Networks Lifetime Maximization in Ad Hoc Wireless Networks With Link-Disjoint Paths Routing

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Abstract – Ad hoc networks are wireless mobile networks can operate without infrastructure and without centralized administration. Traditional techniques of routing are not well adapted. Indeed, their lacks of reactivity with respect to the variability of network changes make them difficult to use. Conserving energy is a critical concern in designing routing protocols for ad hoc networks, because most mobile nodes operate on batteries with limited capacity. Among the solutions proposed multipath routing. The multiple paths are used to lengthen the lifetime of the network, and reduce the overhead generated by the control messages. We show in this paper, an extension of the routing protocol AOMDV called LTAOMDV (Life Time AOMDV). In multipath selection mechanism, we propose a novelty method, is to classify the paths according to the battery capacity and the energy level of their nodes. Our concept of selection has aim to improve the performance of mobile ad hoc networks and prolong the lifetime of the network. The performance is compared between LTAOMDV and AOMDV; the simulation results showed that our protocol is more efficient than AOMDV.

Keywords – *Ad hoc networks; multipath routing; energy efficiency; network lifetime; battery capacity.*

I. INTRODUCTION

An ad hoc network is characterized by frequent changes in network topology, limited bandwidth available, and limited power of nodes. The ad hoc network topology changes frequently as nodes which are able to move collectively or individually and often unpredictable. These characteristics make routing in such a complex network.

The routing problem has attracted considerable interest in the research community. Several research studies have focused on routing in ad hoc networks [1, 2, 3, 4, 5]. While the proposed protocols have certain relevant characteristics, they have limitations, especially considering the high mobility of nodes or high network load.

The traditional approach of routing in mobile ad hoc networks is to adopt a single active route between the source node and destination node for a given communication, this is usually established using proactive or reactive (on demand) protocols[6]. In [7] it is shown that proactive protocols are very expensive in terms of energy consumption compared to the reactive protocols, because of the large routing overhead incurred in the former. But the protocols at the request latency suffer significant produced in the discovery of fresh roads, especially in large networks and dense networks [8].

We focus in recent years on the problems of improvement of ad hoc routing, which has spawned several routing mechanisms. Multipath routing seems to be an effective mechanism in ad hoc networks with high mobility and high load to guard against the problem of links failure. The concept of multipath routing is to give the source node the choice between multiple paths to reach a certain destination. The multiple paths can be used alternately or concurrently with selected criteria. There are two types of disjoint paths, link disjoint path and node disjoint path.

Node Disjoint paths have no nodes in common except the source and destination. In contrast, paths disjoint links have no common links, but can have common nodes.

The multipath between a source and a destination can be used to transmit information on all paths at the same time, to maximize the flow of data and to share the bandwidth [9]. A multitude of multipath routing protocols can reduce the overhead routing, through a single path discovery process can build disjoint paths to the destination node, such as Ad Hoc On Demand Distance Vector Multipath Routing [10-12]. The approaches in [13,14] are improvements of monopath routing protocols, these approaches contribute to reducing delays, increasing bitrate and better resistance to mobility.

In ad hoc networks, each node has battery powered and a limited energy supply. Over time, different nodes will deplete their energy supplies and are eventually deleted from the network, this partitions the network and constrained routing packets. In some cases, nodes removed, may be critical for transmission, in case they provide the only path between some pairs of nodes in the path to the destination node. For this reason, a number of researchers focused on the design of communication protocols that preserve energy so as to avoid network failures as long as possible [15-18].

II. ENERGY-AWARE ROUTING PROTOCOLS

Research in the field of energy conservation has targeted different layers of the network protocol, especially the MAC layer and network layer. Recently, some routing protocols have been proposed to use energy efficiently.

In [19] the authors presented several energy measurements that take into account that tracks energy efficient. The Minimum Total Transmission Power Routing (MTPR) [20] was initially developed to minimize the power consumption of transmitting nodes involved in a path. The Min-Max Battery Cost Routing (MMBCR) [21] considers the remaining power of nodes as a metric for the acquisition of paths in order to extend the lifetime of the network.

In [22], Liang and al. proposed a routing mechanism where the remaining battery capacity, mobility, and distance to destination node sensor candidate in the domain of local communication, they have been taken into consideration to select the next relay node, and fuzzy logic system has been applied to decision-making. The simulation results showed that this mechanism could extend the lifetime of the network.

