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Load-Aware Energy Efficient Routing Protocol with Adaptive Threshold Energy for MANETs

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Abstract: A Mobile Ad hoc Network (MANET) is a collection of wireless mobile nodes forming a temporary network without using any centralized access point, infrastructure, or centralized administration. A typical ad hoc network consists of nodes that are usually battery operated devices such as laptops, PDAs, etc., that come together and spontaneously form a network. Hence energy conservation is a critical issue in case of MANETs. The lifetime of a MANET depends on lifetime of its mobile nodes. Research is being carried out to conserve energy of mobile nodes at various levels, i.e., at the hardware level, operating system level and application level. Lot of work has been done to improve the energy efficiency of existing routing protocols for MANETs. There is little work done that address the lifetime issue of MANETs. In this paper, we propose a new protocol that conserves energy of mobile nodes and, hence, enhances the lifetime of the MANET. It is an on-demand routing protocol based on load balancing that uses adaptive threshold energy. The experimental results are compared with that of the popular on-demand routing protocols namely, DSR and AODV.

Keywords: MANET, threshold, network lifetime, energy conservation.

I. INTRODUCTION

The rapid expansion of wireless services, such as cellular voice, PCS (Personal Communications Services), mobile data and wireless LANs, in recent years is an indication that accessibility and portability are considered as significant key features of telecommunication. Wireless devices have maximum utility when they can be used “any where at anytime”. One of the greatest limitations to that goal, however, is finite power supplies. Since batteries provide limited power, a general constraint of wireless communication is the short continuous operation time of mobile terminals. Since the energy sources have a limited lifetime, power availability is one of the most important constraints for the operation of the ad hoc network. There are different processes of power consumption in a mobile node. Communication is one of the main processes of energy consumption. Since the rate of battery performance improvement is rather slow currently, and in the absence of breakthroughs in this field, other measures have to be taken to achieve the goal of more energy efficient performance utilizing the currently available battery resources.

Communications in ad hoc networks are done using the RF transceivers at the source, intermediate and destination nodes to exchange information. The source node sends control and data messages which are received by one or more receiving nodes, depending on the message type. The receiving node could be the intended receiver of the packet, or it could be on the path to the destination (when the destination is not within range from the source) acting as a forwarder of the traffic. In order to address the energy efficiency issues at the communications level within ad hoc networks, it is important to understand the energy model which represents the power consumption behavior in the wireless interfaces of the ad hoc network nodes.

Therefore, power management is one of the most challenging problems in wireless communication, and most of the current research has been aimed at addressing this problem. Ad hoc routing protocols are usually classified as being table-driven routing protocols or on-demand routing protocols depending on their response to changes in the topology of a network. Table-driven routing protocols (also called proactive protocols) maintain a continuous view of the full topology of the network in each node, whereas on-demand routing protocols (also called reactive protocols) search for a route between a source and a destination when such a route is needed. Table-driven approaches introduce more overhead as compared to reactive ones. This is because whenever there are changes in the topology of the network, control messages are flooded in order to maintain a full knowledge of the network in each node. Initially, the main criterion in these two classes of protocols was the minimum number of hops. However, the main shortcoming of this criterion in terms of energy utilization is that, the selection of routes in accordance with the min-hop principle does not protect nodes from being overused. These are usually some nodes in the core of the network. When they run out of power, the network becomes partitioned and consequently some sessions are disconnected.

In order to alleviate this problem and, also, to achieve energy-efficient consumption, many solutions have been proposed in the literature as extensions of the already existing ad hoc routing protocols. Since table-driven protocols inherently consume more energy as compared to on-demand ones, most of the proposed protocols involve modifications to the reactive protocols. Therefore most of the energy aware routing algorithms are based on on-demand protocols, namely, AODV and DSR. Instead of searching for the shortest path, as traditionally done, these modified algorithms use energysensitive metrics for searching path. In the literature load balancing strategies for ad hoc networks have been explored in the same context as those used for wired networks, i.e., in the prevention and/or alleviation of congestion and fault tolerance.

