An Energy Efficient Dynamic Routing Protocol for ad-hoc wireless networks

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ABSTRACT

An ad hoc network is a network without any infrastructure or centralized administration and which is formed of a group of wireless mobile hosts, each of which have a limited wireless transmission range. In this paper, a dynamic routing protocol for routing in ad hoc networks is proposed. The protocol is called the energy-efficient dynamic routing (EED) protocol. The protocol is dynamic in the manner that it can adapt quickly to the changes in the network structure caused by the frequent nodes motion while minimizing the overhead at the same time. Also, this protocol is energy-efficient because it takes into consideration the nodes' energy, the transmission path length as well as the energy level of the transmission path so as to minimize the energy consumed during the transmission of packets. Effect of network parameters on the performance of the proposed protocol is thoroughly investigated. EED protocol is applied to different case studies and the results are discussed and analyzed in details.

1- INTRODUCTION

The Evolution of communication has driven the humanity into a new era in which the speed of the information transfer has been doubled many times and the capacity of the transmission has significantly increased to secure a huge number of users. The communication techniques now varies from wired communication using the internet to the wireless communication using satellite channels.

In terms of ways of communication wired communication networks such as the internet are usually packet-switched networks so that they would be more effective in delivering its contents. However, wireless communication can be fixed or mobile. The fixed wireless communication is achieved by cellular networks, in which communication is accomplished by a fixed number of base stations with known locations. The capacity of the channel given to a single session in a wireless cellular system can be either a point-to-point or a multipoint communication. The task of sharing the limited capacity in a wireless cellular communication system is done by multiple access methods, such as time division multiple access (TDMA), frequency division multiple access (FDMA), and code division multiple access (CDMA).

On the other hand, the mobile wireless communication, namely mobile ad hoc networks, has no fixed infrastructure or centralized administration and depends on mobile hosts to form a temporary network with infrastructure varies with the hosts' mobility. Wireless ad hoc networks are traditionally used in battlefield communications, law enforcement, disaster recovery, and emergency search and rescue. Lately, wireless ad hoc networks have been extensively used in civilian forms such as electronic classrooms, convention centers, construction sites, and special events [1-4] .

In ad hoc networks, the problem of routing can be divided into two areas: *route discovery* and *route maintenance.* In route discovery, when a host wants to transmit to another, it must initially discover a suitable route for sending packets to that destination. On the other hand, route maintenance is concerned with the route in terms that if the conditions remain unchanged, this route should continue to transmit. Otherwise, if the status of the links or hosts used in this route change, some changes may be done to the route or a new route can be discovered. We must take into consideration different criteria in designing and classifying routing techniques for wireless ad hoc networks. Like, what is the routing information being exchanged, when and how the routing information is exchanged, when and how to compute routes [4-7] .

In terms of routing, wired networks generally use distance vector or link state routing algorithms, both of which require periodic routing acknowledgments to be sent by each router. In distance vector routing (DVR) [1,7,8 , 9,10], each router sends to its neighbors the distance to all hosts, and each host computes the shortest path to the next host. In link state routing (LSR) [6-14], each host sends to all other hosts in the network its view of the status of each of its adjacent network hosts, and each host calculates the shortest distance to each host based on the complete hierarchy of the network obtained from the information collected from all hosts. Also, the basic distance vector algorithm is being used for routing in wireless ad hoc networks, by treating each mobile host as a router.

Depending on when the route is computed, we can divide routing protocols into two categories: precomputed routing and on-demand routing. Precomputed routing is also called *proactive* routing or *table driven* routing in which the routes to all destinations are computed *a priori*. On-demand routing is also called *reactive* routing. In which the route to a destination may not exist in advance and it is computed only when the route is needed.

Based on when the routing information will be disseminated, we can classify routing protocols as periodical update and event-driven update protocols. Periodical update protocols disseminate routing information periodically. Periodical updates will simplify protocols and maintain network stability, and most importantly, enable new nodes to learn about the topology and the state of the network. In an event-driven update protocol, when events occur, (such as when a link fails or a new link appears), an update packet will be broadcasted and the up-to-date status can be disseminated over the network.

In a flat structure, all nodes in a network are at the same level and have the same routing functionality. Flat routing is simple and efficient for small networks. For large networks, hierarchical (cluster-based) routing may be used to solve the above problems [12-18]. In hierarchical routing the nodes in the network are dynamically organized into partitions called clusters, then the clusters are aggregated again into larger partitions called superclusters and so on.

Based on how a route is computed, there are two categories of routing protocols: decentralized computation and distributed computation. In a decentralized computation-based protocol, every node in the network maintains global and complete information about the network topology such that the node can compute the route to a destination itself when desired. In a distributed computation-based protocol, every node in the network only maintains partial and local information about the network topology. When a route needs to be computed, many nodes collaborate to compute the route [19 -24].

Section 2 of this paper contains the general description of the proposed technique (EED); Section 3 describes the detailed operation of the proposed EED technique. In section 4 optimization of EED protocol parameters is described; while in Section 5 simulation and experimental results of the proposed EED protocol are described and compared with the results of the known AODV and DSR techniques, effect of varying network parameters on the performance of EED protocol is thoroughly investigated. Finally conclusions are given in Section 6.

2 – PROPOSED PROTOCOL

2.1 General Description of the proposed EED protocol

This paper proposes a new routing protocol for ad hoc wireless networks that is both dynamic and energy efficient. The protocol is dynamic in terms that it implements dynamic source routing for communication between hosts. The energy efficiency of the protocol is achieved by selecting the path with the highest level of energy, and reducing the length of the transmission path, taking into consideration the distances between the nodes, by selecting the nodes with the most critical level of energy from the path and isolating them so as to ensure that the path is not going to be breached and to avoid a drop in the path during transmission, and finally, by conserving the nodes' level of energy through iterating between an awake/sleep modes. The nodes, belonging to a transmission path, are active during transmission of packets only and are sleep if they are not used in routing packets. We call this proposed protocol Energy Efficient Dynamic (EED) protocol.

In EED protocol, if an error occurs during transmission, error packets are sent to the source node, but the new route will begin to be computed from the node that detected the error not the source node so as to reduce the time consumed in the transmission of packets from the source node to the destination node. One advantage of this technique, is that it does not require an additional overhead for transmitted packets since it is an on-demand technique.

2.2 Main components of the EED protocol

For participating in the ad hoc network, each mobile host maintains a route cache in which it records routes information. When a host wants to send to another host, it first checks that a route cache exists between the sender host and the destination host. If a route is found, the sender makes use of this route to transmit packets. If no route is found, the sender tries to discover another route using the route discovery protocol. While waiting for the route discovery to be completed, the host can continue normal processing and has the ability to send and receive packets with other hosts.

For transmitting the original packet once the route is known during route discovery, the host can buffer the packet, or it may discard the packet, relying on higher-layer protocol to retransmit the packet if needed. Each entry in the route cache is associated with an expiration period, after the expiration period ends, the entry is deleted from the cache. While a host is using a route, it monitors the continued correct operation of that route. For example, if the sender, or the destination, or any of the other hosts in the ad hoc network move out of wireless transmission range of the next or previous hop along the route, the route can no longer be used to reach the destination.

A route will not be able to work if any of the hosts along the route failed or be powered off. This monitoring of the correct operation of a route in use is called *route maintenance*. When route maintenance detects a problem with a route in use, route discovery can be used again to discover another route to the destination.

Figure (1) illustrates the main components of the proposed EED protocol:

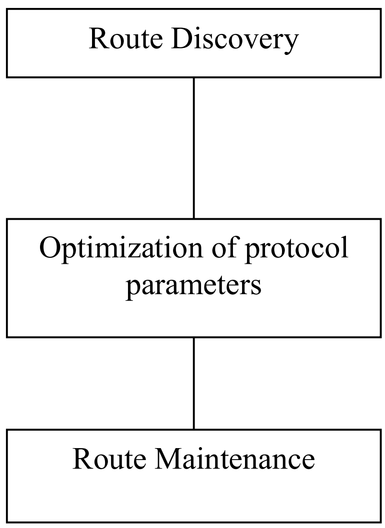

Figure (1) Main components of the proposed EED protocol

In this EED protocol, we focus on the following parameters:

1. Network delays
2. Dynamism in routing packets
3. Energy efficiency during packets transmission

These parameters are discussed in details in section 4.

