Energy Adaptable Distance Aware Routing Protocol for Multicast Wireless ad hoc Networks

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ABSTRACT

An ad hoc network is a dynamically reconfigurable 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. Due to the presence of high node movements and fast network topology changes, routing protocols in wireless multicast ad hoc networks face several challenges during data delivery to destination hosts through multihop routes. This paper presents an Energy Adaptable Distance Aware Routing Protocol (EADARP) for wireless mobile ad hoc networks. EADARP is the multicast version of the proposed unicast protocol called Energy Efficient Dynamic EED[1] routing protocol, with some enhancements done. EADARP selects the most efficient path in terms of distance and energy and performs adjustments of nodes batteries power levels when required, it also increases the network bandwidth when there is a congestion in traffic and decreases it when there is no traffic.

EADARP is an on-demand mesh-based multicast protocol that dynamically builds routes and maintains multicast group membership using the forwarding group idea. EADARP is suitable for ad hoc wireless networks having mobile hosts with high channel capacity, frequent topology changes and constrained power. The proposed protocol is applied to different case studies to compare its performance with other multicast protocols in ad hoc networks and the results of the detailed simulations are discussed and analyzed in depth. It has been proved that EADARP shows similar performance to other protocols in some parameters, and shows better performance when comparing other parameters such as the number of TTL expired and number of unreachable nodes.

1. INTRODUCTION

Wireless communications has two types; fixed or mobile. The fixed wireless communication is often called cellular networks, in which communication is achieved through a fixed number of base stations whose locations are known. 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. Sharing the wireless cellular communication system capacity among multiple users is accomplished through various access methods, such as time division multiple access (TDMA), frequency division multiple access (FDMA) and code division multiple access (CDMA) [1- 4].

Mobile wireless communication; also called mobile ad hoc networks; does not have a fixed infrastructure or centralized administration. Each host in the mobile ad hoc network communicates with the other hosts via packet radios to form a temporary network its infrastructure varies according to the hosts' mobility.

The way of routing information in ad hoc networks is divided into two parts: *route discovery* and *route maintenance*. In route discovery, a host that wants to send information to another host must discover initially a suitable route for transmitting packets to the destination host. In route maintenance, the route should continue to send packets to the destination if the conditions remained unchanged. Otherwise, if the status of the links or hosts used in this route changed, some changes may be done to the route or there is a need to discover a new route [4-6].

Wireless ad hoc networks have several different applications ranging from military applications such as: battlefield communications, law enforcement, disaster recovery, emergency search and rescue and lately to civilian applications such as; electronic classrooms, convention centers, construction sites, and special events. But wireless ad hoc networks have some limitations due to the need of the mobile hosts to communicate with each other over its shared and limited radio channel. So because of the characteristics of the ad hoc networks impose some constraints; building such networks poses a significant technical challenge.

The most important constraint is that the nodes operated by batteries are scare power resources, this requires the routes in the ad hoc network to be "multihop" to adapt to the limited radio propagation range of wireless devices. In addition; it is necessary at the same time to take care of conserving the energy. To increase the size of the ad hoc network, it is important to find solutions to either increase the battery power or to optimize the use of the battery power via the implementation of energy-efficient algorithms and mechanisms.

The objectives of the applications determine if a communication session should be unicast (one-to-one), multicast (one-to-many), broadcast (one-to-all) or group communication (many-to-many). The rise in the number of mobile users has led to a wide variety of applications to become available. Some of these new applications depend on multicast communication to perform their operation.

Multipoint communications [2] is one of the most important areas in the field of networking. Since new technologies have been introduced to the Internet, new applications that support multicasting, such as video conferencing, have became widely used. Multicasting has been implemented to the wireless ad hoc networks to make benefit from the dynamically reconfigurable nature of these wireless ad hoc networks [7-9].

Multicast ad hoc networks are more complex than cellular wireless networks where all mobiles in a cell can be reached in a single hop, not like multicast mobile ad hoc networks where routes are "multihop". Multicast ad hoc networks are semantically identical to wired networks, but have a number of different characteristics and constraints such as: limited power, limited bandwidth, and high error rates. Multicast has an important role to play in a typical multihop adhoc networks because it is required in applications where there is a need for the network hosts to collaborate to carry out a given task. A multicast protocol implemented in an ad hoc network should have the ability to connect all group members and then to maintain this connectivity after topological changes in the network [10-16].

Multicast ad hoc networks is the focus in this paper. Since multicast mobile ad hoc networks face the same constraints previously mentioned as unicast ad hoc networks, the efficient utilization of routing packets and energy efficiency must be taken into consideration when routing packets and recovering route breaks in multicast ad hoc networks. Some papers have considered minimum energy multicast routing in wireless multihop ad hoc networks, and for this purpose, a concept such as virtual relay [17-20] have been proposed. Also, several algorithms for energy efficient multicasting in static wireless ad hoc networks has been presented [21,22]. Energy efficient adaptation of multicast protocols in power controlled wireless ad hoc networks is the basic idea presented in [21].

Also, as another topic in multicasting, some papers discussed achieving maximum multicast throughput in undirected networks having duplex communication links in details. A natural linear programming formulation of the maximum multicast rate problem was presented [23] by applying Lagrangian relaxation on the primal and the dual linear programs (LPs), for the purpose of deriving a necessary and sufficient conditions characterizing multicast rate feasibility, and an efficient and distributed subgradient algorithm for computing the maximum multicast rate [24-26].

The proposed protocol EADARP is similar to ODMRP, a mesh-based protocol that employs the same concept of forwarding group, but here, the forwarding group is a set of nodes responsible for forwarding multicast data on the paths selected based on the most efficient path in terms of distance and energy between any member pairs with two enhancements added: first, the network bandwidth is increased according to the need, second, the nodes' level of energy is adjusted if there is a must.

The remainder of this paper is organized as follows. Section 2 describes different types of multicast ad hoc networks protocols. Section 3 describes the detailed operation of the proposed technique (EADARP). Section 4 describes the simulation environment. While in Section 5 simulation and experimental results of the proposed protocol (EADARP) are described and compared with the results of the known tree-based ADMR, mesh-based ODMRP and FLOODING techniques. Finally, Section 6 gives conclusion for the paper.

2. MULTICAST AD-HOC NETWORKS PROTOCOLS

This section gives brief survey of the most commonly used multicast ad hoc networking protocols. Multicast protocols are divided according to their network structure and formation to three main types; Tree-based multicast protocols, Mesh-based multicast protocols and Overlay multicast protocols.

2.1. Tree-based multicast protocols

The basic idea of tree-based multicast protocols is to build a tree over which multicast data is forwarded. Tree-based protocols are bandwidth-efficient but do not always provide sufficient robustness. Robustness and reliability are key features of MANETs, to make them well-suited for critical environments such as fast deployment (e.g., battlefield or disaster recovery).

The most commonly tree-based multicast ad hoc networking protocols are discussed as follows; The Reservation-Based Multicast (RBM) routing protocol [4] which builds a core based tree whose core is acting as a rendezvous point for each multicast group. RBM is a combination of several principles, including multicast, resource reservation, and admission control protocol where users specify requirements and constraints.

The Ad hoc Multicast Routing protocol utilizing Increasing id-numbers (AMRIS) [7] builds a shared-tree for the objective of delivering multicast data. Each node in the multicast session is assigned an ID number that is being used by the node to adapt to connectivity changes in the network.