The balanced use of a network's resources leads to more efficient energy utilization, which is essential for ad hoc networks. Instead of simply establishing correct and efficient routes between pair of nodes, one important goal of a routing protocol is to keep the network functioning as long as possible. The goal of an energy efficient routing algorithm is minimizing mobile nodes' energy consumption not only during active communication but also when they are inactive. Transmission power control and load distribution are the two approaches used to minimize the active communication energy, and sleep/power-down mode is used to minimize energy during inactivity. The following are the energy-related metrics that have been used to determine energy efficient routing path instead of the shortest one.

a. energy consumed per packet,
b. time to network partition,
c. variance in node power levels,
d. cost/packet, and
e. maximum node cost

The first metric is useful to provide the min-power path through which the overall energy consumption for delivering a packet is minimized. Here, each wireless link is annotated with the link cost in terms of transmission energy over the link and the min-power path is the one that minimizes the sum of the link costs along the path. However, a routing algorithm using this metric may result in unbalanced energy spending among mobile nodes. When some particular mobile nodes are unfairly burdened to support many packet-relaying functions, they consume more battery energy and stop running earlier than other nodes, disrupting the overall functionality of the ad hoc network. Thus, maximizing the network lifetime (the second metric shown above) is a more fundamental goal of an energy efficient routing algorithm. Given alternative routing paths, select the one that will result in the longest network operation time. However, since future network lifetime is practically difficult to estimate, the next three metrics have been proposed to achieve the goal indirectly. Variance of residual battery energies of mobile nodes is a simple indication of energy balance and can be used to extend network lifetime. Cost-per-packet metric is similar to the energy-per-packet metric but it includes each node's residual battery life in addition to the transmission energy.

The corresponding energy-aware routing protocol prefers the wireless link requiring low transmission energy, but at the same time avoids the node with low residual energy whose node cost is considered high. With the last metric, each path candidate is annotated with the maximum node cost among the intermediate nodes (equivalently, the minimal residual battery life), and the path with the minimum path cost, min-max path, is selected. This is also referred to as max-min path in some protocols because they use nodes' residual battery life rather than their node cost.

II. RELATED WORK

In [1], the study about the energy consumption of existing reactive routing protocols, namely, DSR and AODV under Self-Similar traffic (Pareto and Exponential) in comparison with CBR has been presented. The PAAODV [2] reduces power consumption to a possible minimum level in an ad hoc network with the connectivity of the network not being disrupted. Consequently, the overall power consumed in transmission of overhead packets is significantly reduced. A simple and energy efficient on-demand routing scheme, which uses discrete level of power control and priority based packet scheduling, has been developed in [3]. The route selection process is embedded in the distributed packet scheduling based on transmission power level. Also, the energy efficiency is due to data delivery process using minimal discrete level of transmission power.

The EELAR [4] achieves significant reduction in the energy consumption of the mobile nodes' batteries by limiting the area of new route discovery to a smaller zone. Thus, control packets overhead are significantly reduced. In [5], a methodology of routing protocol for misbehaving network called RMP-ANT (Route Management Protocol for Ad Hoc Network) with a power management scheme called as MARI (Routing Intelligent Mobile Agent) protocol is proposed, and the various schemes to improve routing protocol performance by using mobility prediction are discussed. In [6], an approach for reducing the end-to-end delay and increasing network lifetime in mobile ad hoc networks has been proposed. It is based on TORA routing protocol. Energy and delay verifications of query packet have been done in each node. A new energy efficient AODV-based node caching routing protocol with adaptive workload balancing (AODV-NC-WLB) has been developed in [7]. In [8], it has been shown that as the network lifetime increases, the percentage energy consumption decreases with increase in the number of hops and attains a minimum at critical hops. After the critical hops, the energy consumption gradually increases due to increase in cumulative energy consumption of the intermediate nodes .In [9], authors have proposed a new routing algorithm, Local Energy Aware Routing (LEAR), which achieves the trade-off between balanced energy consumption and shortest routing delay and at the same time avoids the blocking and route cache problems. In paper [10], the authors suggest some improvement to AODV routing protocol.