3 - DETAILED DESCRIPTION OF THE EED PROTOCOL

3.1 Route Discovery

Route discovery allows any host in the ad hoc network to dynamically discover a route to any other host in the ad hoc network, either directly or through one or more intermediate network hops through other hosts. A host desiring to initiate a route discovery process, broadcasts a route request packet which can be received by the hosts within its transmission range in the ad hoc network. The route request packet can easily identify the host, referred to as the destination, for which the route is requested. If the route discovery process is successful, the source host receives a route reply packet containing a sequence of network hops through them it can reach the destination.

Besides the address of the original source of the request and the destination of the request, each route request packet contains a route record, in which a record of the sequence of hops taken by the route request packet is stored, as it is propagated through the ad hoc network during the route discovery process. Each route request packet is composed of a unique request id, set by the source from a locally-generated sequence number. In order to detect that there is duplicate route requests received, each host in the ad hoc network maintains a list of the source address, request id pairs that it has recently received for recent route requests.

In the proposed protocol (EED), when any host receives a route request packet, it processes the request according to the following steps:

1. If the pair initiator address, request id for this route request is found in this host’s list of recently seen requests, then discard the route request packet and do not process it further.

2. Otherwise, if this host’s address is already listed in the route record in the request, then discard the route request packet and do not process it further.

3. Otherwise, if the target of the request matches this host’s own address, then the route record in the packet contains the route by which the request reached this host from the initiator of the route request. Return a copy of this route in a route reply packet to the initiator.

4. Otherwise, append this host's own address to the route record in the route request packet, and re-broadcast the request.

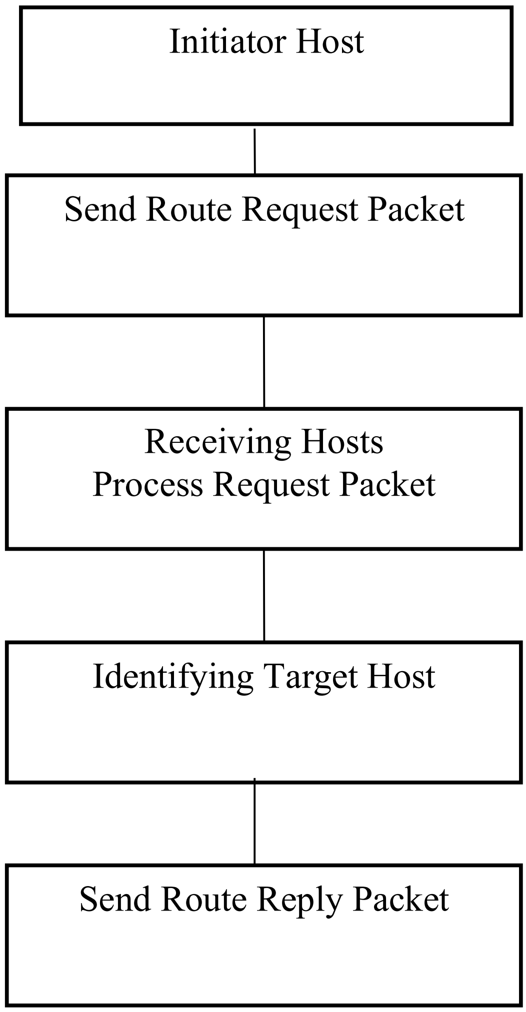

Figure (2) Structure of the Route Discovery Process

3.2 Route Maintenance

To integrate route discovery with route maintenance, traditional routing protocols continuously send periodic routing updates. If the status of a link or router changes, the periodic updates reflect the changes to all other routers, and this presumably results in the computation of new routes. When route discovery is used, there are no periodic messages of any kind from any of the mobile hosts. On the other hand, when a route is in use, the route maintenance procedure monitors the operation of the route and informs the sender of any routing errors through updates.

Since wireless networks are inherently less reliable than wired networks, a hop-by-hop acknowledgment may be used in many wireless networks at the data link layer to provide early detection and retransmission of lost or corrupted packets. In the wireless networks, route maintenance can be easily provided, since at each hop, the host transmitting the packet for that hop can determine if that hop of the route is still working in terms that it has the ability to send and forward packets or not.

If the data link layer can not recover from a transmission problem (for example, because the maximum number of retransmissions has been exceeded), the host that detected the error, sends a route error packet to the original sender. The route error packet contains the addresses of the hosts at both ends of the hop in error: the host that detected the error and the host to which it was going to transmit the packet. When a route error packet arrives at the source, the hop in error is removed from this host's route cache, and all routes that contain this hop must be deleted.

Route maintenance can also be done using end-to-end acknowledgements rather than the hop-by-hop acknowledgements, if the wireless transmissions between two hosts do not work well in both directions. Route maintenance is always possible whenever there are some routes that exists between the two end hosts. An equivalent acknowledgment signal can be used in many environments, if the wireless network does not support such lower-level acknowledgments. After a hop operating its wireless network interface in promiscuous mode sends a packet to the next hop, it can hear the next hop transmitting the packet again.

In the proposed EED protocol, hop-by-hop acknowledgment is used to ensure dynamism in the protocol, and that each error in the route will be solved quickly through periodic route updates. Figure (3) shows the structure of the route maintenance process of EED protocol .

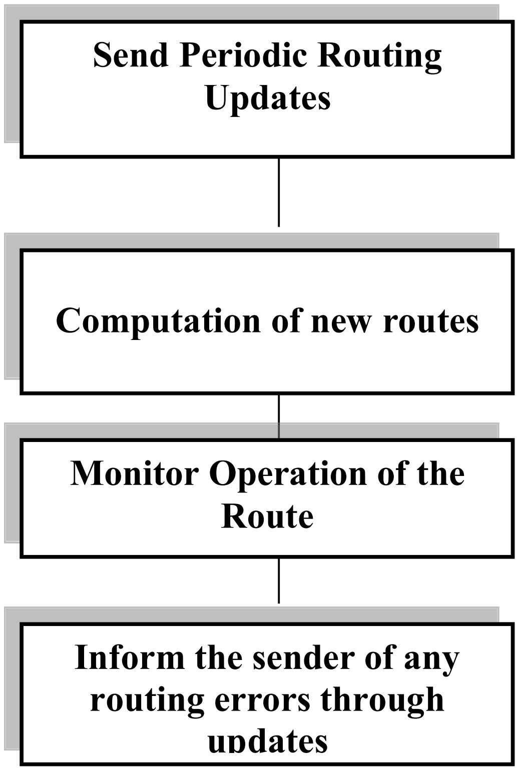

Figure (3) Structure of the Route Maintenance Process

4- OPTIMIZATION OF EED PROTOCOL PARAMETERS

4.1 Dealing with intermittent connected networks (ICN)

In the real world, in a physical ad hoc network, to assume that there is a contemporaneous end-to-end path between any source and destination may not be true and accurate. When nodes are moving in Mobile Ad-hoc Networks (MANETs), links can be obstructed by intervening objects. When the nodes need to conserve power, links are shut down periodically. These events result in what is called intermittent connectivity. Whenever there is not any path between source and destination, network partition could occur. As a result of the network partition, it is possible that two nodes may not be included in the same connected part of the network, this is called intermittently connected networks (ICN).

The networks referred to as delay/disruption tolerant networks (DTN) are applications of ICNs that can tolerate delays beyond traditional IP forwarding delays. Under the routing protocols similar to AODV and OLSR, the packets are usually dropped if they arrive and no permanent end-to-end path for their destination exists, as a result, these protocols do not work properly under DTNs' conditions.

To cope with intermittent connectivity, one natural approach is to extend the store-and-forward routing to store-carry-forward (SCF) routing. In store-carry-forward routing, a next hop may not be immediately available for the current node to forward the data. The node will need to buffer the data until the node gets an opportunity to forward the data and must be capable of buffering the data for a considerable duration.

In the proposed EED protocol, buffers were used to store packets temporarily when no route exists to the destination during nodes' mobility same as SCF scheme to eliminate packets' drops and avoid their losses. Packets are stored during a certain duration and the nodes attempt to send them another time if the route exists, otherwise, packets are dropped. Hence EED protocol reduces the possibility of packets' losses and therefore enhances the ad hoc network performance.