The Lightweight Adaptive Multicast (LAM) protocol is based on a group shared tree principle, and it does not require timer-based messaging. Similar to other tree-based protocols, it suffers from some disadvantages such as: traffic concentration and vulnerability of the core.

The Ad hoc Multicast Routing Protocol (AMRoute) [4] is considered as an overlay protocol that makes use of the shared-tree concept which is based on the idea of allowing dynamic core migration based on group membership and network configuration. Also, AMRoute can be treated as a tree-based protocol.

A multicast extension of Ad hoc On-demand Distance Vector (AODV) routing protocol has been presented in [24]. Its uniqueness stems from using a destination sequence number for each multicast entry. The sequence number is generated by the multicast group head for the purpose of preventing loops and discarding stale routes. The multicast ad hoc on-demand distance vector (MOADV) routing protocol is a tree-based multicast ad hoc protocol. Some studies [23] have been done on transmission range effects on AODV multicast communication, because AODV uses broadcast to transmit multicast data packets between nodes, thus the transmission range plays an important role in determining the performance of AODV. The Adaptive Demand-Driven Multicast Routing (ADMR) [18] is also a multicast tree-based protocol that has the same principles and constraints provided by the tree-based protocols.

Tree-based Multicast protocols used in static networks such as: Distance Vector Multicast Routing Protocol (DVMRP) [9], Multicast Open Shortest Path First (MOSPF), Core Based Trees (CBT), and Protocol Independent Multicast (PIM) [2,3], do not exhibit good performance in wireless ad hoc networks because these protocols have structures that are fragile and must be readjusted continuously as connectivity changes.

2.2. Mesh-based multicast protocols

To overcome the limitations of the tree-based protocols, mesh-based multicast ad hoc protocols have been proposed. Thus, one of the main challenges for multicast routing in MANETs is the need to achieve robustness in the presence of universal mobility and frequent node outages. The basic idea of the multicast mesh protocols is to build a mesh for forwarding multicast data and thus address robustness and reliability requirements with path redundancy inherent to meshes.

ODMRP [3,4] is a mesh-based multicast protocol that provides richer connectivity among multicast members. By building a mesh and supplying multiple routes, multicast packets can be delivered to destinations in the face of node movements and topology changes. In addition, the drawbacks of multicast trees in mobile wireless networks are avoided. To establish a mesh for each multicast group, ODMRP uses the concept of forwarding group [3]. The forwarding group is a set of nodes responsible for forwarding multicast data on shortest paths between any member pairs. ODMRP has been tested in details [30,31], and proved to have good performance under different conditions in comparison with other protocols and to be well suited for ad hoc wireless networks with mobile hosts where bandwidth is limited, topology changes frequently and power is constrained.

Similar to ODMRP, the Core-Assisted Mesh Protocol (CAMP) [26] uses a mesh. However, a conventional routing infrastructure based on enhanced distance vector algorithm (e.g., Wireless Routing Protocol (WRP) [27]) or link state algorithm (e.g., Adaptive Link-State Protocol (ALP)

[28] or Source Tree Adaptive Routing (STAR) [29]) is required for CAMP to operate. Core nodes are used to limit the traffic required when a node joins a multicast group.

Several studies [17-19] have been done on FLOODING. FLOODING is a mesh-based protocol that requires sending copies of the packets to be sent to all the receivers sharing the same network, thus resulting in a high control overhead during packets' transmission inside the network.

2.3. Overlay multicast protocols

Overlay multicast [32-34] has been proposed as an alternative approach for providing multicast services in the Internet. The basic idea of the overlay multicat protocols is that a virtual topology can be built to form an overlay network on top of the physical Internet. Each link in the virtual topology is a unicast tunnel in the physical network. The IP layer provides a best-effort unicast datagram service, while the overlay network implements all the multicast functionalities such as dynamic membership maintenance, packet duplication and multicast routing. When the overlay multicasting technique is applied to the MANETs, the manner in which the overlay layer interacts with the physical network is quite different from that of overlay multicasting in the Internet. In MANETs, each node acts as a router as well as an end host. In most cases, we can assume the bandwidth homogeneity among the nodes in a MANET topology. Whereas in the Internet topology, there is a significant difference in available bandwidth at the end hosts and the routers. Forwarding and duplicating packets at the bandwidth limited end-hosts are inherently less efficient than at the routers. Thus, there is a major efficiency problem in overlay multicasting in the Internet, compared to the network layer multicast. However, this problem does not exist for overlay multicasting in MANET.

AMRoute [35,36] is the first overlay multicast protocol proposed for MANETs. The protocol has two components: the mesh construction procedure and the multicast tree maintenance procedure. It uses a broadcast-based procedure to build the unicast tunnels for the virtual mesh. During the mesh construction process, a logical core node is elected for the entire mesh. Then, the core node periodically disseminates control packets within the virtual mesh to build a shared multicast tree. The data packets flow along the shared tree for delivery. Though the physical network poses dynamic topology, the virtual mesh remains unchanged once built. Using this overlay method, AMRoute does not need any support from the non-member nodes, i.e., all multicast functionality and state information are maintained within the group member nodes. Other advantages are simplicity and flexibility. The protocol does not need to track the network mobility since it is totally handled by the underlying unicast protocols.

Several other overlay multicast methods are proposed for MANETs, aiming at improving the efficiency and reduce the latency of overlay multicast. They include the Location-Guided Tree Method (LGT) [37] and Prioritized Overlay Multicast (POM) [38]. Overlay multicast protocols over dynamic virtual mesh environments has been discussed in [39], and a new protocol PAST_DM has been proposed.

3. EADARP DESCRIPTION

The proposed protocol EADARP is similar to ODMRP, a mesh-based protocol that employs the same concept of forwarding group, but here, the forwarding group is a set of nodes responsible for forwarding multicast data on the paths selected based on the most efficient path in terms of distance and energy between any member pairs with two enhancements added: first, the network bandwidth is increased according to the need, second, the nodes' level of energy is adjusted if there is a must. Figure (1) shows the main components of the proposed EADARP protocol

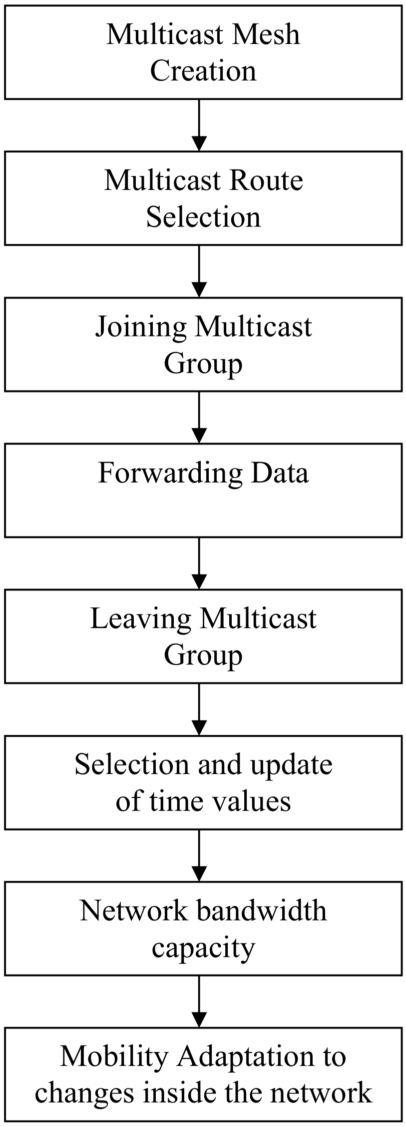

Figure 1: Main Components of EADARP protocol

3.1. Multicast mesh creation

Group membership and multicast routes are established and updated by the source "on demand", a request phase and a reply phase comprise the protocol as shown in figure 2, while a multicast source has packets to send, it floods a member advertising packet with data payload piggybacked. This packet, called JOIN QUERY, is periodically broadcasted to the entire network to refresh the membership information and update the routes as follows:

