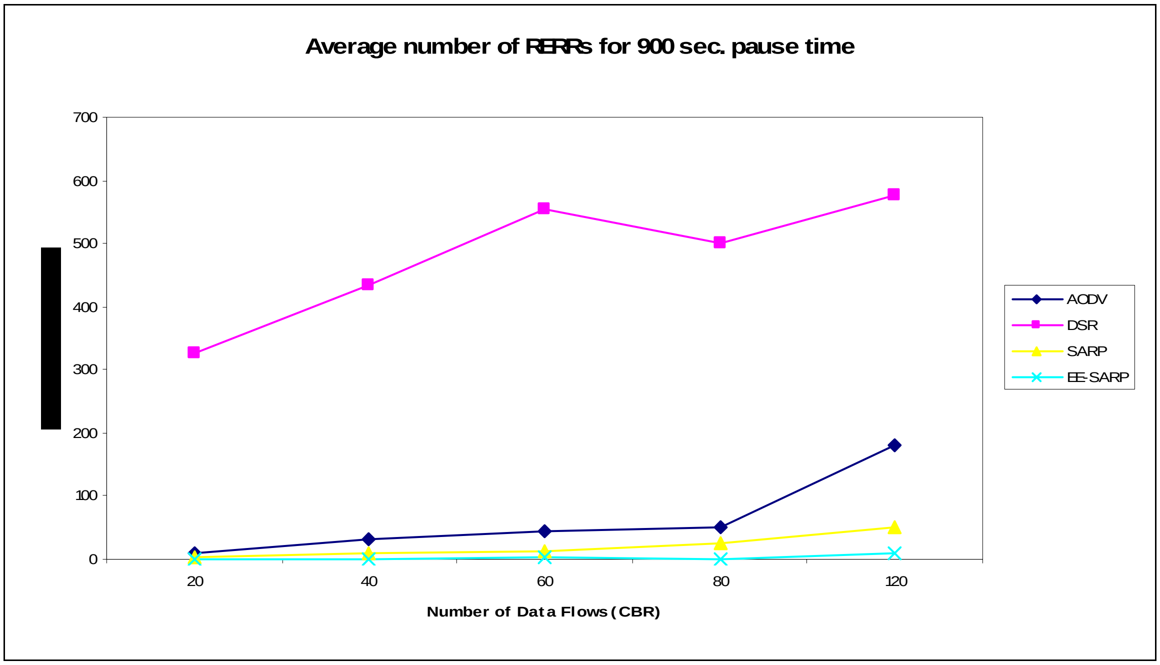

Figure 4.12 Average numbers of RERRs generation for 900 sec pause time.