4.2 Dynamism in the propose EED protocol

This section describes the design and performance of EED routing protocol that uses *dynamic source routing* of packets between hosts that are engaging in communication. Source routing [10,14] depends on sending of a packet to determine the complete sequence of nodes through which to forward the packets to the destination ; the sender explicitly records this route in the packet's header, identifying each coming hop by the address of the next hop to which to transmit the packet on its way to the destination hop.

The proposed EED protocol is designed to be used in the wireless environment of an ad hoc network. The protocol does not provide periodic routing advertisements through the ad hoc network. A host can dynamically determine a route to another host when needed based on cached information and on the information obtained from a route discovery protocol.

EED protocol has some advantages in comparison with the traditional routing protocols in ad hoc networks. The first advantage is that this protocol reduces the network bandwidth overhead because it does not use periodic routing advertisement messages during periods of low host movement or when no significant change in host movement occurs. This results also in conserving battery power on the mobile hosts by not requiring hosts to send and receive advertisements and therefore the host can reduce its power usage by putting itself into "sleep" or "standby" mode when not doing any task. Another point is that there are no redundant paths in the wireless environment when using the proposed protocol because redundant paths lead to an increase in the size of routing updates that must be sent over the network, and this causes an increase in the CPU overhead required to process each update and to compute new routes. In addition EED protocol does not require hosts to work bidirectionally during transmission in normal conditions unless when afforded, unlike distance vector routing that always uses bidirectional transmission between hosts. A final remark is that traditional routing protocols are not designed to support the dynamic topology changes that may be present in ad hoc networks, while the proposed EED protocol adapts quickly to changes such as host movement without requiring routing protocol overhead during periods when no changes occur.

4.3 Energy efficiency during routing in the proposed EED

4.3.1 The basic energy parameters

To keep the network functioning as long as possible and not simply establishing efficient routes between adjacent nodes, mobile nodes' energy must be minimized not only during active communication but also when the nodes are inactive. Control of *Transmission power* and *load distribution* are two methods to minimize the consumed energy during active communication, and the alteration between a*sleep and power-down modes* is used to minimize energy during inactivity.

The most common energy-related metrics that are used to determine energy-efficient routing path are the following:

- Energy consumed/packet,
- Time to network partition,
- Variance in node power levels,
- Cost/packet, and
- Maximum node cost.

The first metric is important because it can provide the min-power path through which the overall energy consumed to deliver a packet is minimized. Each wireless link is marked by the link cost in terms of the amount of transmission energy over the link and the min-power path is the path that has the least sum of the link costs along the path.

The second metric is used to maximize the network lifetime, and this becomes an essential goal of an energy efficient routing algorithm and this can be achieved by giving an alternative routing paths, and selecting the path that will result in the longest network operation time.

Variance of residual battery energies of mobile nodes is an important metric because it may be used to extend the network lifetime since it is simply an indication of energy balance.

Cost-per-packet metric is similar to the energy-per-packet metric but there is a little difference between them that it includes each node's residual battery life besides the transmission energy. An energy-aware routing protocol will generally try the wireless link that uses low transmission energy, but at the same time, will avoid the node having a low residual energy whose cost is relatively high.

The last metric is used to mark each candidate path with the maximum node in terms of cost among the intermediate nodes, and also to select path with the minimum path cost, *min-max path.* This is called also *max-min path* in some protocols when we use the nodes' residual battery life rather than their node cost.

4.3.23 Eliminating nodes at the level of break

In wireless ad hoc networks consisting of battery-limited nodes, communication protocols must be energy-aware to prevent early network failure due to radios exhausting their energy supplies. Energy-preserving routing protocols for ad hoc networks have attracted increasing attention. Generally, including information about nodes battery levels into routing can help to preserve radios with little remaining energy. By using this way of routing we can preserve energy in critical radios, and thus delaying node failure and network partitioning. In the proposed EED protocol, the nodes below a certain level of remaining energy (critical level of energy) were eliminated to avoid network partitioning and transmission failure.

5 - SIMULATION AND EXPERIMENTAL RESULTS

5.1 Description of the simulation model

The proposed EED protocol is simulated within the GloMoSim library [23]. The GloMoSim library is a scalable simulation environment for wireless network systems using the parallel discrete-event simulation capability provided by PARSEC [24].

5.1.1 Movement model

We simulated a network of mobile nodes placed randomly within a 1000 × 1000 square meter. Our simulation network model consists of 30 nodes consecutively.
Each node has been chosen to have a radio propagation range of 250 meters and a channel capacity of 2 Mb/s. We used the IEEE 802.11 distributed coordination function (DCF) as the medium access control (MAC) protocol. Each simulation was executed for 150 seconds.

The nodes move according to the random waypoint mobility model. In the random waypoint model, each node x picks a random destination and speed in the rectangular area and then travels to the destination in a straight line. Once node x arrives at its destination, it pauses, picks another destination, and continues onward. We used a pause time of 30s so that each node is in constant motion throughout the simulation. All nodes communicate with identical wireless radios that are modeled using the commercially available 802.11-based WaveLan wireless radios, which have a bandwidth of 2 Mbps and a nominal transmission radius of 250 m.

TCP packet size was 1460 bytes, and the maximum window was eight packets. Unless otherwise noted, all of our simulation results are based on the average system performance the 30 given patterns. Each pattern, generated randomly, designates the initial placement and heading of each of the nodes over the simulated time. The speed of each node is uniformly distributed using the random waypoint.

5.1.2 Communication model

The goal of the simulation is to compare the performance of each routing protocol, we choose traffic sources to be constant bit rate (CBR) sources. When defining the parameters of the communication model, we used sending rates of 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1250, 1500 packets per second (pps), with networks containing 30 CBR sources, and packet sizes of 1460 bytes.

We fixed the number of CBR sources and varied the sending rate. Hence, for these simulations we chose to fix the sending rate per second, and used 30 different communication patterns corresponding to 30 sources.

All communication patterns were peer-to-peer, and connections were started at times uniformly distributed between 0 and 150 seconds. The communication patterns, taken in conjunction with the different sending rates, provide different scenario files for each maximum node movement.

5.2. Performance metrics

(i) Error Loss percentage
Is measured as the ratio between the data packets sent by the source and not received by the destination because they have been lost during transmission.

(ii) Power consumption
Is the average power consumed by the system, and is measured as the sum of the power consumed at each node at the radio channel over the total number of nodes.

(iii) Control overhead percentage
Is measured as the total number of routing control packets transmitted during the simulation time over the total number of packets including data packets.

(iv) End-to-end delay
Is the time between the reception of the last packet and the first packet?

The following sections presents the performance of various algorithms with respect to error loss percentage, power consumption, control overhead percentage and end-to-end delay. Effect of network parameters on the performance of the proposed EED protocol is thoroughly investigated. The results are discussed and analyzed.

5.3 Simulation results of the proposed protocol(EED)

Figure (4) shows the flow chart designed to compare between EED , DSR and AODV protocols