1) A node receives a non-duplicate JOIN QUERY, it stores the upstream node ID (i.e., backward learning) into the routing table and rebroadcasts the packet.
2) The JOIN QUERY packet reaches a multicast receiver, the receiver creates and broadcasts a JOIN REPLY to its neighbors.
3) A node receives a JOIN REPLY, it checks if the next node ID of one of the entries matches its own ID. If it does, the node realizes that it is on the path to the source and thus is part of the forwarding group. It then sets the Forwarding Group Flag and broadcasts its own JOIN REPLY built upon matched entries.
4) The JOIN REPLY is thus propagated by each forwarding group member until it reaches the multicast source via the route selection method

The forwarding group is a set of nodes which is in charge of forwarding multicast packets. It supports the most efficient path in terms of distance and energy between any member nodes as shown in figure 3.

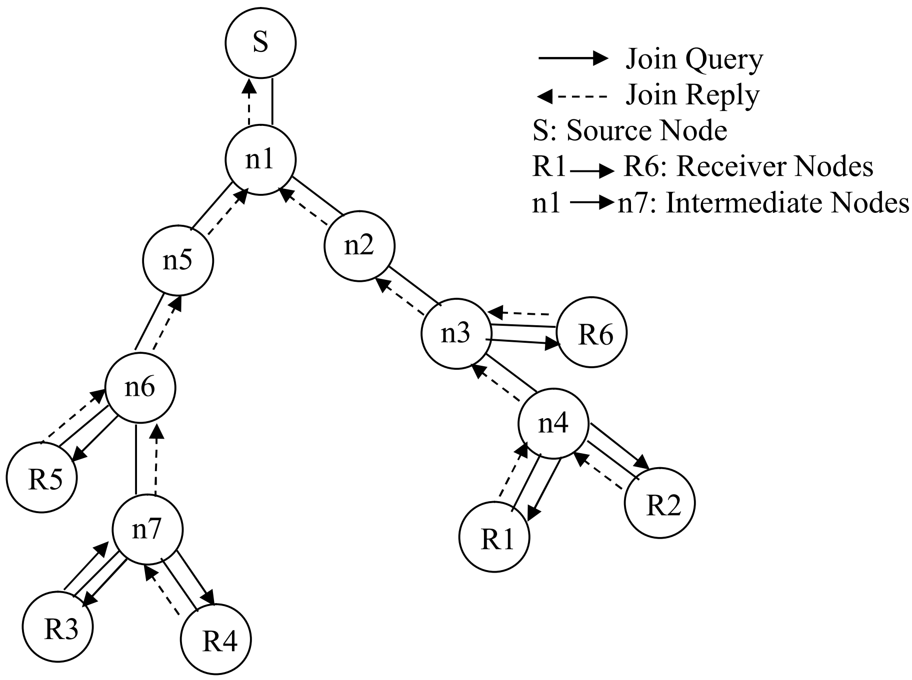

Figure 2: On-demand procedure for membership and maintenance

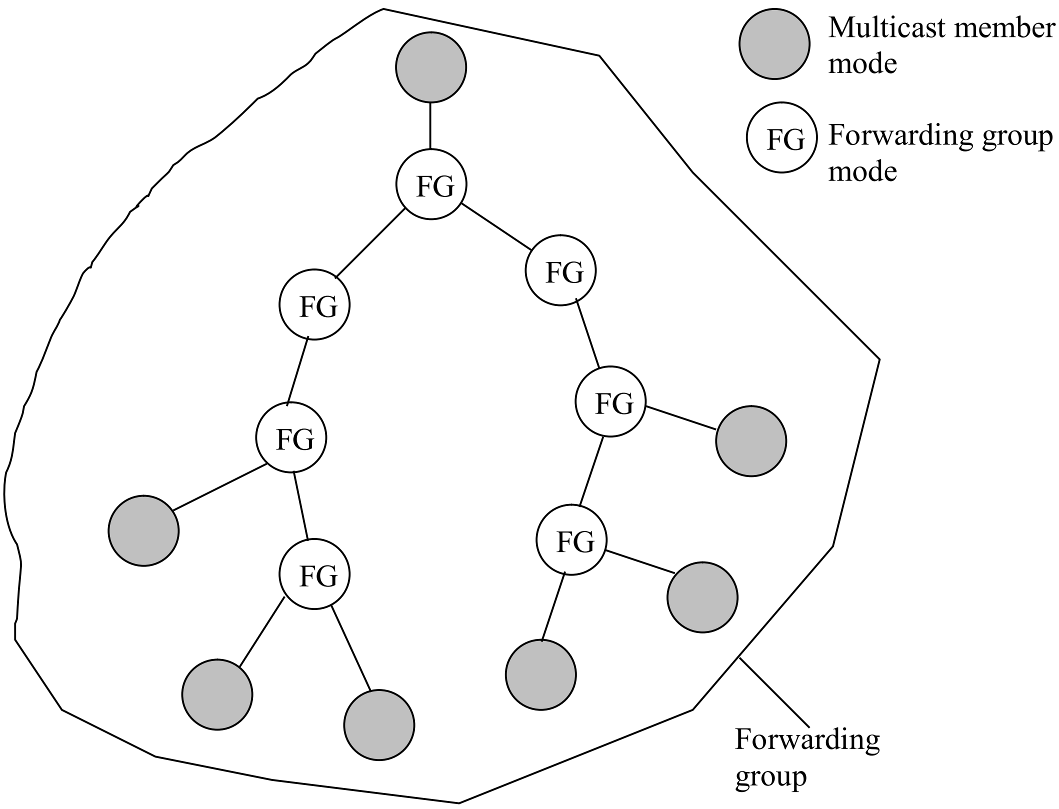

Figure 3: The forwarding group concept

3.2. Multicast Route Selection

In EADARP route selection, a multicast receiver selects the most stable route having the largest remaining energy, in other words, selecting the route with the highest lifetime. Finding the route having the highest lifetime is done by measuring each route's nodes lifetimes, and choosing the node with the least lifetime in each route, and then selecting the route having the node with the highest lifetime among the least energy remaining nodes. Then eliminating the nodes having energy below the level required (energy threshold level) in the selected route, for the purpose of avoiding route breakage if these nodes fail. But the eliminated nodes do not include neither the source node nor the destination node, to preserve the original route. After that, some nodes are eliminated between the source node and the destination node to make the selected route shorter, in other terms, reducing the path length leads to decreasing the power consumption during the transmission. Then, EADARP performs adjustments of nodes batteries power levels when required, and also it increases the network bandwidth when there is a congestion in traffic and decreases it when there is no traffic.

To select a route, a multicast receiver must wait for an appropriate amount of time after receiving the first JOIN QUERY so that all possible routes and their lifetimes will be known. The receiver then chooses the most stable route and broadcasts a JOIN REPLY.

