Multipath Routing for a Balanced Traffic Distribution and Efficient Energy Consumption for MANETs

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Abstract: Routing is a crucial issue in the design of a MANET. In this paper, we specifically examine the multipath routing issue since it is typically proposed in order to increase fault tolerance and to provide traffic-load and energy-consumption balancing. In fact, unbalanced traffic may lead to more delay, packet's dropping and packet delivery rate decreasing. Unbalanced energy consumption leads to node failure, network partitioning and decreases its lifetime. Accordingly, this paper proposes a new multipath routing protocol LPR-AOMDV (Lifetime Prediction Routing based on the well known Ad hoc On-demand Multipath Distance Vector). The idea behind this, is to exploit the multipath mechanism in AOMDV to select the best routes according to a cost metric that we define. For this reason, we introduce a new routing technique called Lifetime Prediction Routing (LPR) which is an on demand source routing protocol that uses energy lifetime prediction. This protocol favors the path whose lifetime is the highest one. Simulation results show the good performances of LPR-AOMDV protocol using various metrics such as overhead, energy consumption and packet-delivery rate.

Keywords: Energy consumption, mobile ad hoc networks, load balancing, AOMDV

1 Introduction

A mobile ad hoc network (MANET) is a decentralized network which does not depend on existing infrastructure such as routers in wired networks and managed access points in wireless networks where the nodes are randomly moving following specific trajectories. Several wireless ad hoc networks are being widely deployed in various domain so as the human life is increasingly depending on them. This rapid development makes MANET an open area for research and innovation which has led to the appearance of the so called dynamic and adaptive routing protocol.

Regarding the difficulty of routing in ad hoc networks, existing strategies use a v ariety of techniques to override encountered challenges. According to these techniques, several classifications have emerged, among which we will mention the one presented by [1] that classifies the protocols into proactive and reactive.

Proactive protocols are table driven where nodes maintain information about the routes whereas the reactive protocols search a route when a node generates a traffic to send.

The coherent energy availability for the devices is an important challenge in ad hoc networks, since a node has to perform its task completely while considering the limitations of its energy's source. Therefore, it is a great need to develop eco-energy management strategies and operations to increase the performance of ad hoc networks.

Energy and mobility are among the major factors that impact MANET networks in the context that the network stations are in constant activity (radio: listening to the channel, reception, transmission or higher level: routing, information processing, ...). These activities could be continuous if only batteries could stay alive for a long period of time. Several studies have demonstrated that the activity of a wireless network is very costly energy.

In recent years, a number of studies have been done on different OSI layers to ensure energy conservation. We deal in particular with the multi path routing in MANETs. This kind of routing allows the establishment of multiple routes between a single source and a destination. Multipath routing is, generally reassuring the reliability of the network regarding the data delivery.

Unlike our study, most of the existing routing protocols without energy considerations tend to use the same paths for the totality of given traffic. These results in a rapid depletion of energy nodes along the path, if traffic demand is long lasting and concentrated. AOMDV (Multi hoc on Demand Distance Vector ad-path routing) is a reactive routing protocol extended from AODV to provide multiple paths for the same traffic. In this protocol, each RREQ (Route Request) and RREP respectively (Route Reply) defines an alternative route to the source or destination.

Our work is inspired from the existing AOMDV protocol to which we introduce a new cost metric considering the energy consumption to obtain an energy-efficient algorithm. The advantage of using AOMDV is that it allows intermediate nodes to respond to RREQs, while selecting disjoint paths. But it introduces more overhead during route discovery due to the increased flooding.

In this paper, we propose three energy efficient routing algorithms (LEAR-AOMDV, PAR-AOMDV and LPR-AOMDV) that minimize the energy consumption and lead to greater autonomy. They are based on one of the well known multi-path routing protocols AOMDV (Ad hoc On-Demand Multipath Distance Vector) [2].

The LPR-AOMDV is an on demand source routing protocol that uses energy lifetime prediction. The objective of this routing protocol is to extend the service life of MANET in a dynamic topology. This protocol favors the path whose lifetime is the largest one.