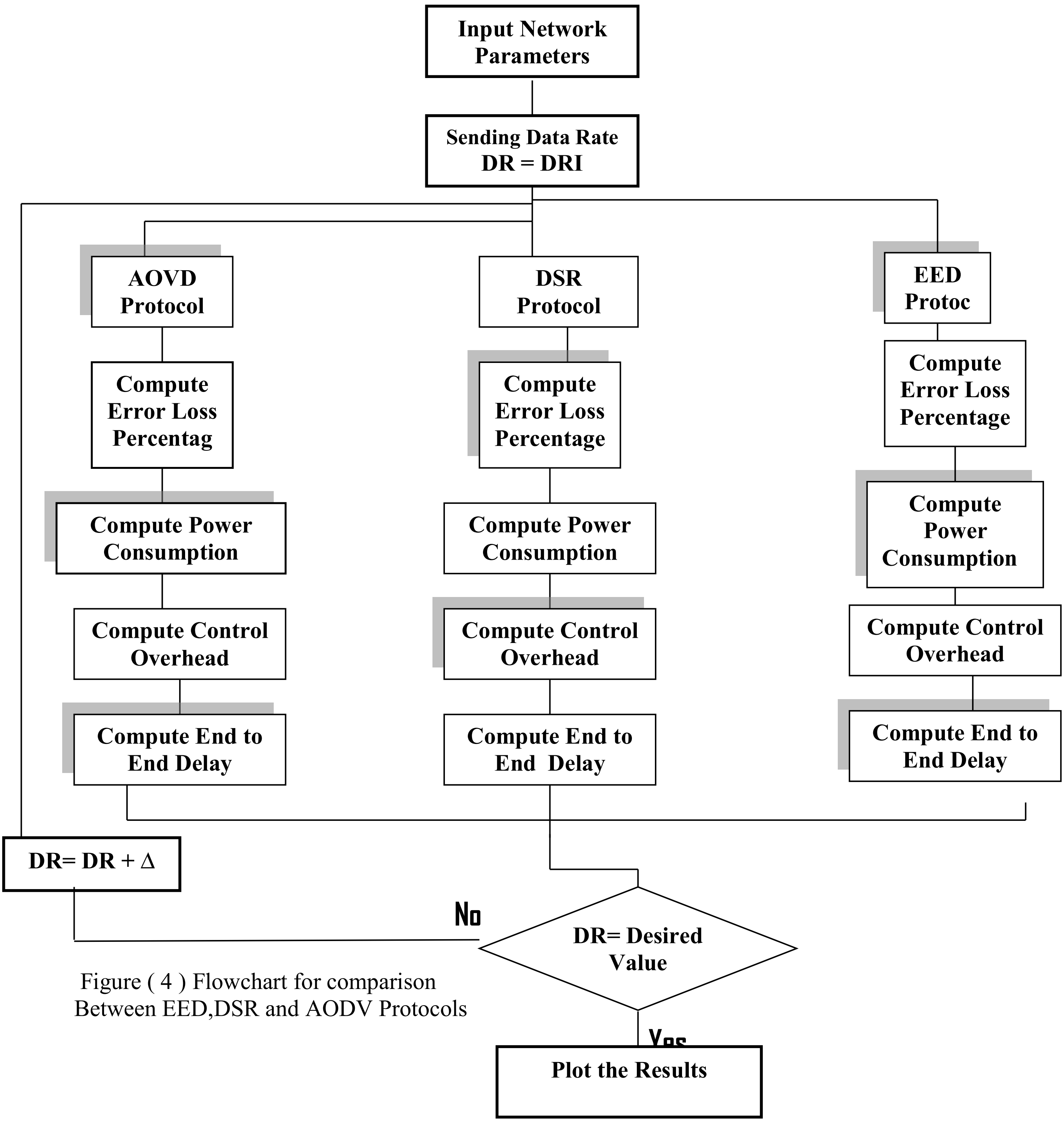

Figure (4) Flowchart for comparison Between EED,DSR and AODV Protocols

5.3.1 Comparison of EED with DSR and AODV protocols

(1) Error loss percentage

Error loss percentage is an important metric for comparing these protocols as it measures the ratio of the packets delivered and shows the system throughput.
It is clear from figure that the error loss (also called throughput) of DSR and EED are a little higher than that of AODV. But, the margin of the variation of error loss percentage is minimal, due to lower network partitions and lower network overheads in our algorithms. Nodes in the simulation move according to a model that we call the random way point model.

The movement scenario files used for each simulation are characterized by a pause time. Each node begins the simulation by remaining stationary for pause time seconds. Upon reaching the destination, the node pauses again for pause time seconds, selects another destination, and proceeds.

The simulation run with movement pattern generated with a constant pause time but with different sending rates. The error loss percentage of all protocols for random waypoint mobility using uniformly distributed speed is shown in Figure (5)

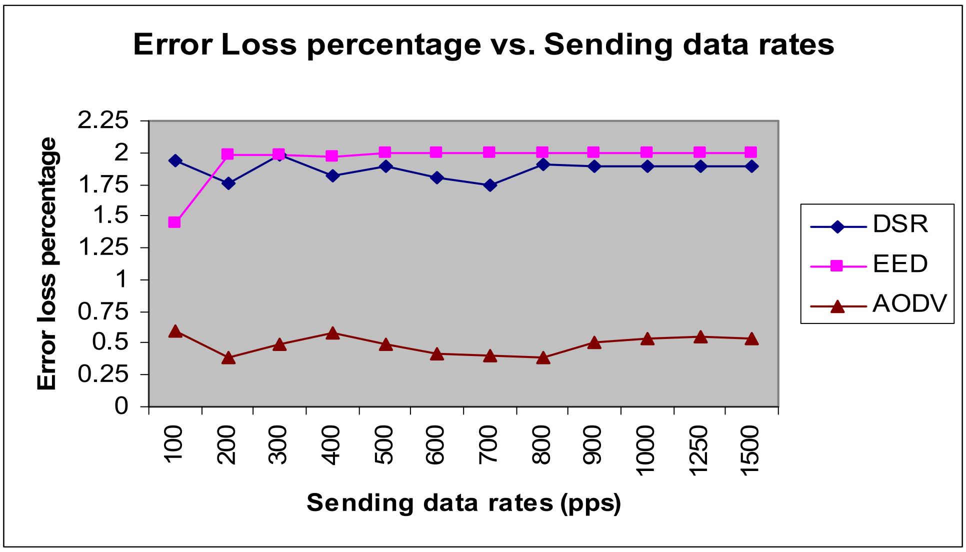

Figure (5)Error loss percentage vs. sending data rates

In order to see how the protocols change as the sending rate varies, we changed the sending rates as 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1250, and 1500 pps and took notice of the error rate at each sending rate.

From Figure (5) , all protocols deliver more than 98% of the packets at different sending rates. In terms of error loss percentage, AODV shows better performance but the difference between AODV and the other protocols is not very large. AODV error loss percentage is between 0.5% and 0.58% for sending rates between 100 and 1500 respectively.

While DSR error loss percentage values is near that of EED between 100 and 1500 sending rates. DSR error loss percentage values range between 1.9 and 1.6 at 100 to 1500 sending rates. While EED error loss percentage values range between 1.5 and 1.99 at 100 to 1500 sending rates.

(2) Power consumption

Figure (6) shows average power consumption vs sending data rate for :
EED, DSR, and AODV protocols

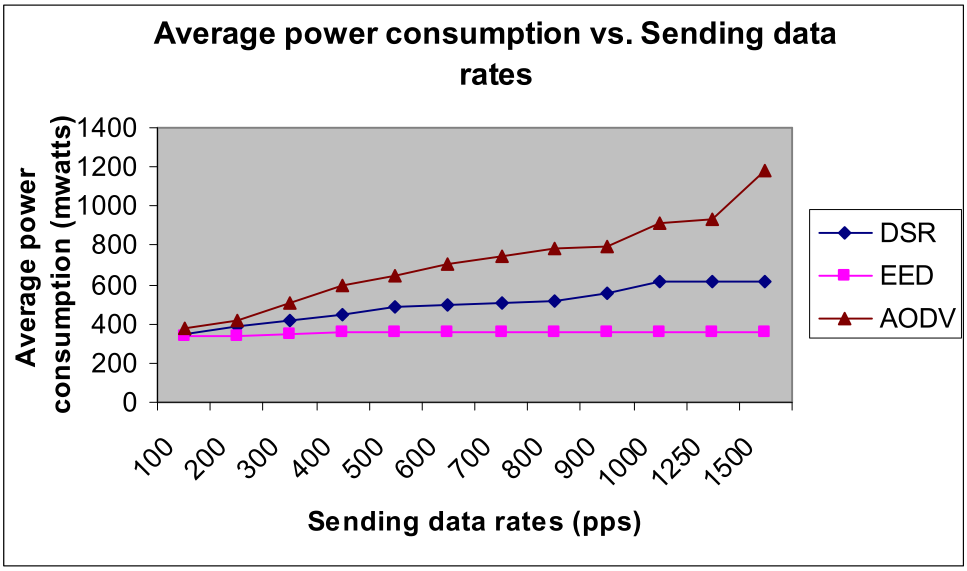

Figure (6) Average power consumption vs. sending data rates

It can be inferred from Figure (6) that the power consumption of EED is less than that of DSR and AODV with respect to varying sending rates, which shows that the proposed protocol EED is better than DSR and AODV in terms of power consumed.
Since battery power is a scare resource, we are trying to minimize power consumed during transmission.