An example showing the difference between two route selection algorithms is presented in figure 4. Two routes are available from the source *S* to the receiver *R*. Route 1 has the path of (*S*–*A*–*B*–C–D–*R*) and route 2 has the path of (*S*–E–F–G–H–*R*). The receiver will select the route with the maximum lifetime, and hence route 2 is chosen. Suppose that the energy threshold level is 2.5, then node E from route 2 is eliminated as in figure 5, and then node F could be eliminated based on nodes' positions, because it makes the route longer, and the energy consumed during transmission higher.

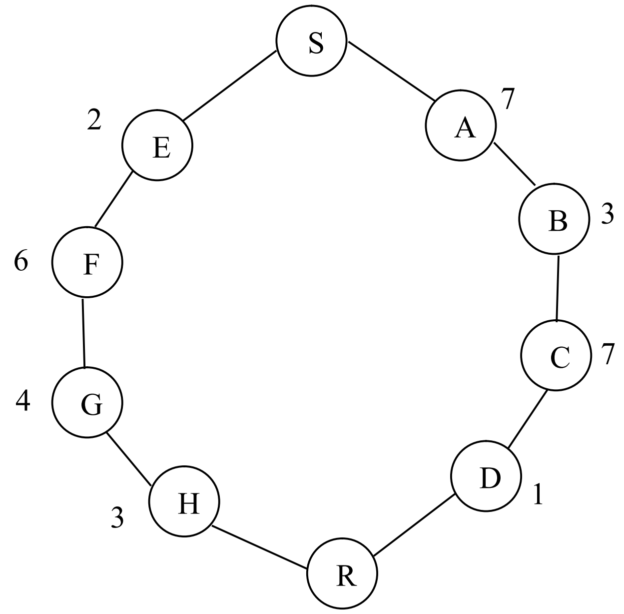

Figure 4: Route selection method

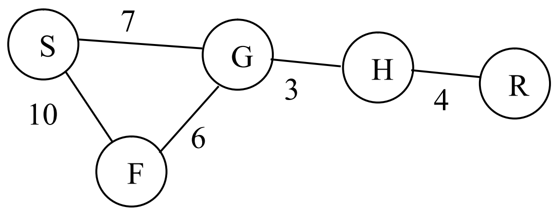

Figure 5: Route figure after eliminating node E

3.3. Joining a Multicast Group

In EADARP, the transmissions of JOIN REPLY are often broadcasted to more than one upstream neighbors since we are handling multiple sources. Another option for reliable delivery is to subdivide the JOIN REPLY into separate sub-tables, one for each distinct next node.

These JOIN REPLIES are separately unicasted. Since the number of neighbors is generally limited (typically, about six neighbors is the optimum in a multihop network), the scheme still scales well to large number of sources. Figure 6 illustrates this mechanism. When node *B* transmits a packet to node *C* after receiving a packet from node *A*, node *A* can hear the transmission of node *B* if it is within *B*'s radio propagation range. Hence, the packet transmission by node *B* to node *C* is used as a "passive acknowledgment" to node *A*. We can utilize this passive acknowledgment to verify the delivery of a JOIN REPLY.

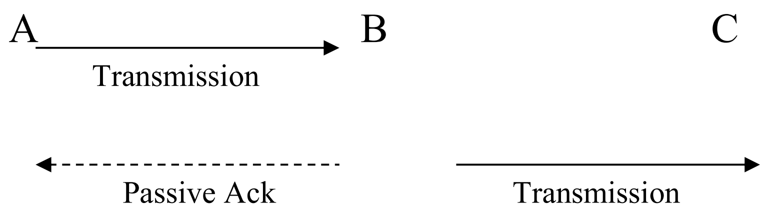

Figure 6: Passive acknowledgments

Two adjacent nodes forwarding their JOIN REPLIES received from the same receiver at the same time may overlap with each other. If these nodes are within receiving range of the receiver, they will recover because of the carrier sense feature in CSMA (Carrier Sense Multiple Access). However, if they are out of range of the receiver, they will be unaware of the "hidden terminal" condition of the receiver, which cannot hear the passive acknowledgments.

3.4. Forwarding Data

After the group establishment and route construction process, a source can multicast packets to receivers via selected routes and forwarding groups. When receiving the multicast data packet, a node forwards it only when it is not a duplicate. This procedure minimizes the traffic overhead and prevents sending packets through stale routes.

Network hosts running EADARP are required to maintain the following data structures:

(1) Route table

A route table is created on demand and is maintained by each node. An entry is inserted or updated when a non-duplicate JOIN QUERY is received. The node stores the destination (i.e., the source of the JOIN QUERY) and the next hop to the destination (i.e., the node which the JOIN QUERY is received from).

(2) Forwarding group table

When a node is a forwarding group node of a multicast group, it maintains the group information in the forwarding group table. The multicast group ID and the time when the node was last refreshed are recorded.

(3) Message cache

The message cache is maintained by each node to detect duplicates. When a node receives a new JOIN QUERY or data packet, it stores the source ID and the sequence number of the packet.

3.5. Leaving a Multicast Group

If a multicast source wants to leave the group, it simply stops sending JOIN QUERY packets since it does not have any multicast data to send to the group. If a receiver no longer wants to receive from a particular multicast group, it does not send the JOIN REPLY for that group.

3.6. Selection and update of timer values

Timer values for route refresh interval and forwarding group timeout interval have impacts on EADARP performance. The selection of these soft state timers should be adaptive to network environment (e.g., traffic type, traffic load, mobility pattern, mobility speed, etc.). When small route refresh interval values are used, fresh route and membership information can be obtained frequently at the expense of producing more packets and causing network congestion. On the other hand, when large route refresh values are selected, even though less control traffic will be generated, nodes may not know up-to-date route and multicast membership. Thus, in highly mobile networks, using large route refresh interval values can yield poor protocol performance.

The forwarding group timeout interval should also be carefully selected. In networks with heavy traffic load, small values should be used so that unnecessary nodes can timeout quickly and not create excessive redundancy. In situations with high mobility, however, large values should be chosen so that more alternative paths can be provided. It is important to note that the forwarding group timeout value must be larger (e.g., three to five times) than the value of route refresh interval.

The nodes' lifetimes are updated periodically to ensure the ability of one node for sending to another distant node. This update is done in the following manner:

```
If  RNL (remaining-node-lifetime) of node A < the energy required to send to node B
        Increase node A's lifetime by an amount equal to the difference between Energy required
          to B and A
   Else
        Do nothing
```

3.7. Network bandwidth Capacity

The network bandwidth capacity is varied according to different situations, the network bandwidth is increased when the number of messages is high to avoid congestion, and the network bandwidth is decreased when there is a little number of messages in the following manner:

If the number of messages > capacity of the network bandwidth
        Increase the capacity of the network
    Else if the number of messages < capacity of the network bandwidth/2
        Decrease the capacity of the network
    Else
        Do nothing

3.8. Mobility Adaptation to changes inside the network

EADARP requires periodic flooding of JOIN QUERY to refresh routes and group membership. Excessive flooding, however, is not desirable in ad hoc networks because of bandwidth constraints. Furthermore, flooding often causes congestion, contention, and collisions. Finding the optimal refresh interval is critical in EADARP performance. Basically, transmission power samples are measured periodically from packets received from a node's neighbor. From this information it is possible to compute the rate of change for a particular neighbor's transmission power level. Therefore, the time when the transmission power level will drop below the acceptable value can be predicted. This method of measuring periodically transmission power levels for each node is the method we adopted for computing the rate of change in power level for a certain node.