In [23], Bergamo and al. designed DPC (Distributed Power Control), a routing protocol efficient energy consumption for ad hoc networks, which acts in combination with the routing layer, is based on a mechanism for estimating the amount of energy needed for reliable communications links. This energy is then used both to transmit a packet over the link, and as the link weight in a minimum-weight path search algorithm.

In this way, transmit power can be tuned in order to build the desired connectivity diagram. In addition, the transmit power information is used to privilege lower energy paths when looking for a packet route.

Ant-based Energy Aware Disjoint Multipath Routing Algorithm (AEADMRA) [24] is a protocol based on swarm intelligence and especially on a meta-heuristic based on the principle of ant colonies. The protocol Multipath Energy-Efficient Routing Protocol (MEER) [25], extends the lifetime of the network using a control mechanism for rational power, the route discovery phase in which the source is trying to discover routes to high performance energy is similar to SMR [26].

The Lifetime-Aware Multipath Optimized Routing (LAMORA) [27] is based on the lifetime of a node that is linked to its residual energy and traffic conditions. Power-Aware Multi-Path Routing Protocol (PAMP) [28] is an extension of existing AODV by changing the management mechanism of RREQ and RREP to manage the reservation of energy and multiple paths.

Max-Min Residual Energy (MRME-AOMDV) [29] is a multipath routing protocol based on AOMDV [12]. It uses minimal nodal residual energy of nodes, exploiting on maximum of them. It is designed primarily for ad-hoc networks highly dynamic with battery limited.

The existing routing protocols such as proactive and reactive protocols can be modified to incorporate the function power control which prolong lifetime and optimize energy consumption in ad hoc networks.

III. MULTIPATH ROUTING PROTOCOL LTAOMDV

In this section, an improved routing protocol, named Life time AOMDV (LTAOMDV), is presented. The main aim of proposed routing is to increase the lifetime of mobile ad hoc network, for that we are based on AOMDV [12] protocol, and exploits nodes residual energy. Our resulting protocol LTAOMDV, is a reactive protocol for multipath routing which selects the path to preserve the energy of the nodes constituting the paths. LTAOMDV uses the same types of message than AOMDV with some modifications in their structures. We first define some assumptions, and then we provide the details of multiple paths discovery, selection and maintenance.

A. Assumptions and problem definition

A wireless network is represented by undirected graph, G=(V,E) where V is the set of nodes and E is the set of bidirectional links.

Let w(u), u∈V, represent the residual energy at node u.

Let c(u, v), (u, v)∈E, be the energy required to transmit a packet from node u to node v. We assume that c(u, v)=c (v, u), for all (u, v) ∈E. Let Pi(u0, uk) = u0, u1, . . ., uk, be a ith path in G.

The total residual energy of the path Pi(u0, uk) denoted esum(P(u0, uk)) is given by:

$$e_{sum}\left(P_i\left(u_0,u_k\right)\right)=\sum_{j=0}^{k} w\left(u_j\right)$$

Let eaverage(Pi(u0, uk)) the average residual energy of a path is given by:

$$e_{average}\left(P_i\left(u_0,u_k\right)\right)=\frac{e_{sum}\left(P_i\left(u_0,u_k\right)\right)}{k+1}$$

The average residual energy of the network is denoted by eaverageNet, this average for the nodes that participated in the discovery phase. Considering that we discover n paths in the discovery phase, eaverageNet is given by:

$$e_{averageNet}=\frac{\sum_{i=1}^{n} e_{average}\left(P_i\left(u_0,u_k\right)\right)}{n}$$

We define elevel (uj), the energy level of node j given by:

$$e_{level}\left(u_j\right)=\frac{w(u_j)}{e_{averageNet}}$$

The node battery capacity bc(ui) is the amount of the remaining energy of the node battery, expressed as a percentage. We choose two limits 10% and 40%, to define the intervals.
Given a source s, a destination d, and a data packet to be routed, we initiate the discovery of multipath. The path selection is based on energy level and the energy capacity of nodes, this made it possible to classify paths and transmit the data by choosing the best of them.