From Figure (6) we notice that the power consumed of EED is below the levels of DSR and AODV. The power consumed when using the EED protocol ranges between 320 and 360 when increasing the sending rates from 100 to 1500. The power consumed when

using the DSR protocol ranges between 330 and 550 when the sending rates increases from 100 to 1500. The power consumption when using the AODV protocol ranges between 330 and 1180 when varying the sending rates from 100 to 1500.
A final remark is that the three protocols at the start when the sending rate is 100, show approximately the same power consumption rate.

(3) Control overhead percentage

Routing protocol overhead is an important metric because it is used to compare these protocols by measuring the scalability of a protocol in congested or low-bandwidth environments and its efficiency in terms of the amount consumed of the node battery power.
In general, the protocols that depend on sending a large number of routing packets can also increase the probability of packets collision and data packets delays in network interface transmission queues.
Figure (7) shows the differences in overhead control between the three protocols is small. Among all, DSR algorithm generates lesser slightly overhead compared to OADV and EED.

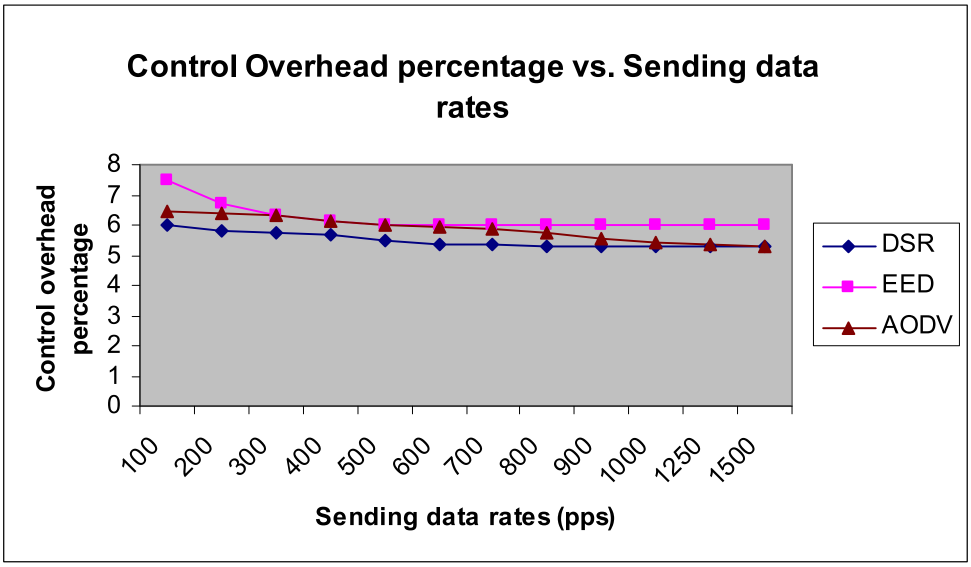

Figure (7) Control overhead percentage vs. sending data rates

In general, at the highest mobility, more control packets are needed to acquire routes, thereby increasing the overheads. So, when the overhead does not increase too much from 100 to 1500 sending rates means that the mobility does not change too much.
From Figure 8, we noticed that the control overhead of EED ranges from 7.5 and 6 when varying the sending rates from 100 to 1500. The control overhead of DSR ranges between 6.1 and 5.7 when varying the sending rates from 100 and 1500. While, the

control overhead of OADV ranges between 6.3 and 5.8 when varying the sending rates from 100 and 1500.

(4) End-to-end delay

Figure (8) shows End to End delay vs sending data rate for :
EED, DSR, and AODV protocols

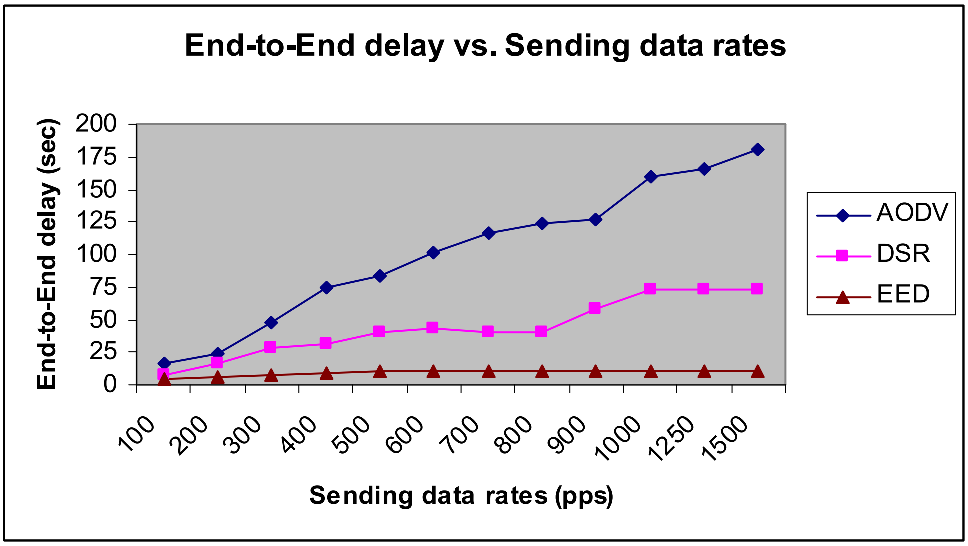

Figure (8) End to End delay vs. sending data rates

The average end-to-end delay performance of the proposed protocol EED is better than that of DSR and AODV. We noticed that the end-to-end delay for any one of the three protocols over an ascending sending rate does not change too much, but changes from one protocol to another. So, when the sending rate is 100 and becomes 1500 for any of the three protocols, the end-to-end delay is changed but the end-to-end delay performance of the proposed protocol EED is better where end to end delay of EED is much smaller than that of DSR and AODV .

5.3.2 Effect of packet size on performance of EED protocol

Figure (9) shows the flow chart designed to study the effect of packet size on the performance of EED protocol