This paper is organized as follows: Section 2 briefly discusses the literature survey relevant to our paper and discusses the related works carried out in the area. Section 3 provides a detailed description of our proposed protocol LPR-AOMDV. Section 4 presents and discusses the obtained results. In the last Section a conclusion is presented.

2 Related works

In this section, we introduce the proactive multipath routing protocol and we survey some new energy efficient routing algorithms.

In this article, we have proposed energy efficient AODV for low mobility ad hoc networks in which the energy consumption of the overall network is reduced by dynamically controlling the transmission power by utilizing a novel route cost metric. Three extensions to traditional AODV protocol, named Local Energy Aware Routing (LEAR-AODV), Power Aware Routing (PAR-AODV), and Lifetime Prediction Routing (LPR-AODV) have been proposed in [3], for balanced energy consumption in Ad hoc Networks. These algorithms use energy efficiency as a routing metric and try to reduce the energy consumption of nodes by routing packets using optimal routes.

In [4], the improved energy-efficient AODV for low mobility ad hoc networks is studied because nodes in an ad hoc network operate with limited energy. To extend the lifetime of the low mobility ad hoc networks, the energy consumption of the overall network is reduced by dynamically controlling the transmission power while maintaining all nodes balanced power use by utilizing a novel proposed route cost metric.

In [5], authors propose the MMRE-AOMDV routing protocol that exploits maximal minimal nodal residual energy concept. It balances the nodal energy consumption. This protocol calculates the minimal nodal residual energy of each path in the route discovery process then sorts the routes in a descending order and uses the route with maximal residual energy to forward the data packets.

In [6], authors present an innovative energy-aware routing protocol for wireless ad hoc network called Energy Efficient Ad hoc On Demand Multipath Distance Vector (E2AOMDV) routing protocol. E2AOMDV is a multipath routing protocol that is mainly designed for highly dynamic ad hoc networks where link failure and route break occurs frequently and the management of energy is a critical issue for the deployment of these networks because the nodes have small battery powered devices.

In [7], Power Awareness is introduced in the AOMDV (PAAOMDV) routing protocol so that the shortest path with maximum energy is established. In PAAOMDV, each node should maintain an Energy Reservation Table (ERT) instead of the route cache in the common on-demand protocols. Each item in ERT is mapped to a route passing by this node, and records the corresponding energy reserved.

3 Energy efficient routing algorithms

In this section, we introduce new energy efficient algorithms for routing. They are designed to increase the network lifetime with the network connectivity and achieve greater autonomy. This is in contrast to AOMDV which does not consider the power, but optimizes the routing while considering the delay. Protocols that we have developed (LEAR-AOMDV, PAR-AOMDV and LPR-AOMDV) ensure a large survivability of the mobile ad hoc network. They are all based on the routing protocol AOMDV described lower.

A)Ad hoc on demand multipath distance vector routing (AOMDV) with energy

The idea behind the modified protocol is to find the nodal residual energy of each route in the path selection process and select the route with the minimum energy consumption. Once a new route with less nodal energy is emerging, it is again selected to forward the rest of the data. This algorithm can improve the individual node's battery power utilization and hence prolong the entire network's lifetime. The protocol is working as follow:

Step 1: Calculate the nodal energy of each path during the route discovery process.
Step 2: Find the path with minimum nodal energy.
Step 3: Find all the routes and organize them based on the decreasing value of the residual energy of nodes.
Step 4: Select the route with maximum nodal energy to forward the data packets.