To predict the duration of time routes will remain valid. we assume a free space propagation model [40], where the received signal strength solely depends on its distance to the transmitter. We also assume that all nodes in the network have their clock synchronized. Therefore, if the motion parameters of two neighbors (e.g., speed, direction, radio propagation range, etc.) are known, we can determine the duration of time these two nodes will remain connected. Assume two nodes *i* and *j* are within the transmission range *r* of each other. Let (x_i, y_i) be the coordinate of mobile host *i* and (x_j, y_j) be that of mobile host *j*. Also let v_i and v_j be the speeds, and θ_i and θ_j ($0 <= \theta_i, \theta_j < 2\pi$) be the moving directions of nodes *i* and *j* , respectively. Then, the amount of time that they will stay connected, D_t , is predicted by [31],

$$D_t = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2}, \text{------------------------} (1)$$

Where,

$a = v_i \cos\theta_i - v_j \cos\theta_j$,

$b = x_i - x_j$,

$c = v_i \sin\theta_i - v_j \sin\theta_j$,

$d = y_i - y_j$,

Note that when $vi = vj$ and $\theta i = \theta j$, Dt is set to ∞ without applying the above equation. The next hop neighbor, upon receiving a JOIN QUERY, predicts the link expiration time between itself and the previous hop using equation (1). The reason is that as soon as a single link on a path is disconnected, the entire path is invalidated.

When a multicast member receives the JOIN QUERY, it calculates the predicted LET (last link expiration time) of the last link of the path. The minimum between the last link expiration time and the MIN_LET value is the RET (Route Expiration Time).

4. SIMULATION ENVIRONMENT

We are going to describe the simulation environment in which we simulated the multicast protocols, and produced the results which are compared after that to conclude the characteristics of each protocol.

4.1. Description of the Simulation Model

Several important parts of the simulation environment are going to be described below, including the model itself, channel and radio model we used here, Medium Access Control protocol, multicast protocols used here, parameter values used in the simulation, the traffic pattern and the mobility model.

4.1.1. Model Description

For evaluating EADARP and other multicast routing protocols, a simulation program was implemented within the GloMoSim library [41]. The GloMoSim library is a scalable simulation environment for wireless network systems using the parallel discrete-event simulation capability provided by PARSEC [42].

The simulation is based on modeling a network of 30 mobile hosts placed uniformly within a 1000 m×1000 m area. Radio propagation range for each node was 250 m during all experiments. The used channel capacity is 8 Mbps when comparing the protocols with each others and when evaluating the performance of EADARP using different packet sizes. Each simulation is executed for 100 sec of simulation time. The network traffic loads used were between 100 packets/sec and 1500 packets/sec.

4.1.2. Channel and radio model

We used a free space propagation model [40] in our experiments. In the free space model, the power of a signal attenuates as $1/d^2$ where d is the distance between radios. In the radio model, we assumed the ability of a radio to lock onto a sufficiently strong signal in the presence of interfering signals, i.e., radio capture. If the capture ratio (the ratio of an arriving packet's signal strength over the sum of all colliding packets) was greater than a predefined threshold value, the packet was received while all other interfering packets were dropped.

4.1.3. Medium Access Control protocol

The IEEE 802.11 MAC with Distributed Coordination Function (DCF) [47] was used as the MAC protocol. DCF is the mode which allows nodes to share the wireless channel in an ad hoc configuration. The specific access scheme is Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) with acknowledgments.

4.1.4. Multicast protocols

In addition to ODMRP, we implemented two multicast protocols for ad hoc networks; ADMR and Flooding and compared them with EADARP. When implementing the protocols, we followed the specifications of each protocol as defined in the published literature. Both ODMRP and Flooding are loop-free mesh-based protocols. ODMRP requires periodic messaging including control packets but ODMRP requires periodic messaging of JOIN QUERY only when sources have data packets to send, but Flooding does not, since all nodes inside the network are possible recipients and because of routes redundancy. ADMR is tree-based protocol, while EADARP is a mesh-based protocol. In EADARP, group membership and multicast routes are established and updated by the source "on demand". Similar to on-demand unicast routing protocols, a request phase and a reply phase comprise the protocol.

4.1.5. Protocols parameters

Some parameter values for ODMRP are set as follows;

- Maximum number of multicast groups in simulation is 10,
- Maximum number of sources for each multicast group is 20,
- JOIN QUERY refresh interval is 3 sec ,
- JOIN REPLY acknowledgment timeout is 25 msec,
- Maximum JOIN REPLY retransmissions is 3,
- Congestion time is 250 msec,
- and Interval to check for implicit acknowledgments is 75 msec.

Some parameter values for EADARP are set as follows;

- Maximum number of multicast groups in simulation is 10,
- Maximum number of sources for each multicast group is 30,
- JOIN QUERY refresh interval is 3 sec,
- JOIN REPLY acknowledgment timeout is 25 msec,
- Maximum JOIN REPLY retransmissions is 3,
- Congestion time is 250 msec,
- and Interval to check for implicit acknowledgments is 75 msec.

Some parameter values for ADMR are set as follows;

- Periodic flooding interval is 5 sec,
- Periodic flooding maximum interval is 30 sec,
- Waiting time for explicit acknowledgments is 200 msec,
- ADMR broadcast jitter is 10 msec,
- and sending buffer timeout is 10 sec.

One of the most important parameter values for Flooding is flooding size bitmap recent sequence numbers, which is set at 5.

The values of the parameters set for each protocol are defined as they are in the Glomosim [33] library, except for the EADARP, we changed some parameters used with other protocols, while others are used without change.

4.1.6. Traffic pattern

To study the impact of data traffic load on multicast protocols, the traffic loads were used varied on the network. The network traffic loads are between 100 packets/sec and 1500 packets/sec. A traffic generator was developed to simulate constant bit rate (CBR) sources. The size of the data payload (packet) was 512 bytes when comparing the protocols with each others and when evaluating the performance of EADARP using different channel capacities. The senders were chosen randomly among multicast members who in turn were chosen with uniform probability among 30 network hosts. The member nodes join the multicast session at the beginning of the simulation and remain as members throughout the simulation. There were three multicast groups and the multicast group size was three. One sender has been used for each multicast group, which represents the group core and three nodes representing receivers.

4.1.7. Mobility Model

For simulation, the random-waypoint model was used for mobility, so there are some packets dropped due to nodes' mobility which stands at 10 m/sec in maximum, unlike the cases when no mobility is used, the packet drops are only caused by buffer overflow, collision and congestion. With mobility random-waypoint pause of 30 sec, and the mobility random-waypoint minimum speed stands at 0 m/sec; the nodes' placement during their mobility is uniform. The network traffic loads used were between 100 packets/sec and 1500 packets/sec.

4.2. Performance Metrics

The following performance metrics are proposed to evaluate the performance of EADRARP protocol:

4.2.1. Efficiency

Efficiency is the ratio of the number of data packets delivered to the destinations versus the number of data packets supposed to be received. This number presents the effectiveness of a protocol. Efficiency is also called the packet delivery ratio.

Efficiency = Total number of delivered packets/Total number of sent packets (calculated at each node) for all nodes and then the sum of ratios is divided by the number of active nodes.

4.2.2. Total number of control packets

It is the total number of control packets delivered during packets transmission in the network. Control packets include: beacons, route updates, join requests, acknowledgments, ------ etc.

Total number of control packets = beacons + CTRL + acknowledgments + join requests + join tables + route updates packets for all nodes.

4.2.3. Total power consumed

It is the sum of the power consumed at each node measured in mw/hr (milli watts per hour) during packets transmission in the network.