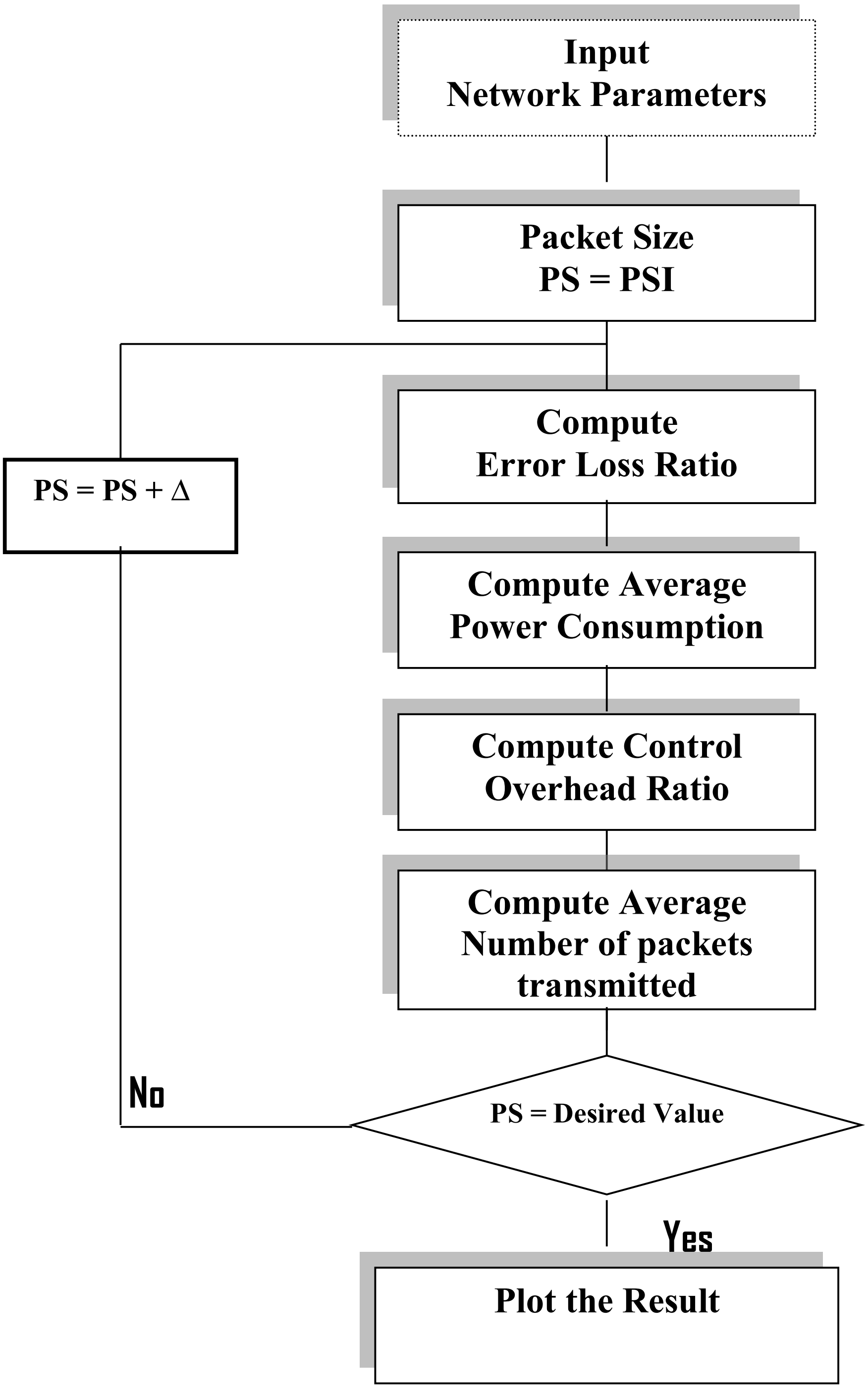

Figure (9) Flow chart designed to study the effect of packet size on the performance of EED protocol

(1) Error loss ratio

Figure (10) shows Error loss ratio vs sending data rates for different packet sizes (1000 , 1200, 1400 , 1600 bytes)

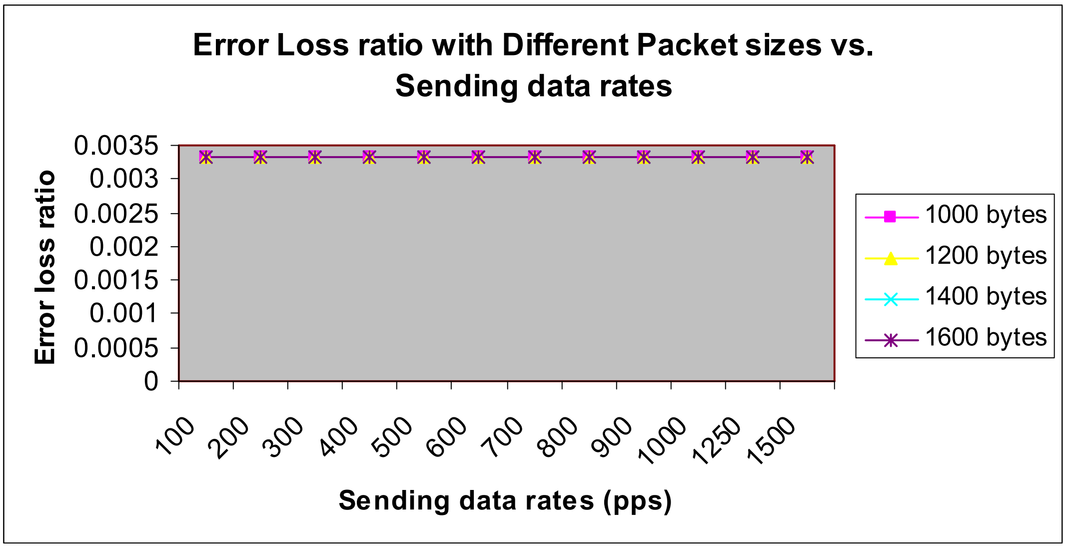

Figure (10) Error loss ratio vs sending data rates

From Figure (10) we notice that increasing packet size in the range 1000 bytes to 1600 bytes does not increase appreciably the error loss ratio for EED protocol.

(2) Power consumption

Figure (11) shows average power consumption vs sending data rate for different packet sizes (1000, 1200, 1400, 1600 bytes)

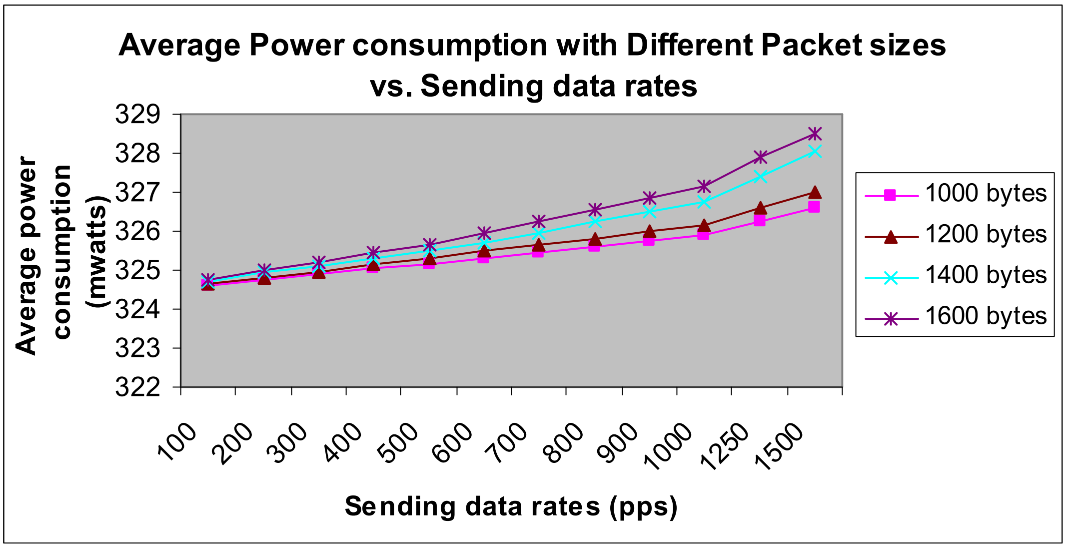

Figure (11) Average power consumption vs sending data rates

It can be inferred from Figure (11) that the power consumption of EED is increased when packet size is increased, the highest increase in power consumption when changing packet size from 1000 bytes to 1600 bytes does not exceed 1% .

(3) Control overhead ratio

Figure (12) shows control overhead ratio vs sending data rate for different packet sizes (1000, 1200, 1400, 1600 bytes)

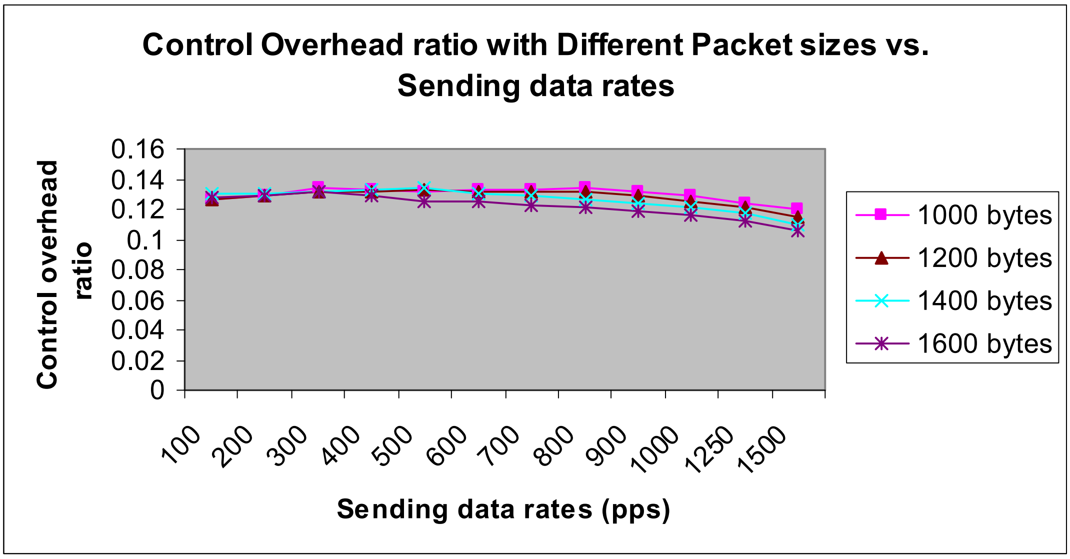

Figure (12) Control overhead ratio vs sending data rates

From Figure (12) we notice that increasing packet size between 1000 bytes to 1600 bytes does not increase appreciably the error loss ratio for EED protocol.