B. Multipath routing discovery

When a source requires a route to a destination, it will check its routing table for any available path. If the path is not present or is invalid, the source performs route discovery with a broadcast of FREQ to all its neighbors. When a node receives RREQ, it ensures that the received RREQ is not a duplicate RREQ, in order to prevent looping paths. Otherwise, the neighbour nodes see whether they have any valid path in their tables. If they do, they forward RREQs to that path. Otherwise, they send new RREQ to all their neighbor nodes to find the destination. When the destination gets the first RREQ, it waits for time and collects all other RREQ coming in this time interval. Several changes are needed in the AOMDV route discovery procedure to enable computation minimal, maximal and average nodal residual energy of network composed of participants' nodes in multipath discovery operation. Each RREQ now carries additional field called sum_re_energy, represent sum of residual energy for source at current node. Another field re_energy is added, so that a node knows residuals energy of its neighbors. When the intermediate node receives a RREQ, increases the field sum_re_energy by the value of its residual energy. This treatment must take into account sequence number in order to ensure the freshness of paths [12]. The same process is repeated until the RREQ message reaches its final destination, see Figure1.

***if** (seqnumdi<seqnumdj) **then** seqnumdi :=seqnumdj;*
  if** (i ≠d) **then
   sum_re_energydj:= sum_re_energydj + re_energyi;
   advertised_hopcountdi:=∞;
   route_listdi:= NULL;
   insert (j , advertised_hopcountdj +1, re_energyj) into route_listdi;
  else
   advertised_hopcountdi:=0;
  endif
elseif** (seqnumdi=seqnumdj) **and** ((advertised_hopcountdi,i)>(advertised_hopcountdj,j)) **then
   sum_re_energydj:= sum_re_energydj + re_energyi;
   insert (j , advertised_hopcountdj +1, re_energyj) into route_listdi;
  endif

Figure 1 LTAOMDV process discovery path

Each node maintains route_list which is shown in Figure 2. We still add two new fields re_energy and marked in the route_list. The field re_energy denotes the residual energy of a node and the field marked indicates if a node has been selected by a reverse path.

Destination
Sequence_number
Advertised_hopcount
Route list {(nexthop1, hopcount1, re_energy1, marked), (nexthop2, hopcount2, re_energy2, marked), …}
Expiration timeout

Figure 2 Structure of routing table entries for LTAOMDV

C. Multipath routing selection

After reception of the first RREQ packet, the destination node waits for a certain period of time Wait_time fore starting route selection procedure. When this period of time expires, destination node generates a route reply RREP packet and sends it to the source. In the conventional AOMDV, route request packets RREQs propagation from the source towards the destination establishes multiple paths. It does not consider the energy in the paths; here LTAOMDV has been proposed. Our idea is to classify nodes following their energies level. Three classes of nodes are supposed and accepted:

- **Low:** The energy level of node is below of the threshold α.
- **Average:** The energy level of node is between the thresholds α and β.
- **High:** The energy level of node is above of the threshold β.

We combine these three classes to a pair (energy level and battery capacity), the node is ignored if its battery capacity or its energy level is very low.
After received a RREP message, an intermediate node judges if the RREP message is repeated, if is, directly discards it, otherwise it calculates the energy level and determine its class according to the principle described above. In the protocol AOMDV the intermediate node establishes a reverse path by selecting the first neighbor node of the table. In our protocol the intermediate node determines the class of each neighbor node stored in the table, and links with the neighbor node of the same class. In case there is no neighbor node of the same class it

selects a node with nearest class. This process is repeated until the source node. To ensure link-disjointness in the first hop of the RREP, the destination only replies to RREQs arriving via unique neighbors. After the first hop, the RREPs follow the reverse paths, which are links-disjoint. The trajectories of each RREP may intersect at an intermediate node, but each takes a different reverse path to the source to ensure link-disjointness.

D. Data transmission phase

When the node source receives the first RREP message, it waits a specified time before selection the best path. The choice of the best path between a source node s and destination node d depends on two values: battery capacity and energy level, to determine the class path (low, average or high). In AOMDV transmits data using the main path when multiple paths are set up, in our LTAOMDV protocol, paths are grouped by classes high, average and low according the path type high, average and low respectively. The paths of the group high are selected first to forward the data packets, once the group is exhausted we move to the group average then the group low. One path is selected at a time for transmission. If the selected path failed we chose the following path in the order of the group. Path discovery initiates again when all the routes failed.

E. Maintenance

Route error detection of LTAOMDV is similar to the route error detection in the AOMDV. It is launched when a link fails between two nodes along a path from a source to a destination. When a node detects a failure of a link in an active path, it sends an error RERR (Route ERRor) message to the node which precedes it on the path; this mechanism is repeated until the RERR message reaches the source node. When a source node receives a RERR message, it erases the route from his table, and it looks for an alternate path towards the destination node if available, otherwise it initiates a path discovery process to resume the data transmission. The the alternative path is selected as described in section 3.D.