Total power consumed = The sum of power consumed for all nodes = $Pow._{node1}$ +-----+ $Pow._{node30}$

4.2.4. Total number of collisions

It is the total number of collisions that occurred during packets transmission in the network.

Total number of collisions = The sum of collisions for all nodes = $Coll._{node1}$ +----+ $Coll._{node30}$

4.2.5. Total number of unreachable nodes

It is the total number of unreachable nodes during packets transmission in the network.

Total number of unreachable nodes = The sum of unreachable nodes for all nodes = $Unreach._{node1}$ +------+ $Unreach._{node30}$

4.2.6. Total number of TTL (Time-To-Live) expired

It is the total number of TTL (Time-To-Live) expired during packets transmission in the network.

Total number of TTL expired = The sum of TTL expired for all nodes = $TTL\_exp._{node1}$ +------+ $TTL\_exp._{node30}$

5. SIMULATION RESULTS OF THE PROPOSED EADARP PROTOCOL

This section presents the performance of the proposed EADARP protocol in comparison with other protocols with respect to the different proposed performance metrics. We simulated the proposed protocol EADARP with the following three protocols representing different architectures; ADMR protocol, ODMRP protocol and FLOODING protocol. The four protocols were tested under the same conditions and the results were compared and evaluated to evaluate the performance of each protocol.

For the evaluation of the performance of FLOODING, ADMR and ODMRP protocols in comparison with EADARP protocol, the metrics mentioned in section 4.2 are used to evaluate their performance under different network traffic loads ranging from 100 packets/second to 1500 packets/second.

Figure (7) shows the flow chart designed to compare between ***EADARP , ODMRP, ADMR and FLOODING protocols.***

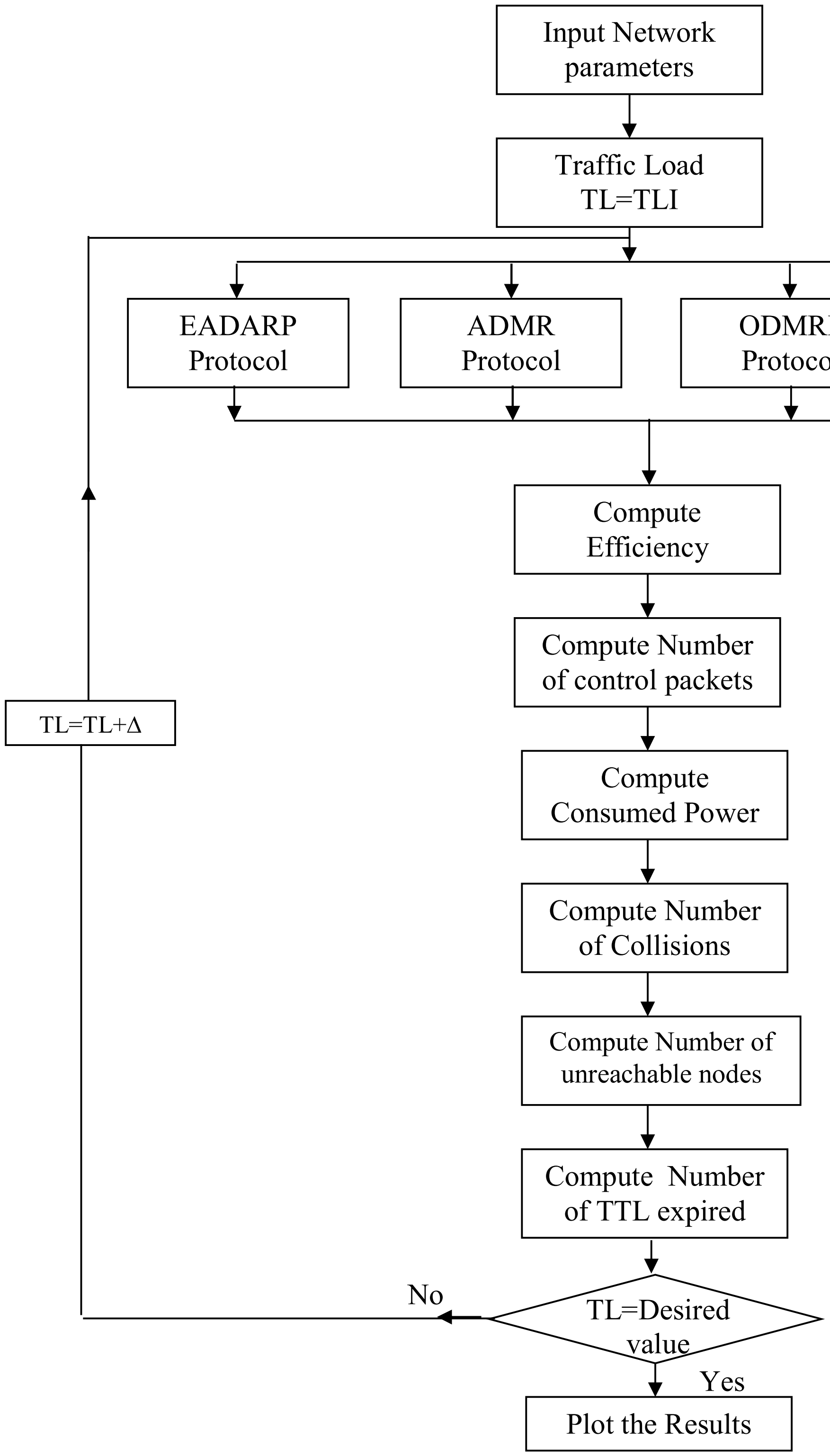

Figure 7: Flow chart for comparison between EADARP, ADMR, ODMRP and FLOODING protocols

5.1 Efficiency

Figure 8 illustrates the efficiency of the protocols under different traffic loads. The performance of the four protocols seems a little similar, because they began with a lower efficiency when the traffic load is lower and ends with a higher efficiency when the traffic load is higher and their efficiency becomes fixed when the traffic load reaches 500 packets/second. Comparing the four protocols, we notice that flooding has the highest efficiency, followed by ADMR, then ODMRP and finally EADARP. But the differences in efficiency between these protocols is very small.
This was expected because the protocols have reached a saturation point at which increasing the traffic load has no effect on the efficiency.