B)Local Energy Aware Routing based on AOMDV (LEAR-AOMDV)

We present here the first on-demand routing protocol LEAR-AOMDV (Local Energy-Aware Routing based on AOMDV) we have designed. In fact, we were inspired from the same mechanism used in [8] where the authors propose to extend the DSR (Dynamic Source Routing) protocol [9]. In their approach, each mobile node relies on local information about the remaining battery level to decide whether to participate in the selection process of a routing path or not. An energy-hungry node can conserve its energy power by not forwarding data packets on behalf of others. The decision-making process in LEAR-AOMDV is distributed to all relevant nodes. The main objective of LEAR-AOMDV is the balancing of energy between nodes in the ad hoc network equation (1), such as E_{res}: represent residual energy, and μ: is threshold value energy. Node will relay data packets only if it's residual energy is higher than a certain threshold μ, and that is, each node monitors the decrease of its residual energy.

$$E_{res} \leq \mu \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

1) Route Discovery

Unlike AOMDV protocol where each chosen node in the path must forward packets, in LEAR-AOMDV, a node participates in the decision making and decides whether to accept and forward the RREQ message or not depending on its remaining battery power (Eres). When its energy is lower than a threshold value μ (Eres≤μ), the RREQ is dropped; otherwise, the message is forwarded. The destination will receive a route request message only when all intermediate nodes along the path have enough battery levels.

2) Route maintenance

Route Maintenance is needed either when connections between some nodes on the path are lost due to node mobility or when the energy resources of some nodes on the path are depleting too quickly.
In the first case, and similar to AOMDV, LEAR-AOMDV introduces the threshold μ and the route maintenance is done in three steps:
Step 1: Source node

Send RREQ packet and if no answer is received after a period of time the threshold μ is exchanged by Ψ.

When the source node receives a RREP packet, it adds a new route to its routing table

Use a different path after changing the threshold μ by Ψ and send a new RREQ packet if no received RREP

Step 2: Intermediate node

If the residual energy (E_{res}) is bellow or equal to the threshold μ then the RREQ packet is dropped.

If node i has a route to the destination, it sends a RREP to the source indicating the minimum energy of the path it has. Else it compares its energy with minimum energy of the previous nodes and forwards the RREQ.

If $E_{res} < \mu$ then send RRER packet and delete the path, else return the previous node.

Step 3: When the destination receives a RREQ packet, it sends back a RREP packet to the source via the same route as the RREQ.

C) Power Aware Routing based on AOMDV (PAR-AOMDV)

This section presents the second on-demand routing protocol PAR-AOMDV (Power-Aware Routing based on AOMDV). PAR-AOMDV solves the problem of finding a route π at the route discovery time *t*. The main objective behind this protocol is to increase the life of an ad hoc network such that the following cost function [10] is minimized:

$$\mathrm{C}(\pi,\mathrm{t}) = \sum_{i\in\pi} C_i(t) \qquad (2)$$

Where:

$$C_i(t) = p_i\left(\frac{F_i}{E_{r,i}(t)}\right)^{\alpha} \qquad (3)$$

P_i*:* is the transmition power of node *i*, F_i is its total energy, $E_{r,i}$ *(t)* represents its remaining residual energy at time *t* and α is a weighting factor.

Cost-min is the cost min path of energy

1) Route Discovery

In PAR-AOMDV, the process of discovery begins when the source node floods the network with RREQ packets when it has data to send. All nodes except the source and the destination calculate their link cost Ci using (3) and add it to the path cost in the header of the RREQ packet (equation (2)).
Step 1: Node source

When a node receives a RREQ packet for the first time, it sends a RREP packet to the source.

Step 2; Intermediate node

When a node i forward a RREQ packet, it keeps the cost in the header (Cost-Min).

If another packet RREQ is received with the same destination with a new cost, the node compares the Cost-Min of the new and the previous RREQ.

When a new packet arrives with a lower cost and the intermediate node i has no valid route to the destination, the minimum Cost-Min is updated and the RREQ is rebroadcasted.

If a new RREQ packet with a lower cost and the intermediate node i has a route to the destination, it sends a message (unicast) including the calculated cost.

if the new RREQ packet and node *i* at Cost-Min greater cost then remove

Step3: Destination node

When a destination receives a RREQ packet, it calculates the cost Cost-Min and sends back a RREP packet including the total cost of the route.

Finally, This RREP packet message contains the cost of the selected path. The source node will select the route with the minimum Cost-Min in the routing table

2) Route maintenance

The route maintenance in PAR-AOMDV is the same as in LEAR-AOMDV. Hence, in PAR-AOMDV when any intermediate node i has a lower residual energy then its threshold value ($E_{res} \leq \mu$), any request is simply checked in the routing table.

