An Energy Efficient Routing Protocol Based on Adaptive Transmission Range and Adaptive Threshold Energy

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Abstract— Wireless network devices, especially in ad hoc networks, are typically battery-powered. The growing need for energy efficiency in wireless networks, in general, and in mobile ad hoc networks (MANETs), in particular, calls for power enhancement features. In this paper, an on-demand routing protocol to extend network lifetime by improving energy utilization in MANET routing based on adaptive transmission range and adaptive threshold energy (ATRATE) has been presented. Instead of using fixed transmission range, transmission power is varied in accordance with the required transmission range ensuring sufficient number of mobile nodes to maintain network connectivity. Further, a power aware routing algorithm based on the adaptive threshold energy is used for routing of packets. The results are compared with the traditional AODV routing protocol, load-aware energy efficient routing protocol (LAEE) and power aware routing algorithm based on adaptive fuzzy threshold energy (AFTE). The proposed routing algorithm based on adaptive transmission range with adaptive threshold energy (ATRATE) is able to extend network lifetime longer as compared to AODV, LAEE, and AFTE routing algorithms.

Index Terms— MANET, transmission power, threshold energy, residual energy, fuzzy logic, load-aware

I. INTRODUCTION

The areas in which there is little or no communication infrastructure or the existing infrastructure is expensive or inconvenient to use, wireless mobile users may still be able to communicate through the formation of an ad hoc network. In such a network, each mobile node operates not only as a host but also as a router, forwarding packets for other mobile nodes in the network that may not be within direct wireless transmission range of each other. Each node participates in an ad hoc routing protocol that allows it to discover “multi-hop” paths through the network to any other node. The idea of ad hoc networking is sometimes also called infrastructureless networking, since the mobile nodes in the network dynamically establish routing among themselves to form their own network “on the fly”. Some examples of the possible uses of ad hoc networking include students using laptop computers to participate in an interactive lecture, business associates sharing information during a meeting, soldiers relaying information for situational awareness on the battlefield, and emergency disaster relief personnel coordinating efforts after a hurricane or earthquake. Many different protocols have been proposed to solve the multi-hop routing problem in ad hoc networks, each based on different assumptions and intuitions. Most of these routing protocols base their routing decisions on the metrics like delay, distance, cost etc. The nodes in a mobile ad hoc network (MANET) use batteries with a limited capacity for their computation and communication. Thus, efficient

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usage of battery power is most essential factor while making routing decisions. There has been a lot of research in the field of design of energy aware routing protocols for MANETs. The main consideration is to ensure that the each node consumes as less energy as possible and lasts for a longer period leading to the extended network lifetime of the MANET.

Ad hoc networks have to suffer many challenges at the time of routing. Dynamically changing topology (due to Brownian motion of the nodes of the network) and no centralized infrastructure are the biggest challenges in the designing of an ad hoc network. The position of the nodes in an ad hoc network continuously varies due to which it very difficult to say that any particular protocol will give the best performance in each and every case. Since topology varies very frequently, a protocol which dynamically adapts to the situation is to be selected. Another challenge in MANET is limited bandwidth. If we compare it to the wired network, wireless network has less but more varying bandwidth. So, bandwidth efficiency is also a major concern in ad hoc network routing protocol designing because sometimes data has to be transmitted within real time constraints. Limited power supply is the biggest challenge in an ad hoc network. If it is desired to increase the network lifetime (duration of time when the first node of the network runs out of energy) as well as the node lifetime, then, a proper energy efficient routing protocol has to be used. Various strategies have been proposed to improve the existing routing techniques such as introduction of power management, topology control, energy-related costs or fairness or improvement of interoperability between different protocol layers, etc. Most of the energy-conscious protocols have focused on either topology control through the adjustment of transmission power for the packets, or on using energy aware routing costs to minimize the energy costs of sending packets in the network. In contrast to 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. This goal can be accomplished by minimizing mobile nodes’ energy not only during active communication but also when they are inactive. Transmission power control and load balancing are two approaches to minimize the active communication energy, and sleep/power-down mode is used to minimize energy during inactivity. Each node has the functionality of acting as a router along with being a source or destination. The failure of some nodes’ operations can greatly impede performance of the network and even affect the basic availability of the network. Thus, it is of paramount importance to use energy efficiently when establishing communication patterns. In a network, power is consumed during computation and transmission of packet. The computation power is negligible as compared to transmission power cost. Recently, efforts are made to control the transmission power by incorporating different power control mechanisms. Since energy conservation is not an issue of one particular layer of the network protocol stack, many researchers have focused on cross layer designs to conserve energy more effectively. One such effort is to employ power control at the MAC layer and to design a power aware routing at the network layer. Power control is a mechanism that varies transmission power level of a node when sending packets. The primary benefit of power control is to increase channel capacity by reducing interferences among network nodes. The secondary benefit is to conserve energy by utilizing only necessary transmit power for packet transmissions. The transmission power determines the range over which the signal can be coherently received, and is therefore crucial in determining the performance of the network. The selection of the optimal transmission range has been investigated extensively in the literature. It has been shown that a higher network capacity can be achieved by transmitting packets to the nearest neighbor in the forward progress direction. The intuition behind this is that, halving the transmission range increases the number of hops by two but decreases the area of the reserved floor to one fourth of its original value, hence allowing for more concurrent transmissions to take place in the same neighborhood. In addition to improving the network throughput, reducing transmission range plays a significant role in reducing the energy required to deliver a packet in a multi-hop fashion. The power consumed by radio frequency (RF) power amplifier of the network interface card (NIC) is directly proportional to the power of the transmitted signal, and thus it is of great interest to control the signal transmission power to increase the lifetime of the mobile nodes. Presently, RF power amplifier consumes almost half of the total energy consumed by the NIC. This ratio is expected to increase as the processing components become more power efficient. Therefore, there is potential for significant energy saving by reducing the signal transmission power (range) and increasing the number of hops to the destination.