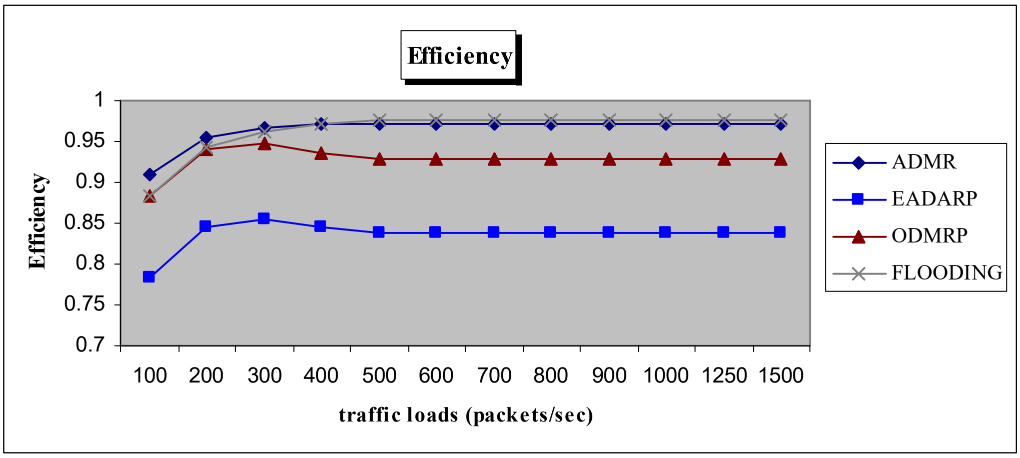

Figure 8: The efficiency vs Traffic Load

5. 2 Total number of control packets

Figure 9 illustrates the behavior of the chosen protocols using different network traffic loads. The control packets types and numbers vary from one protocol to another because the nature of the operation inside the network vary from one protocol to another. The figure shows that the total number of control packets in the flooding protocol highly exceeds those in the other three protocols, but the same performance is reached using the four protocols, they began with a smaller number of control packets when the network traffic load is 100 packets/seconds and increase this number as the traffic load reaches 1500 packets/second, also, the total number of packets become fixed from the traffic load 500 packets/second till 1500 packets/second. The other three protocols ADMR, ODMRP and EADARP have a close number of control packets, there is no big difference between them concerning the total number of control packets.
This was expected due to the fact that increasing traffic loads tend to increase the number of transmitted packets, but all the protocols reach a saturation point at which increasing traffic load has no effect on the number of control packets, because a node receiving a packet will retransmit it as it is to other nodes.

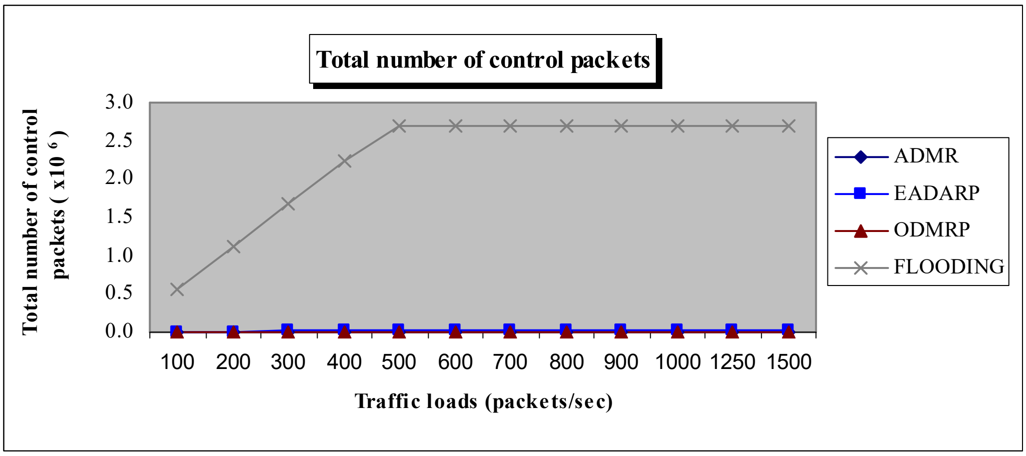

Figure 9: The total number of control packets vs Traffic Load

5.3 Total power consumed

Figure 10 illustrates the total power consumed during packets transmission using different network traffic loads for the four protocols. The flooding protocol consumes more power than the other protocols, followed by EADARP, then ADMR and then finally ODMRP, but in general the total power consumed values in the four protocols are very close, and the differences between them is very small. Flooding, EADARP and ODMRP show the same behavior, in terms that they begin with a smaller value for total power consumed at a traffic load of 100 packets/second and end with a higher value for total power consumed when the traffic load reaches 1500 packets/second, ADMR protocol represents the exception because it begins with a higher power consumed at a traffic load of 100 packets/second and then the total power consumed value is reduced then this value increases again. But, all the protocols have fixed values in terms of total power consumed when the traffic load reaches 500 packets/second till 1500 packets/second.

This was expected due to the fact that when we increase the traffic loads, the number of transmitted packets increases which requires more power consumption.

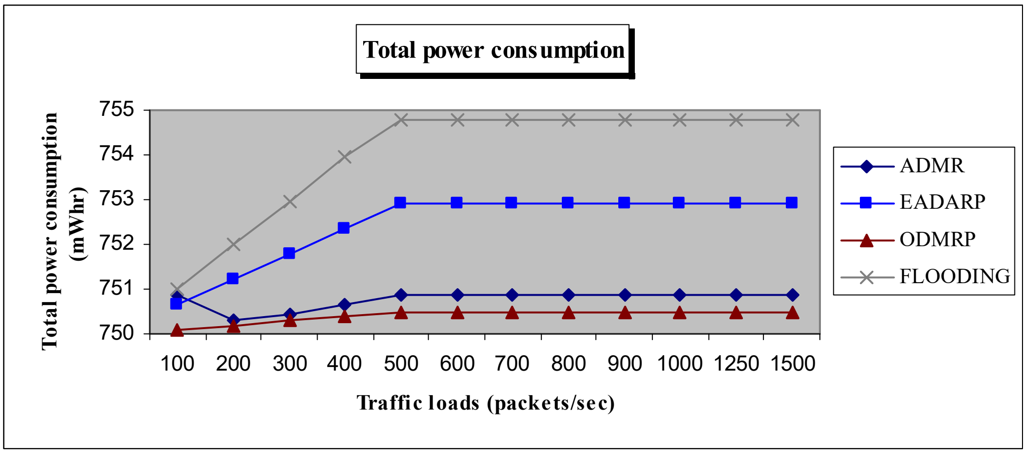

Figure 10: The total power consumption vs Traffic Load

5.4 Total number of collisions

Figure 11 illustrates the total number of collisions for the four protocols using different network traffic loads. Flooding has the highest number of collisions in comparison with other protocols, followed by EADARP, then ADMR, and finally ODMRP. All the protocols begin with a lower number of collisions when the traffic load is 100 packets/second and ends with a higher number of collisions when the traffic load reaches 1500 packets/second, and the total number of collisions in all protocols becomes fixed between 500 packets/second and 1500 packets/second.
This was expected due to the fact that increasing traffic loads means increasing the number of packets transmitted, then the possibility of these packets to collide also increases, making the number of collisions increases.