The protocol, called AODV-UI, improved AODV in gateway interconnection, reverse route and in energy consumption. They also measure performance indicators for some metrics, such as energy, routing overhead, end-to-end delay, and packet delivery ratio. Paper [11] proposes Dynamic Transmission Power Assignment for Energy conservation routing (abbreviated as DPAECR) in MANETs. DPAECR updates the transmission power for every packet transmission. For the purpose of energy conservation, each node can dynamically adjust its transmitting power based on the distance of the receiving nodes. In the book chapter [12], the authors discuss about various issues in MANETs, energy consumption model, energy aware metrics and network life time.

III. PROPOSED LOAD AWARE ENERGY EFFICIENT PROTOCOL

The specific goal of the load distribution approach is to balance the energy usage of all mobile nodes by selecting a route with underutilized nodes rather than the shortest route. This may result in longer routes but packets are routed only through energy-rich intermediate nodes. Protocols based on this approach do not necessarily provide the lowest energy route, but prevent certain nodes from being overloaded, and thus, ensure longer network lifetime. The lifetime of MANET is very vital parameter. It is expected that a MANET lasts for a longer duration. To achieve this, we need to ensure that no node is overused during routing process. Hence, the routing load needs to be equally distributed among all the neighboring nodes. Otherwise, it results in early network partitioning. In this paper, a variable threshold energy policy is proposed, in which only the nodes with energy above the threshold value can take part in the route discovery process. Once the node energy of all the neighboring nodes is less than the threshold value, we keep updating the threshold value

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$$C_i = 1/ RE_i$$

where RE_i is the residual energy of node i. The cost of a node to forward a packet keeps increasing as its residual energy continues to decrease. The residual energy defines the reluctance or willingness of intermediate nodes to respond to route requests and forward data traffic. When energy RE_i in a node i is lower than a predefined threshold level *Th*, i. e, $RE_i \leq Th$, the node does not forward the route request control message, but simply drops it. Thus, it does not participate in the selection and forwarding phase. Whenever all the neighboring nodes' residual energy reaches threshold level, no node is willing to forward the route request message, then, the threshold value is modified as follows:

$$Th_{new} = Th_{old} - \frac{1}{n^2}\sum_{i=1}^{n}(RE_i)$$

where Th_{new} and Th_{old} denote the updated value and the previous value of the threshold energy respectively. Instead of reducing the threshold by some random value, the threshold value is recomputed using a function of average energy at a particular hop and the number of neighbors. This adaptive thresholding accounts for the fact that, if there are more number of neighbors having path to destination, the threshold value gets decremented by small amount, so that routing load gets distributed equally among all the neighbors. If there are fewer neighbors having the path to destination, then the decrease in threshold is more, so that nodes are used for longer duration without need for updation in threshold.

The proposed routing algorithm is, thus, the modified AODV routing protocol incorporating the adaptive energy thresholding during route discovery stage and it is given below.

Algorithm: **Load Aware Energy Efficient Routing (LAEE).**

Step 1. Let S be the source node having n neighbors with residual energy levels RE_i , i = 1,..,n. Initialize hopcount = 0.

Step 2. For node S, compute initial threshold *Th* given by :

$$Th = \frac{1}{n}\sum_{i=1}^{n}(RE_i)$$

Step 3. The node S floods request packet RREQ to all its neighbors after embedding the value *Th* into RREQ, for establishment of path connection to destination node D.

Step 4. Each intermediate node, which receives RREQ, checks whether its residual energy is greater than *Th*. If 'yes', go to step 5 else simply drop the RREQ packet.

Step 5. Intermediate node responds by sending reply packet RREP if it has a path to destination. Go to step 7.