IV. PERFORMANCE EVALUATION OF LTAOMDV

In this section, we present simulation results to demonstrate the efficacy of the proposed multipath protocol for a improving the performance of ad hoc networks.

A. Performance Parameters

We evaluate two key performance metrics: i) Life time of network. The network lifetime is defined as the duration from the beginning of the simulation to the time of K% of the nodes in a network to die; ii) Energy Consumption. The average energy consumption is the average of the energy consumed by the nodes participating in packets' transfer from source node to the destination node.

B. Performance Evaluation

We carried out simulations to determine the effectiveness of our protocol. The principal goal of these simulations is to analyze our protocol by comparing it with other protocols, mainly AOMDV[12]. The values of simulation parameters are summarized in Table 1.

Table 1 Simulation Parameters

Communication Model	Constant bit rate (CBR)
Network Interface Type	Phy/WirelessPhy
MAC Type	IEEE 802.11
Mobility Model	Random way point
Terrain Range	1000 m × 1000 m
Transmission Range	250 m
Number of Mobile Nodes	70 and 90
Data Payload	512 bytes

To evaluate LTAOMDV, we use the network simulator ns-2 [30]. A dense wireless network of 70 and 90 nodes is simulated in a field with 1000m*1000m area. Each simulation has duration of 300 seconds. During each simulation, constant bit rates (CBR) connections are generated, producing 4 packets per second with a packet size of 512 bytes.

The 'Random Waypoint' model is used to simulate node movement. The radio model uses characteristics similar to a commercial radio interface, Lucent's Wave LAN. Wave LAN is a shared-media radio with a nominal bit-rate of 2 Mb/sec and a nominal radio range of 250 meters [31]. The two-ray-ground reflection model is used as propagation model. We assumed that a node consumes 281.8mW receiving, and 281.8mW while transmitting. The energy consumption during the idle time is not considered in this model. In our simulations, we initialized the energies of the nodes randomly between 10 and 60 joules.

After several tests and simulations with varying network topology and progressive allocation of values to α andβ, we chose α=1.1 and β=1.6. The nodes are classified according to information on their residual energies. Table 2 shows the correspondence between the capacity of the batteries and the energy level of nodes and the decision-making (discarded or accepted).

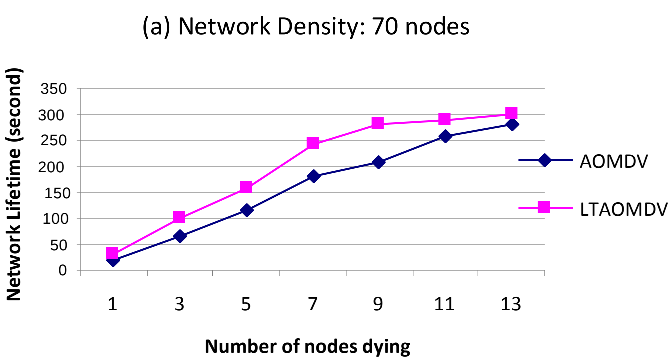
Table 2 Selection based on the energy level and the battery capacity

Battery capacity Energy level	<10%	[10% ,40%]	>40%
<=1.1	discard	accept-low	accept-average
]1.1, 1.6]	discard	accept-average	accept-average
>1.6	discard	accept-average	accept-high

We chose to consider that at least 10% of node capacity battery, the node is ignored. If it is between 10% and 40% with an energy level less than 1.1 the node is classified low. The node is classified high if its energy level is greater than 1.6 with a capacity battery above 40%, the remaining cases the node is considered average.
The Network life depends on the node expiration which in turn depends upon energy consumption and threshold value. The node life time is indirectly proportional to the energy consumption and it is also directly proportional to the threshold value of the node.
If battery capacity of node reaches zero then node will die. The network lifetime can be defined in many ways:

- It may be defined as the time taken for K% of the nodes in a network to die.
- It might be the time taken for the first node to die.
- It can also be the time for all nodes in the network to die.

In our simulations, we choice the first way. We evaluate the performance of LTAOMDV by comparing with AOMDV routing protocol. During simulation, we observed and estimated the network lifetime parameter is shown in Figure 3 with different network's densities: 70 and 90 nodes.
The lifetime of the LTAOMDV is longer than that of AOMDV as shown in Figure 3 (a) and (b) it is clear that the network lifetime of LTAOMDV is increased by 28% as compared to simple AOMDV on average.