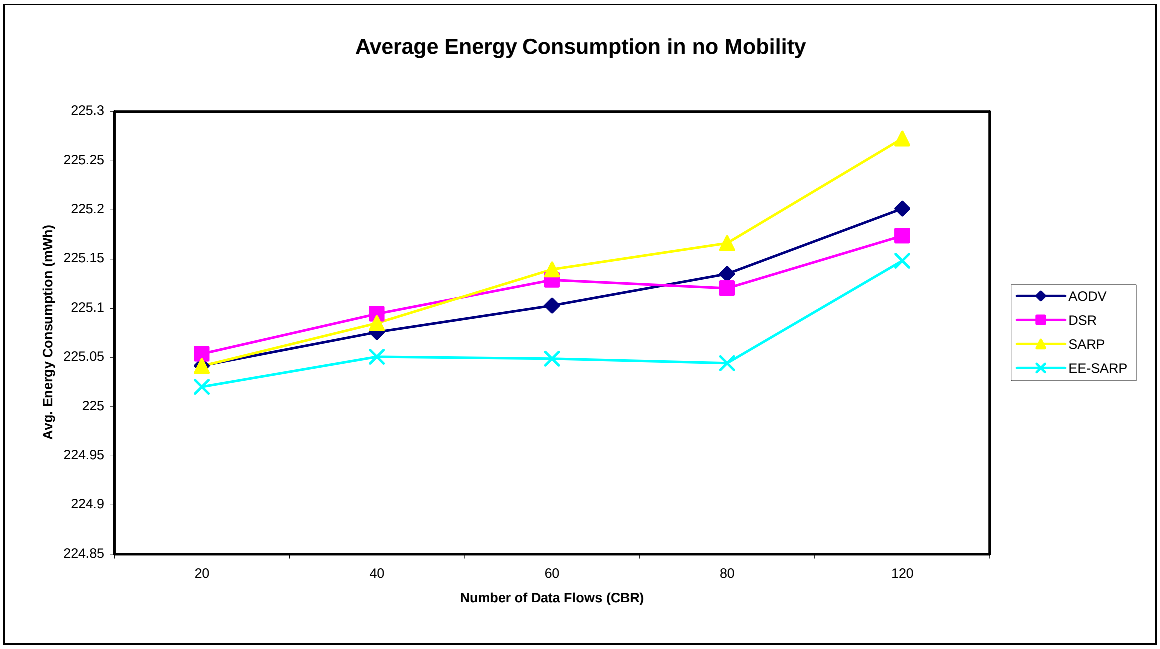

Figure 4.13 Average energy consumption for 900 sec pause time.

is however unrealistic in the ad – hoc environment, it is used to compare the RREQs generation and energy consumption pattern of the four protocols. The comparison graph for this scenario is shown in figure 4.11 which revels that during the low volume data transfer, RREQs generation pattern of EE-SARP is higher compared to AODV, SARP and DSR. However for higher at higher rate of data transfer, EE-SARP still generates less number of RREQs than SARP. As the mobility goes on decreasing, the routing protocols except DSR shows stable route discovery and maintenance process. This is depicted by the reduced number of route error generated in the network. Due to the less number of control packet generation for EE –SARP, the overall average energy consumption is still less than other protocols.

4.4 Statistical Analysis

4.4.1 The T- test

The independent sample t – test *statistically* compares the mean scores of the two groups on a given variables in relation to the variation in data (expressed as the standard deviation of the difference between the mean).

Mathematically,

$$t = \frac{\overline{x}_1 - \overline{x}_2}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 5.1$$

Here, it has been tried to test whether the reduction in the energy consumption for EE – SARP is significantly lower than the energy consumption of SARP. While performing the t – test, the following assumptions are being made:

1. The two protocols have approximately equal variances for energy consumption.
2. The energy consumption patterns of two protocols are independent of one another.

We establish a null and alternate hypothesis as follows:

H_0: The mean of the energy consumption pattern of EE – SARP and SARP are not significantly different.

H_1: The mean of the energy consumption pattern of EE – SARP and SARP are significantly different.

Scenario 1:

The group statistics for scenario 1 with pause time 0 sec and CBR 20 is shown below:

Group Statistics:

Protocols		N	Mean	Std. Deviation	Std. Error Mean
Scenario 1	SARP	40	225.0511	0.01792	0.00283
	EE - SARP	40	225.0111	0.01481	0.00234

Here it can be seen that the mean energy consumption of EE – SARP is lower than that of SARP. That is, the participating nodes running EE – SARP as their routing protocol consumes less energy than those which run SARP within the mobile ad hoc network.

Independent Sample Test:

		t - test for Equality of Means						
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence interval of the difference	
							Lower	Upper
Scenario 1	Equal variances assumed	10.876	78	0.000	0.03998	0.003676	0.0327	0.0447

From the table above, it can be seen that significance is less than 0.05. Therefore, the null hypothesis is rejected signifying that there exists the significant difference between the energy consumption patterns of two routing protocols. *Hence, we can* ***statistically*** *infer that EE – SARP consumes significantly less energy than SARP*.

As it can be seen from the figure 4.4, the energy consumption pattern of EE - SARP for other CBR sources is lower than that of SARP and therefore supports the above conclusion. This result holds true for other scenarios also as we can see that significance for each scenario is less than 0.05. The t – test result for all four scenarios are provided in the appendix of this thesis (these results are for CBR 20 only).