Step 6. Intermediate node forwards RREQ after replacing the embedded *Th* value by the modified threshold value given by $Th \leftarrow Th - \frac{1}{k}\ [\ \frac{1}{k}\sum_{i=1}^{k}(RE_i)\ ]$, where k is the number of neighboring nodes of the intermediate node and RE_i, i = 1,..,k are their residual energy levels.

Step 7. Increment the hopcount by 1.

Step 8. Repeat Steps 4 to 7 until packet sent by node S reaches the destination node D. Output the value of the hopcount.

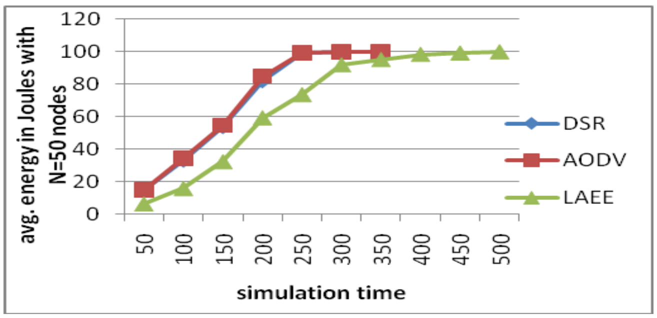
IV. RESULTS AND DISCUSSIONS

The proposed protocol is implemented using NS2 simulator, for different simulation times (50,100,.., 500), for different pause times (0, 10, 20, 30, 40, 50 sec) and for different number of nodes (50,100,…, 300). The other parameters used for simulation are given below in Table 1. The simulation results for 50,150 and 250 nodes are shown below in Fig.1–3. The complete simulation results are given in Table 2. The results are compared with the performance of the commonly used on-demand routing protocols, namely, AODV and DSR.

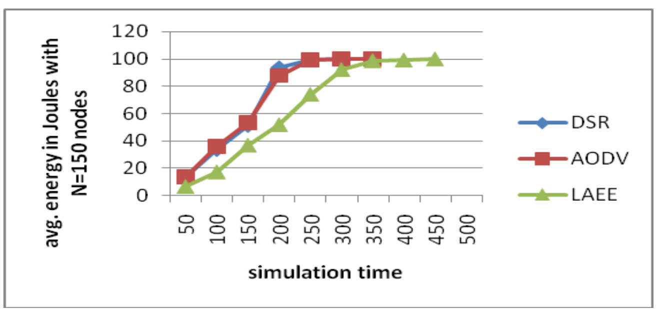
Table 1 Simulation Parameters

Parameter	Value
Simulation Time	500sec,100sec.
Terrain Area	500 X 500 sq. mts
Number of Nodes	50,100,150
Pause Time	0,10,20,30,40,50 sec.
Node placement	Random
Propagation Model	RWP
Channel Frequency	2.4 G.Hz.
Routing Protocol	DSR,AODV,LAEE
Transmission Range	250mts
Initial Energy for each node	100 Joules

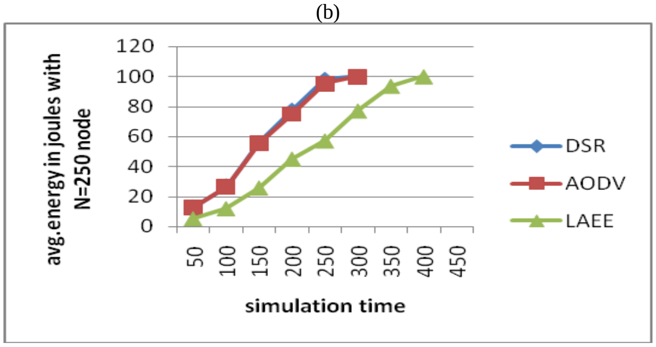
In Fig.1, it is observed that as the simulation time increases, the average energy consumed by the mobile nodes keeps on increasing.