D) Lifetime Prediction Routing based on AOMDV (LPR-AOMDV)

Our LPR-AOMDV approach favors the route with maximum lifetime, and balanced traffic. It calculates routes that do not contain nodes with a weak predicted lifetime. LPR-AOMDV solves the problem of finding a route π at the route discovery time t, such that the following cost function is maximized:

$$\underset{\pi}{Max}\left(T_\pi(t)\right) = \underset{\pi}{Max}\left(\underset{i\in\pi}{Min}\left(T_i(t)\right)\right)$$

Where T_π *(t)* is the lifetime in route π and T_i *(t)* is the expected lifetime of the node i in route π.

The objective of LPR-AOMDV is to: (i) extend the survivability of the ad hoc network, (ii) favor the route whose lifetime is longer. It uses the energy lifetime prediction. Every node tries to estimate its energy lifetime based on its past activities. This is achieved using a recent history of node activities. When a node i sends data packets, it keeps a track of its residual energy value ($E_i(t)$) and the equivalent time instance t. This information is recorded and stored in the node. After N sent packets, node i gets the time instance t' and the equivalent residual energy value ($E_i(t')$). This recent history, {(t, $E_i(t)$), (t', $E_i(t')$)} is a good indicator of the traffic crossing the node. Our approach is a d ynamic distributed load-balancing mechanism that avoids power congestion in the nodes and chooses paths that are carelessly loaded. The route discovery and route maintenance of LPR-AOMDV are described below.

1) Route Discovery

In LPR-AOMDV, all nodes except the destination and source calculate their predicated lifetime, *Ti* using equation (5). In each route request, there is another field representing the minimum lifetime *(Min_lifetime)* of the route.

A node *i* in the route replaces the *Min_lifetime* in the header with T_i, if T_i is lower than existing *Min_lifetime* value in the header.

$$T_i(t) = \frac{E_i(t)}{D_i(t)} \quad (5)$$

Where $D_i(t)$ is the discharging rate calculated by dividing the capacity by the time

$$D_i(t) = \frac{E(t') - E(t)}{t - t'} \quad (6)$$

Where $E_i(t)$ is the remaining energy of node i at time t.

t is the current time corresponding to the moment when node i sends the current packet.
t' is the time instance corresponding to the moment when the N^{th} predecessor to current packet was sent by node i. We tested several values for N, and this is the value of 10 gives the best results (.$N=10$ will be a good value).
More exactly, when an intermediate node receives the first RREQ packet, it keeps the *Min_lifetime* in the header of that packet. If additional RREQs arrive with the same destination and sequence number, the *Min_lifetime* of the newly arrived RREQ packet are compared to the previously stored value of *Min_lifetime*.

In a route discovery process, we have four steps:
Step 1: If the new packet has a greater *Min_lifetime* and the intermediate node does not know any valid route to the destination, the *Min_lifetime* is changed to this new value and the new RREQ packet is re-broadcast.

Step 2: If the new packet has a greater *Min_lifetime* but the intermediate node has a route to the destination, the node forwards (broadcast) a *COMPUTE_lifetime* message. to get the total lifetime of this route.

Step 3: If a new packet with a lower *Min_lifetime* the RREQ packet is dropped.

Step 4: When the destination receives either a RREQ or a *COMPUTE_lifetime* message, it generates a R REP message. The RREP is routed back to the source via the reverse path. This reply message contains the lifetime of the selected path. The source node will select the route with the maximum lifetime.

3) Route maintenance

Route maintenance is needed either when a node becomes out of direct range of a sending node or there is a ch ange in its predicted lifetime. In the first case (node mobility), the mechanism is the same as in AOMDV. In the second case, the node sends a route error (RERR) back to the source even when the predicted lifetime is below then a threshold level *($Ti<\phi$)*. This route error message forces the source to initiate the route discovery process again. This decision depends only on t he remaining battery capacity of the current node and its discharging rate. Hence, it is a local decision.
In a route maintenance process we have three steps:

Step 1: at source node

Rule 1: Forward RREQ packet.