Chapter 5

Conclusion and Future Works

5.1 Conclusion

This research work proposes the novel approach called Optimal Zonal Protocol to contain excessive rebroadcast of control packets in mobile ad – hoc network. During the route discovery and maintenance procedure, an excessive amount of control packets are generated and rebroadcasted within a network. However, such rebroadcasting is a common and frequent operation in mobile ad – hoc environment where the host mobility is high. Because radio signals are likely to overlap with others in a geographic area, a straightforward broadcasting by flooding is usually very costly and will result in serious redundancy, contention, and collision causing a broadcast storm. This broadcast storm causes the increase expenditure of precious energy of the participating nodes. Thus, this research work tried to address the issue of excessive rebroadcasting and energy consumption. The Optimal Zonal (OZON) concept was deployed in the existing SARP. According to this concept, each node determines its own optimal zone of certain radius within which the mobile nodes are refrained from rebroadcasting the control packets. Only those nodes beyond this optimum zone and included within the transmitting range of the source node have a privilege to rebroadcast. The effect of this controlled rebroadcast is to reduce the number of control packet in the networks thereby reducing the energy consumption. The effectiveness of the proposed OZON concept was evaluated using GloMoSim software. The result showed that we have significant reduction in generation of control packets up to 40 % in case of RREQs and 92 % in RERRs within the networks. In effect, these reductions in control packets lead to the reduced energy consumption of the participating nodes. Also, the t – test confirms that the energy consumed by EE – SARP is significantly less than that of SARP ($p<0.05$). In conclusion, the proposed OZON protocol has been successfully implemented for SARP with the achievement of the research goal put forth by this thesis.

5.2 Future works

The future works consists of adaptively fine tuning of rebroadcast parameters according to the real application. Dynamically evaluating the optimal zone in heterogeneous networks to refrain the nodes from rebroadcasting the control packets might be sought as future works. The evaluation of sensitivity to potentially misleading information and obsolete neighborhood can be carried out. Also, the energy consumption in ad – hoc network can be reduced by deploying sleep mode for participating nodes. The combination of OZON concept with SLEEP_TABLE [16] implementation can result in better energy efficient scheme.

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APPENDICES

APPENDIX A

RREQ Packets

Simulation Scenario # 1 Pause Time = 0 sec

No. of Data Flows	Protocols			
	AODV	DSR	SARP	EE-SARP
20	806	50	614	325
40	1205	53	1039	613
60	1758	73	1531	900
80	1866	85	1666	965
120	2366	69	2841	2024

A1. Average RREQs packets generation for 0 sec. pause time.

Simulation Scenario # 2 Pause Time = 300 sec

No. of Data Flows	Protocols			
	AODV	DSR	SARP	EE-SARP
20	475	90	409	319
40	744	54	765	574
60	1232	111	1006	743
80	1333	97	1175	833
120	2117	128	2271	1788

A2. Average RREQs packets generation for 300 sec. pause time.

Simulation Scenario # 3 Pause Time = 600 sec

No. of Data Flows	Protocols			
	AODV	DSR	SARP	EE-SARP
20	321	38	281	250
40	615	66	568	559
60	862	104	698	686
80	970	82	885	761
120	1812	341	1814	1416

A3. Average RREQs packets generation for 600 sec. pause time.

Simulation Scenario # 4 Pause Time = 900 sec

No. of Data Flows	Protocols			
	AODV	DSR	SARP	EE-SARP
20	114	24	86	193
40	283	37	205	483
60	426	78	309	582
80	514	48	502	683
120	1302	116	1213	1119

A4. Average RREQs packets generation for 900 sec. pause time.

RERR Packets

Simulation Scenario # 1 Pause Time = 0 sec

No. of Data Flows	Protocols			
	AODV	**DSR**	**SARP**	**EE-SARP**
20	72	124	35	1
40	131	149	54	2
60	216	170	98	4
80	246	215	112	4
120	336	212	141	14

A5. Average RERRs packets generation for 0 sec. pause time.

Simulation Scenario # 2 Pause Time = 300 sec

No. of Data Flows	Protocols			
	AODV	**DSR**	**SARP**	**EE-SARP**
20	40	177	20	1
40	89	368	51	3
60	154	420	57	3
80	184	458	70	3
120	316	571	100	19

A6. Average RERRs packets generation for 300 sec. pause time.

Simulation Scenario # 3 Pause Time = 600 sec

No. of Data Flows	Protocols			
	AODV	**DSR**	**SARP**	**EE-SARP**
20	24	286	14	1
40	67	364	32	1
60	105	504	37	2
80	113	486	48	2
120	257	555	72	12

A7. Average RERRs packets generation for 600 sec. pause time.

Simulation Scenario # 4 Pause Time = 900 sec

No. of Data Flows	Protocols			
	AODV	**DSR**	**SARP**	**EE-SARP**
20	8	328	4	0
40	30	433	11	1
60	46	554	13	2
80	52	501	25	1
120	180	576	50	9

A8. Average RERRs packets generation for 900 sec. pause time.