(a)



(b)

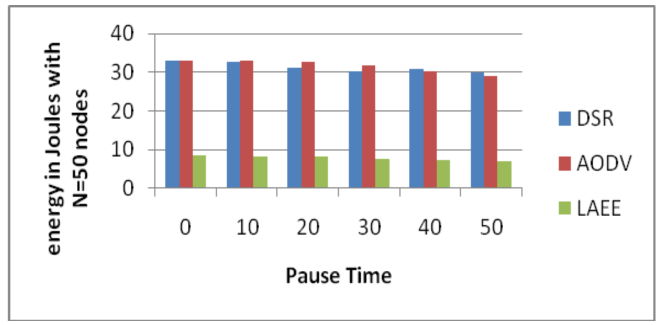


(c)

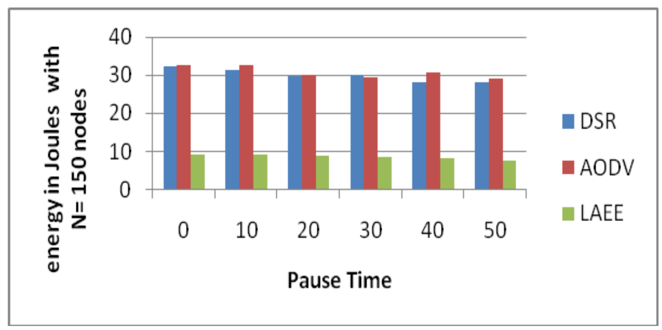
Figure 1 The average energy consumed vs. simulation time

The average energy consumption for DSR and AODV is almost same. The proposed routing algorithm LAEE consumes lesser energy as compared to both DSR and AODV routing algorithms. All the nodes drain off their residual energy by 350 sec. for DSR and AODV, whereas for the proposed LAEE algorithm it occurs at 500 sec. for 50 nodes, at 450 sec. for 150 nodes and at 400 sec. for 250 nodes. The Fig.2 shows the average energy consumption as the pause-time is increased from 0 to 50 sec. in steps of 10 sec., with simulation time being 100 sec. and initial energy 100 Joules. In this case also the proposed algorithm performs better, as it consumes 75% less energy as compared to the other two on-demand routing algorithms, DSR and AODV. There is decrease in average energy consumption as the pause time is increased.

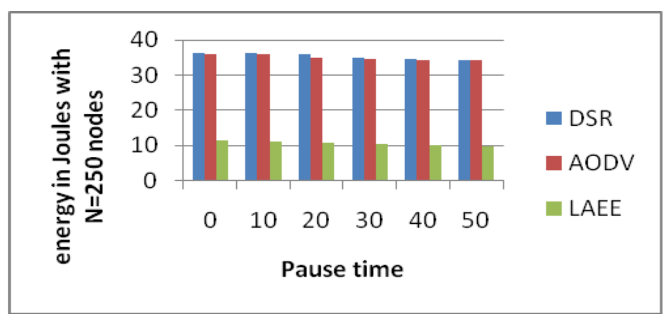
The Fig.3 shows the percentage of dead nodes as the simulation time varies from 50 to 500 sec. in steps of 50 sec. When the nodes lose all their residual energy, they can be declared as dead nodes. The network life time depends on the lifetime of the nodes.



(a)



(b)