(4) Average number of packets transmitted

Figure (13) shows average number of packets transmitted vs sending data rate for different packet sizes (1000, 1200, 1400, 1600 bytes)

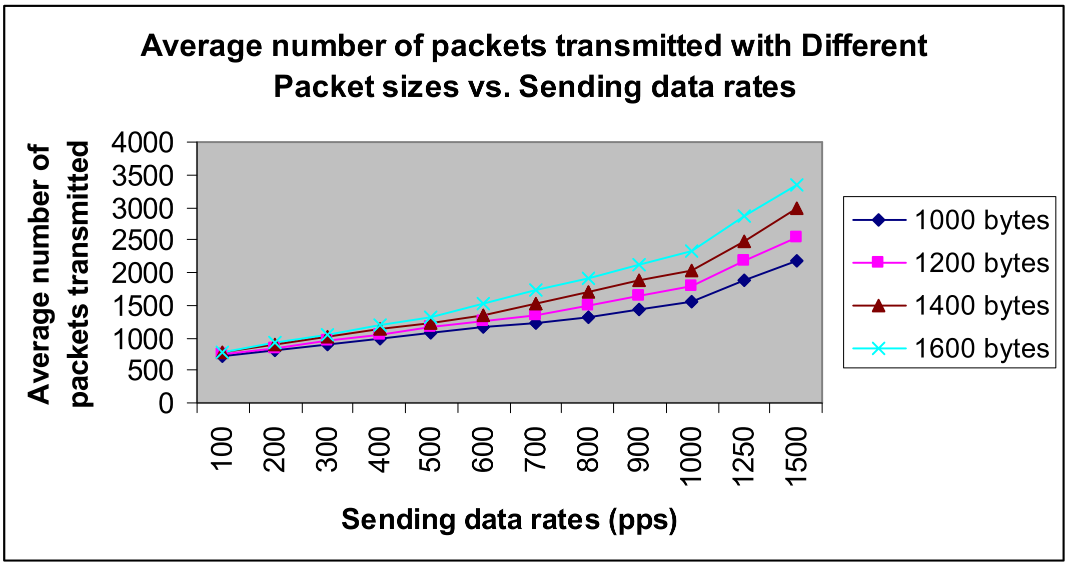

Figure (13) Average number of packets transmitted vs sending data rates

It is shown from Figure (13) that the average number of packets transmitted for EED protocol is increased when packet size is increased, the highest increase in average number of packets transmitted when changing packet size from 1000 bytes to 1600 bytes reach about 25 % .

From the above analysis it is clear that the EED protocol is robust to changes in packet sizes.

5.3.3 Effect of Bandwidth on performance of EED protocol

Figure (14) shows the flow chart designed to study the effect of bandwidth on the performance of EED protocol

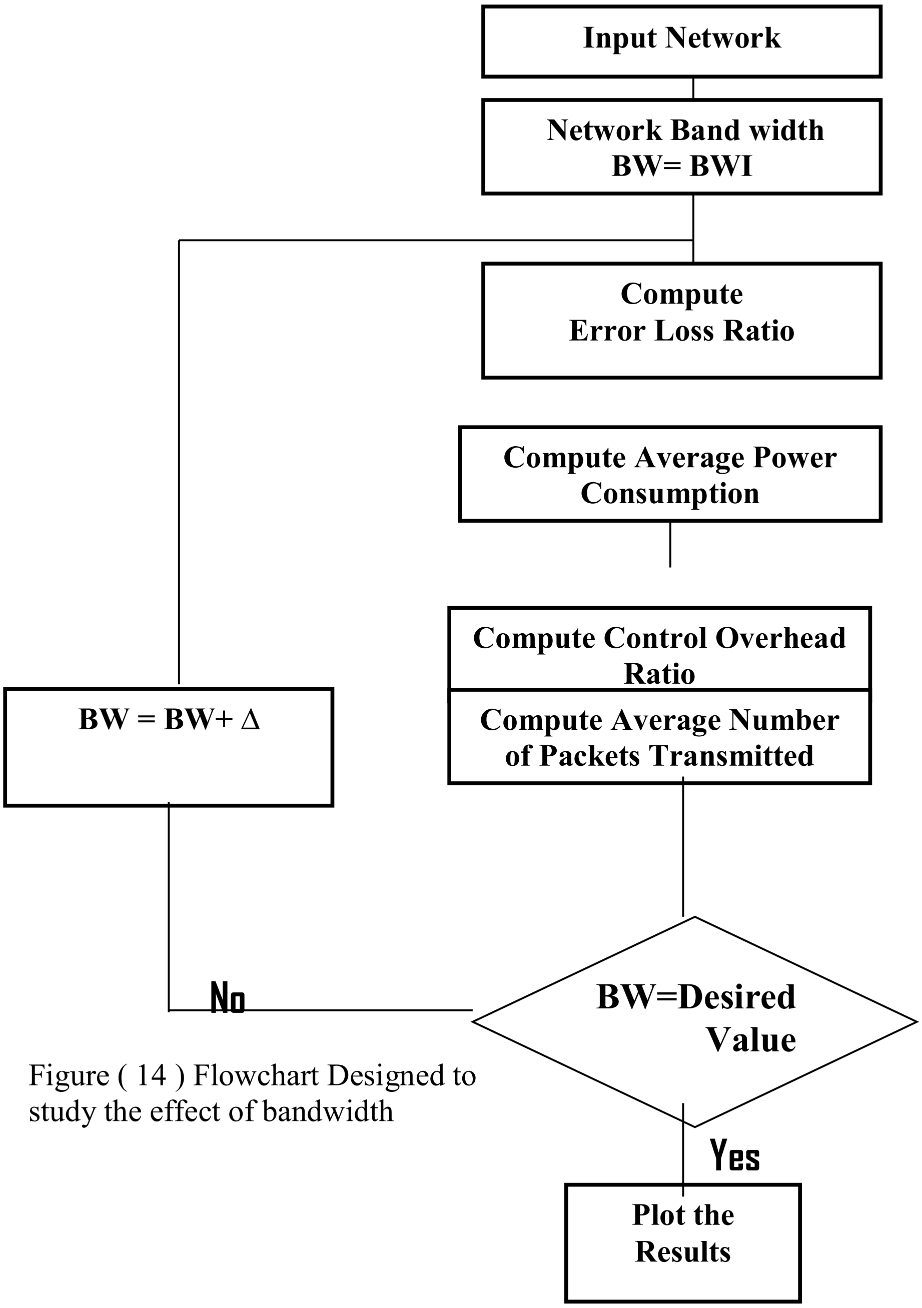

Figure (14) Flowchart Designed to study the effect of bandwidth

(1) Error loss ratio

Figure (15) shows Error loss ratio vs sending data rate for different network bandwidths (1, 2, 3, 4 Mbytes)

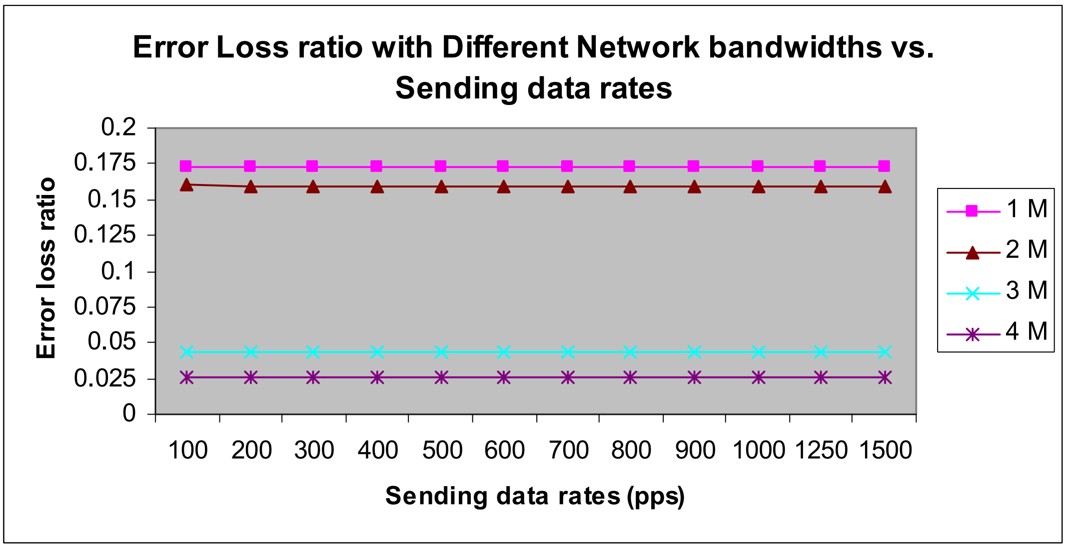

Figure (15) Error loss ratio vs sending data rates

From Figure (15) we notice that increasing bandwidth reduce greatly the error loss ratio .It is seen from the figure that changing bandwidth from 1 Mbyte to 4 Mbyte reduces the error loss ratio of about 7:1.