If no response after a time period t, then change the threshold ϕ by λ.

Rule 2: If the source receives a RREP, it adds the new carried route in its routing table.

Rule 3: Receive RRER.

Use a different path in the routing table.

If no path available then change the threshold μ by ф, and resend RREQ.

Step 2: At intermediate node

Rule 1: RREQ

if $(T_i(t)<\phi)$ then drop the RREQ packet.

If node i has a route to destination, then forward RREP to the source containing the maximum lifetime of nodes in that route. Else, compare the max lifetime of the precedent nodes then forward RREQ.

Rule 2: Data packet

If $(T_i(t)<\phi)$ then send RERR message, drop the packet and delete the route. Else return to the next hop.

Step 3: at destination node

The destination node after receiving RREQ packet will send RREP packet back to the source with maximum lifetime.

4 Simulations results

We conducted extensive simulations, using NS2 [11], to determine the effectiveness of our routing protocol LPR-AOMDV. We compare it to the well-known routing protocol AOMDV in terms of packet delivery ratio, overhead, energy consumption, end-to-end delay, and network lifetime.
Nodes move according to the Random Waypoint mobility Model (RWP) in which they move from

one waypoint to the next. A specific speed and duration are chosen for every transition. After the stipulated transition duration ends, the node may pause for a specific duration before starting its transition towards the next waypoint. Table 1 summarizes the simulation parameters.

Parameter	**Value**
Number of nodes	20
Simulation time	500 s
Pause time	100 s
Radio range	250m
Velocity	(4m/s, …, 20m/s)
Simulation area	900 x 900 m2
Initial energy	100 Joule
Tx power, Rx power, Idle power	0.4, 0.3, 1.0 (Watt)
MAC protocol	IEEE 802.11

Table 1. Simulation parameters

The network lifetime is illustrated by the time elapsed until a node in the network dies. Figure 1 shows the variation of this metric regarding the density of the network.

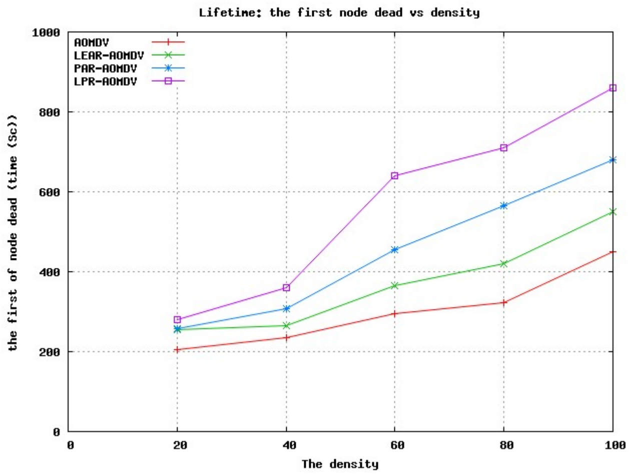

Fig. 1 Network lifetime vs the first node dies

Figure 1 shows the first node died over the density of the ad hoc network. We notice that LPR-AOMDR protocol provides a better network lifetime (the same for the number of alive nodes vs time, figure2) compared to AOMDV, LEAR-AOMDV and PAR-AOMDV protocols because it uses the energy cost function at the selection process of paths. Thus, LPR-AOMDV reduces the rates of energy consumption of the nodes along a path and guarantees their lifetime extension in terms of energy. It also guarantees the life duration of the path from the source to the destination, ensures load balancing and avoids early network fragmentation.