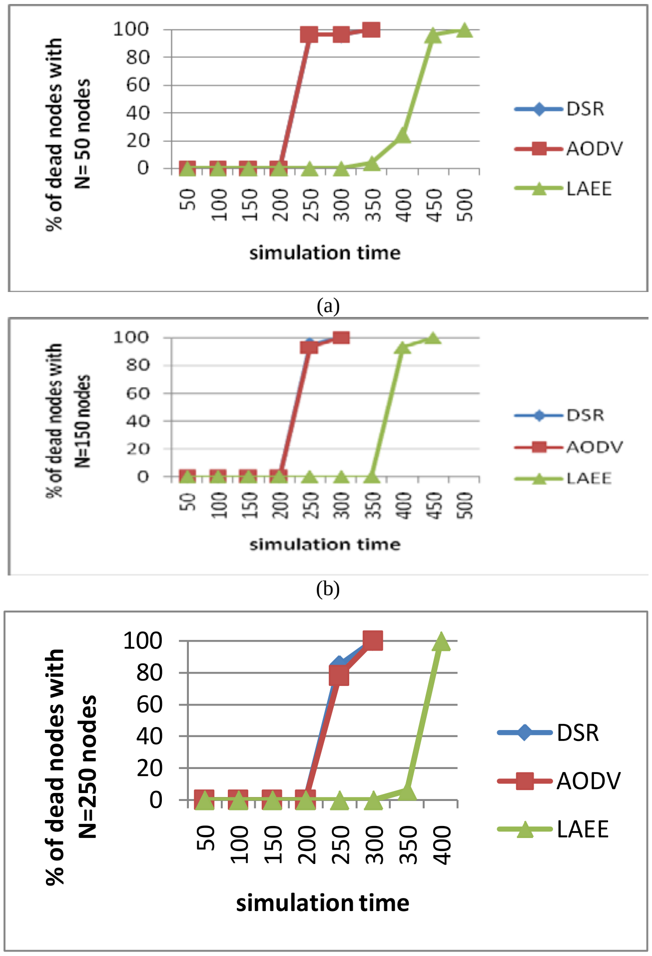
(c)

Figure 2 The average energy consumed vs. pause time

Network partitioning is usually defined [12] according to the following criteria:

a. The time until the first node burns out its entire battery budget.
b. The time until a certain portion of the nodes fails.
c. The time until the network partitioning occurs.

It can be seen that in case of DSR and AODV, the network partitioning occurs between 200 to 250sec.



(a) (b) (c)

Figure 3. The percentage of dead nodes vs. simulation time

For the proposed LAEE protocol, the network partitioning occurs between 300 to 350 sec. for 50 and 250 nodes, whereas it occurs between 350 to 400 sec. for 150 nodes. It can also be seen that the residual energy of all the nodes becomes zero at simulation time t=350sec. (for n=50), and at t=300 sec. (for n = 150 and 250 nodes) for DSR and AODV protocols, whereas, it happens at simulation time t=500, at t=450 and at t=400 correspondingly for n= 50, n=150 and n=250 for the proposed protocol LAEE. Further the nodes lose all their residual energy (thus become dead) rapidly in case of DSR and AODV as compared to the gradual decrease of energy in case of LAEE protocol. Hence, the LAEE protocol is able to provide more life time for the network. The life time of MANET for various node densities ranging from 50 to 300 in steps of 50 is given in Table 2. From Table 2, we observe that, the proposed protocol, achieves 23 to 71% increase in network life time when network partitioning due to first node failure occurs, an increase of 56 to 80% network life time when 50% of nodes fail and an increase of 28 to 43% life time when 100% of nodes fail as their residual energies become zero.

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V. CONCLUSION

In this paper, a novel load-aware energy efficient LAEE routing algorithm is proposed. In the proposed protocol, the energy of a mobile node is conserved by employing threshold energy for each node which is always a function of the residual energy of neighbors of that node. The network life time is enhanced by 23 to 71% using the proposed protocol as compared to other routing protocols, namely, AODV and DSR. The simulation experiments have been conducted using NS2 simulator. The experimental results show that the proposed algorithm performs better as compared to the commonly used on-demand routing protocols, namely, DSR and AODV.

Table 2. LComparison of proposed method LAEE with AODV and DSR in terms of life time of MANET for various node densities.

No. of Nodes	Time when first node's residual energy becomes zero			Time when 50% of nodes' residual energy becomes zero			Time when 100% of nodes' residual energy becomes zero		
	AODV	DSR	LAEE	AODV	DSR	LAEE	AODV	DSR	LAEE
50	212	214	320	232	237	423	350	350	500
100	220	220	362	228	230	425	350	350	500
150	210	212	360	230	235	422	300	300	450
200	212	214	362	240	242	392	350	350	450
250	213	214	308	232	230	383	300	300	400
300	210	210	260	238	236	372	300	300	400

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