Energy Consumption Patterns

Simulation Scenario # 1 Pause Time = 0 sec

No. of Data Flows	Protocols			
	AODV	DSR	SARP	EE-SARP
20	225.036675	225.0324	225.05105	225.011075
40	225.06225	225.04075	225.09565	225.0177
60	225.0809	225.052925	225.1431	225.027225
80	225.09515	225.069875	225.187525	225.04305
120	225.11645	225.070025	225.291525	225.089075

A9. Average energy consumption for 0 sec. pause time.

Simulation Scenario # 2 Pause Time = 300 sec

No. of Data Flows	Protocols			
	AODV	DSR	SARP	EE-SARP
20	225.04045	225.03445	225.052475	225.012325
40	225.069675	225.0662	225.1063	225.039775
60	225.09955	225.094625	225.14665	225.03515
80	225.13305	225.1058	225.19055	225.0408
120	225.1798	225.149075	225.3084	225.138425

A10. Average energy consumption for 300 sec. pause time.

Simulation Scenario # 3 Pause Time = 600 sec

No. of Data Flows	Protocols			
	AODV	DSR	SARP	EE-SARP
20	225.0422	225.04825	225.048475	225.015925
40	225.071725	225.083175	225.093775	225.04425
60	225.099525	225.1175	225.128075	225.04475
80	225.13045	225.119925	225.166575	225.040275
120	225.190775	225.1607	225.283475	225.1381

A11. Average energy consumption for 600 sec. pause time.

Simulation Scenario # 4 Pause Time = 900 sec

No. of Data Flows	Protocols			
	AODV	DSR	SARP	EE-SARP
20	225.04155	225.053525	225.041375	225.02015
40	225.075875	225.094425	225.08485	225.050875
60	225.102675	225.128975	225.139475	225.048925
80	225.135125	225.1205	225.166125	225.044325
120	225.20145	225.17365	225.272525	225.148475

A12. Average energy consumption for 900 sec. pause time.

APPENDIX B

T – test Statistics

Group Statistics for Scenario 1

Protocols		N	Mean	Std. Deviation	Std. Error Mean
Scenario 1	SARP	40	225.0511	0.01792	0.00283
	EE - SARP	40	225.0111	0.01481	0.00234

Independent Sample Test for Scenario 1

Scenario 1	Equal variances assumed	t - test for Equality of Means						
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence interval of the difference	
							Lower	Upper
		10.876	78	0.000	0.03998	0.003676	0.0327	0.0447

B1. Group Statistics and Independent Sample Test for Scenario 1

Group Statistics for Scenario 2

Protocols		N	Mean	Std. Deviation	Std. Error Mean
Scenario 2	SARP	40	225.0525	0.02066	0.003267
	EE - SARP	40	225.0123	0.01679	0.002654

Independent Sample Test for Scenario 2

Scenario 2	Equal variances assumed	t - test for Equality of Means						
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence interval of the difference	
							Lower	Upper
		9.539	78	0.000	0.04015	0.004209	0.03177	0.04853

B2. Group Statistics and Independent Sample Test for Scenario 2

Group Statistics for Scenario 3

Protocols		N	Mean	Std. Deviation	Std. Error Mean
Scenario 3	SARP	40	225.0485	0.03136	0.004958
	EE - SARP	40	225.0159	0.03804	0.006015

Independent Sample Test for Scenario 3

		t - test for Equality of Means						
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence interval of the difference	
							Lower	Upper
Scenario 3	Equal variances assumed	4.176	78	0.000	0.03255	0.007795	0.01703	0.04807

B3. Group Statistics and Independent Sample Test for Scenario 3

Group Statistics for Scenario 4

Protocols		N	Mean	Std. Deviation	Std. Error Mean
Scenario 4	SARP	40	225.0414	0.03442	0.005442
	EE - SARP	40	225.0202	0.05664	0.008956

Independent Sample Test for Scenario 4

		t - test for Equality of Means						
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence interval of the difference	
							Lower	Upper
Scenario 4	Equal variances assumed	2.025	78	0.046	0.02122	0.01048	0.0003618	0.04209

B4. Group Statistics and Independent Sample Test for Scenario 4