(2) Average power consumption

Figure (16) shows Error loss ratio vs sending data rate for different network bandwidths (1, 2, 3, 4 Mbytes)

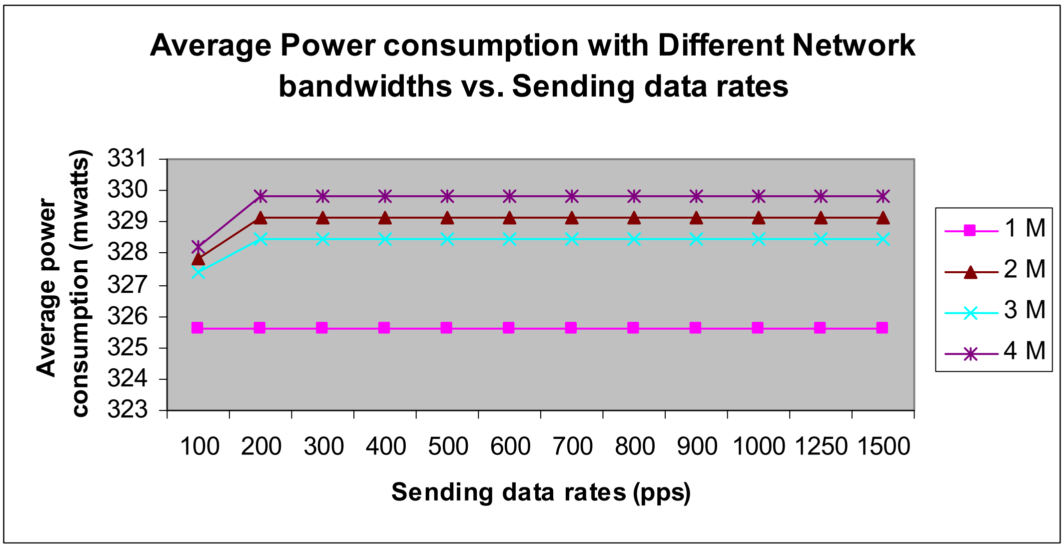

Figure (16) Average power consumption vs sending data rates

From Figure (16) we notice that increasing bandwidth in the range 1Mbytes to 4 Mbytes does not increase appreciably average power consumption for EED protocol, where maximum change in power consumption does not exceed 1.5 %

(3) Control overhead ratio

Figure (17) shows Control overhead ratio vs sending data rate for different network bandwidths (1, 2, 3, 4 Mbytes)

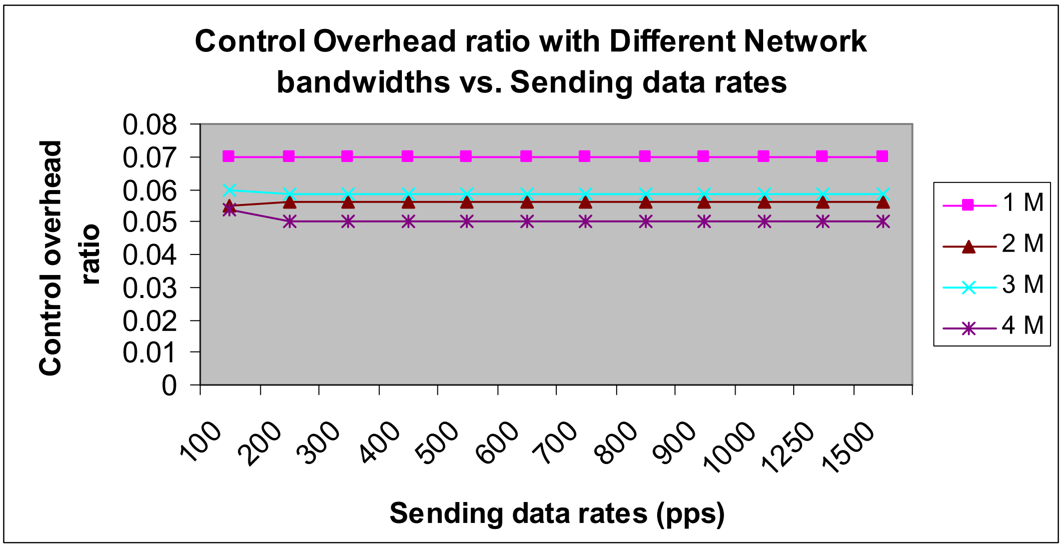

Figure (17) Control overhead ratio vs sending data rates

From Figure (17) we notice that increasing bandwidth reduce greatly the control overhead for EED protocol; where it is seen from the figure that changing bandwidth from 1 Mbyte to 4 Mbyte reduces the control overhead by more than 30 %

(4) Average number of packets transmitted

Figure (18) shows Average number of packets transmitted vs sending data rate for different network bandwidths (1, 2, 3, 4 Mbytes)

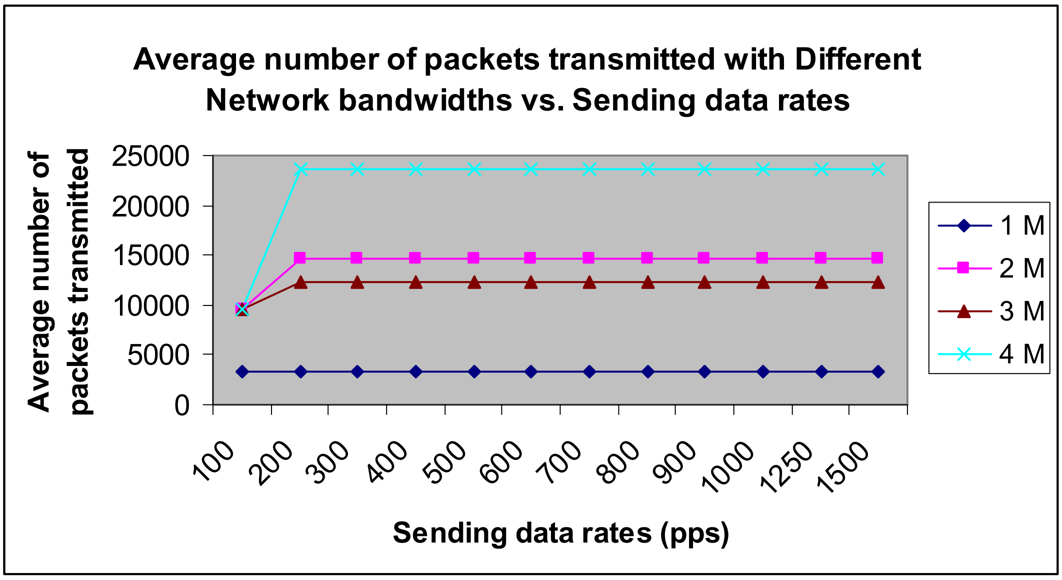

Figure (18) Average number of packets transmitted vs sending data rates

It is shown from Figure (18) that the average number of packets transmitted for EED protocol is increased greatly when bandwidth is increased, the highest increase in average number of packets transmitted when changing bandwidth from 1Mbytes to 4 M bytes is about five times.

From the above analysis it is clear that the performance of EED protocol is improved when bandwidth is increased

6 - <u>CONCLUSION</u>

In this paper, a dynamic routing protocol for routing in ad hoc networks is proposed. The protocol is dynamic in the manner that it can adapt quickly to the changes in the network structure caused by the frequent nodes motion while minimizing the overhead at the same time. The proposed protocol is energy-efficient because it takes into consideration the nodes' energy, the transmission path length as well as the energy level of the transmission path so as to minimize the energy consumed during the transmission of packets. The proposed protocol showed good results compared to other protocols concerning error loss rate, power consumption as well as end to end delay, besides the proposed EED protocol is robust to changes in packet sizes and its performance EED is improved when bandwidth is increased.

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