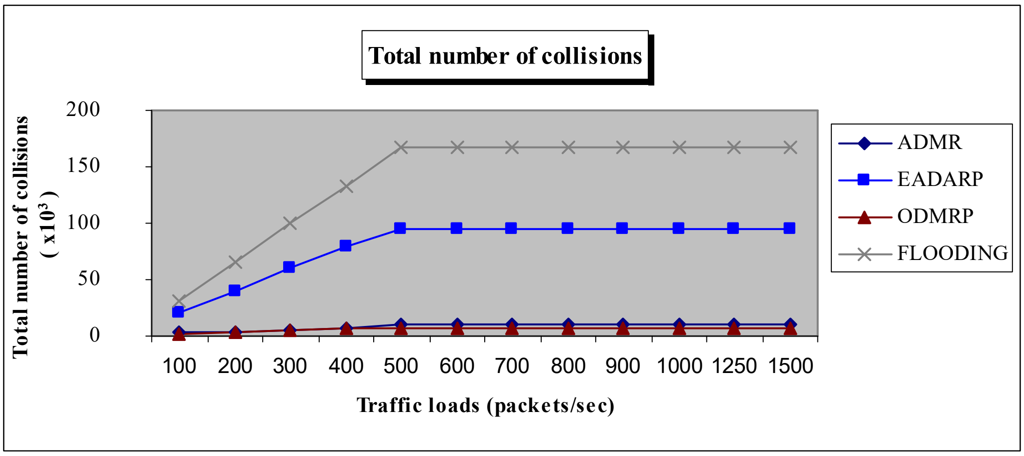

Figure 11: The total number of collisions vs Traffic Load

5.5 Total number of unreachable nodes

Figure 12 illustrates the total number of unreachable nodes in the four protocols using different traffic loads. Flooding has the biggest number of unreachable nodes in comparison with the other three protocols, followed by ADMR, and then both ODMRP and EADARP. ODMRP and EADARP have a zero number of unreachable nodes from the beginning of the simulation when the traffic load is 100 packets/second to the end of the simulation when the traffic load is 1500 packets/second, meaning better performance. Flooding and ADMR have similar performance, since they begin with a lower number of unreachable nodes when the network traffic load is 100 packets/second and end with a higher number of unreachable nodes when the traffic load reaches 1500 packets/second, the total number of unreachable nodes in the two protocols becomes fixed between a traffic load of 500 packets/second till a traffic load of 1500 packets/second.
This was expected due to the fact that increasing the traffic loads tend to increase the number of packets transmitted, and at the same time increasing the total number of nodes that can't be reached from other nodes until reaching a saturation point at which every node retransmits the received packets as they are without adding any changes.

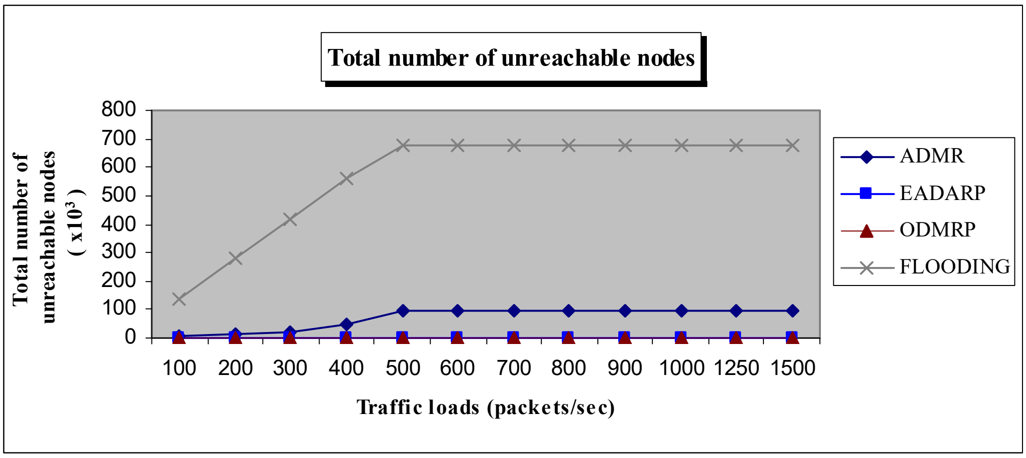

Figure 12: The total number of unreachable nodes vs Traffic Load

5.6 Total number of TTL expired

Figure 13 illustrates the total number of TTL expired in the four protocols using a variable network traffic load. ADMR has the highest number of TTL expired, followed by ODMRP, then EADARP, and finally Flooding. Flooding performs the best, because it has a zero number of TTL expired and this value is fixed from the beginning of the simulation when the traffic load is 100 packets/second till the end of the simulation when the traffic load is 1500 packets/second. ADMR, ODMRP and EADARP begin with a lower value when the network traffic load is 100 packets/second and end with a higher network traffic load is 1500 packets/second. ADMR is the worst performer and ODMRP has approximately the triple number of TTL expired as in EADARP, and Flooding is the best with none of TTL expired.

This was expected due to the fact that increasing the traffic loads tend to increase the number of packets transmitted, and at the same time increasing the possibility of a node with a certain TTL (time-to-live) value wanting to join a group that its TTL value expire.

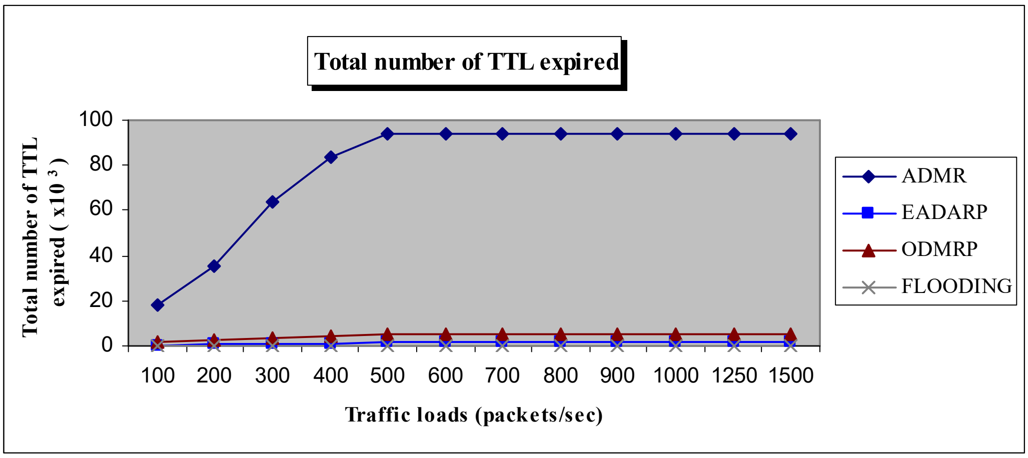

Figure 13: The total number of TTL expired vs Traffic Load

5.7 General comparison between the four protocols

Table 1 illustrates the average values for the different parameters for each protocol.

	Efficiency	Control Overhead	Power Consumed	Collisions	Unreachable nodes	TTL expired
EADARP	0.836559	17999	752.4406	80236	0	1218
ODMRP	0.927764	2560	750.3928	6271	0	4514
ADMR	0.964414167	8525	750.7686	8017	70046	79373
FLOODING	0.9639995	2258074	754.005	139116	565212	0

Table 1 The values for the different parameters for each protocol

Note: Values in the table are the average of the original values

6. CONCLUSION

In this paper, the EADARP protocol for multicast wireless ad hoc networks is proposed. EADARP builds and maintains a mesh for each multicast group. Providing multiple paths by the formation of mesh configuration makes the protocol robust to mobility. Alternate routes enable data delivery in the face of mobility and link breaks while the primary route is being reconstructed. The protocol does not yield excessive channel overhead in highly mobile networks because no control packets are triggered by link breaks. EADARP also applies demand-driven, as opposed to periodic, multicast route construction and takes soft state approach in membership maintenance. The key properties of EADARP are; simplicity, low channel and storage overhead, usage of up-to-date shortest routes, reliable construction of routes and forwarding group, robustness to host mobility, maintenance and utilization of multiple paths, exploitation of the broadcast nature of the wireless environment, and unicast routing capability.

The EADARP protocol is compared to the other three protocols. To perform this comparison, a simulation program was built in Glomosim. From the simulation results, EADARP shows approximately similar performance to other protocols in some situations, such as efficiency, and some times shows better performance such as number of TTL expired, number of unreachable nodes. In terms of number of control packets delivered during transmission, EADARP has approximately the same number of control packets as ODMRP and ADMR, but Flooding is exceeding all the other three protocols in the number of control packets, providing a very high control overhead in the network. EADARP is in the middle in terms of performance between Flooding and ODMRP, ADMR in the number of collisions and power consumption. But, one of the EADARP constraints is that it has the longest simulation time.

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