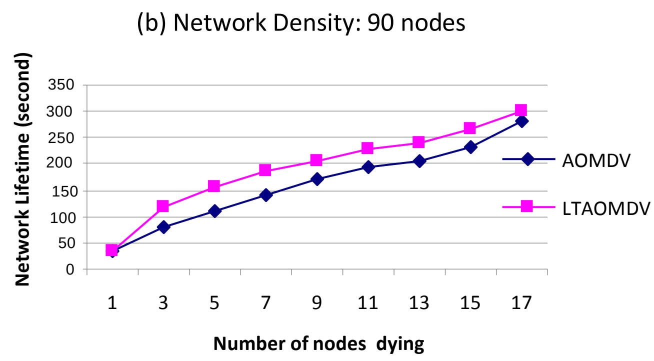
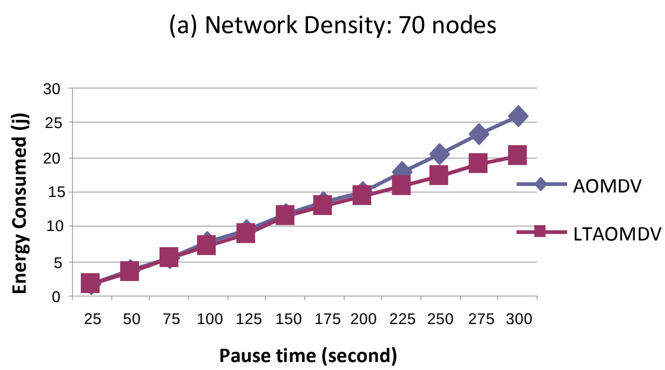


Figure 3 Network Lifetime vs Number of nodes Dying

This justifies that LTAOMDV can balance the energy among different nodes and prolong the individual node's lifetime and hence the entire network lifetime.
Graphs in Figure 4 shows the energy consumed in different sessions, by LTAOMDV and AOMDV. LTAOMDV does not perform too well in the beginning as compared to AOMDV, but it improves later. Initially, it is not better than AOMDV because, initially the majority of packets are not transmitted, so the total energy of sending and receiving packets is not important. But at a later stage, as time increases, there is some imbalance of energy that comes into play and then our algorithm's impact comes into play. We can see that Energy consumed in LTAOMDV is less compared to AOMDV.



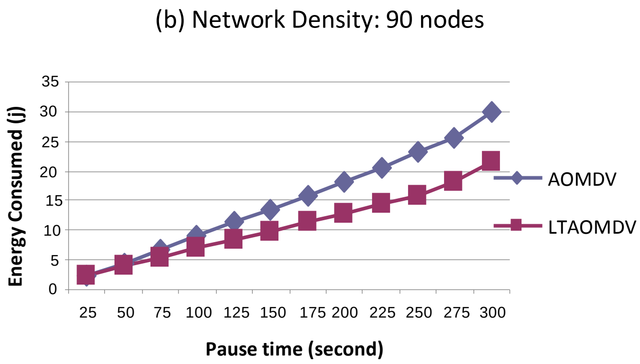


Figure 4 Energy Consumed vs Pause Time

The LTAOMDV consumes less energy than to AOMDV because the LTAOMDV approach tries to distribute evenly the energy consumption among nodes by using their residual battery capacity.

V. CONCLUSION

Through this article we have provided a solution to the problems of routing in an ad hoc network, characterized by their high dynamicity where link failures and route breaks occur frequently. However, the rapidly changing topology makes the limited power nodes exhaust rapidly, which makes the network split early with the decrease of the networks performance. A new multipath routing protocol LTAOMDV has been proposed in this paper for performing energy aware routing in mobile ad hoc networks. The proposed protocol is a energy efficient routing protocol for mobile ad hoc networks, it was shown that it improves the network lifetime and reduce the energy consumed, when compared with other solutions known in the literature. LTAOMDV routing protocol is an extension of the existing multipath routing protocol AOMDV. The routing model uses the energy aware selection mechanism and classification of paths according to the capacity battery and the energy level of their nodes concept to prolong node's lifetime and preserve node's battery capacity. By comparing the performance of LTAOMDV with AOMDV, LTAOMDV is able to balance the energy of the networks with the lifetime increase at least 28% for network density of 90 node, LTAOMDV consumes less energy than that of AOMDV, because the paths are built to the energy level of their nodes, and the best path is selected. In the future we will cooperate with MAC layer power-control technical to decrease ad hoc's energy consumption.

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