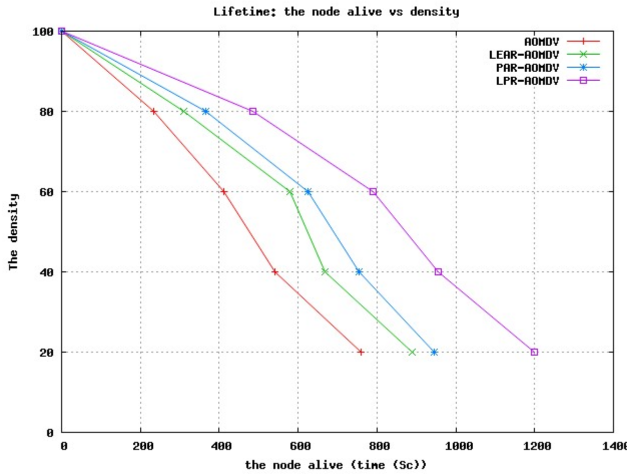

Fig. 2 Network lifetime the number pf node alive vs. time

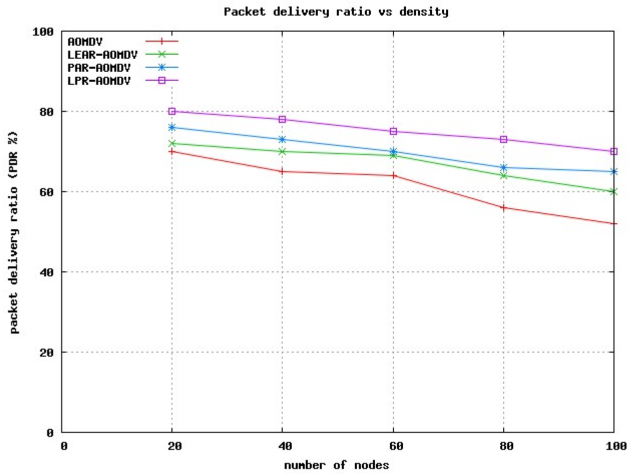

Fig. 3 Average packet delivery ratio vs nodes' density

In figure 3 we represent the packet delivery ratio (%) variation depending on the network density. We notice that the ratio guaranteed by LPR-AOMDV protocol is greater than the ratio offered by AOMDV, LEAR-AOMDV and PAR-AOMDV.

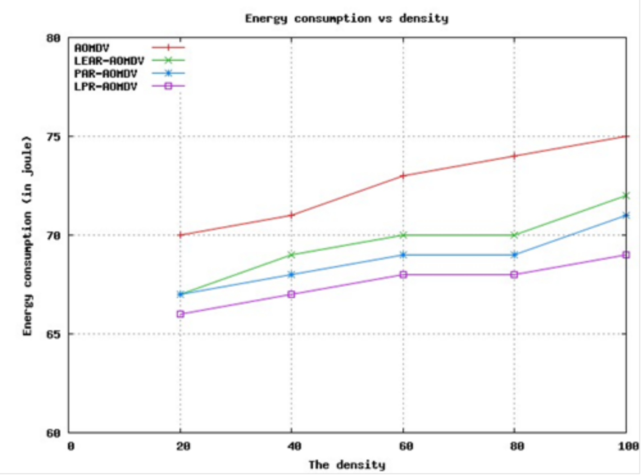

Fig. 4 Average overhead vs. number of nodes'

We notice in figure 4 that the average consumed energy is the lowest in our LPR-AOMDV protocol. This enhances the network lifetime. Actually, the introduced weighting metric (survivability equation) is very important to select the best nodes as dominant ones in order to avoid the frequent topology update. To improve the survivability of the network, we must use strong nodes in terms of weight, reduce energy consumption and distribute traffic**.**

5 Conclusion

We propose in this paper an extension of the LPR-AODV protocol to support the multipath, for load balancing purposes.

The LPR-AOMDV route construction is done judiciously since the path selection process uses a new weighting parameter that depends on energy, quality of the link and connectivity. This parameter is introduced in order to increase the route lifetime and as a result enhance the network performances.

We offer a balanced energy consumption with minimum overhead. Simulation results show that our LPR-AOMDV minimizes and balances the energy consumption among mobile nodes and achieves an obvious improvement of the network lifetime.

We are currently extending this work by performing other extensive simulations to compare our routing protocol with other existing energy-based protocols to enrich our approach.

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