II. RELATED WORK

The impact of variable transmission range on power saving in MANETs is investigated in [1]. The performance analysis was done on two routing protocols, minimum hop routing (MHR) and minimum
total power routing (MTPR). It is observed that power consumed using MHR is always higher than MTPR as it takes a path that tries to minimize the number of nodes to reach destination as against MTPR which tries to select a path that tries to minimize the total power from source to destination. The impact of variable transmission power on link quality has been studied in [2]. It proposes variable power link quality control techniques to enhance the performance of data delivery in wireless sensor networks. It also proposes a packet-based transmission power control mechanism that incorporates blacklisting to enhance link reliability while minimizing interference. Two transmission power control algorithms called common power control (CPC), and independent power control (IPC) that adaptively change the transmission power used by stations in the network based on the load conditions have been proposed in [3]. It shows that the optimal transmission range is a function of the load in the network. Two approaches to adjust transmission power in WSNs have been presented in [4]. The first approach employs dynamic adjustments by exchange of information among nodes, and the second one calculates the ideal transmission power according to signal attenuation in the link. It shows that transmission power control is an effective method to decrease energy consumption, and incurs in a negligible loss in packet delivery rates. A scheme to control the transmission power of a node according to the distance between the nodes has been presented in [5]. It also includes energy information on route request packet and selects the energy efficient path to route data packets. The impact of individual variable-range power control on the physical and network layer connectivity, network capacity, and power savings of wireless multi-hop networks such as ad hoc and sensor networks has been done in [6]. It quantifies the pros and cons of common-range and variable-range transmission control on the physical and network layer connectivity. A distributed power control protocol [7] is proposed as a means to improve the energy efficiency of routing algorithms in ad hoc networks. Each node in the network estimates the power necessary to reach its own neighbours, and this power estimate is used both for tuning the transmit power (thereby reducing interference and energy consumption) and as the link cost for minimum energy routing. The purpose of topology control is to assign per-node optimal transmission power such that the resulting topology satisfies certain global properties such as connectivity. Due to the multi-hop nature of ad-hoc networks, establishing network connectivity may require nodes to use their power resources to service other nodes. Since nodes have limited power they may act selfishly in order to minimize their power (energy) consumption. A new on-demand routing protocol based on load balancing that uses adaptive threshold energy (LAEE) to conserves energy of mobile nodes and, hence, enhances the lifetime of the MANET is proposed in [8]. An on-demand energy efficient routing protocol based on adaptive threshold energy has been presented in [9]. The energy of a mobile node is conserved by employing fuzzy based threshold energy for each node which is always a function of the residual energy of neighbours of that node.

The objective of the present paper is to propose a cross layer design, in which adaptive transmission range is employed in MAC layer for each node depending on the node density in its neighbourhood, while energy efficiency is achieved by using the average threshold energy for onward data transmission in the network layer. The experimental results demonstrate the effectiveness of the proposed methodology.

III. PROPOSED METHODOLOGY

The radio transceiver of a wireless node consumes current at different rates depending on its state: sleep, idle listening or transmission, and setting the radio transmission power changes the current consumption at transmission state. Since increasing the radio transmission power has positive (reduced number of hops to the destination) and negative effects (increased interference among nodes), the radio transmission power needs to be set to the right level to achieve the best performance. The radio transmission power of each node can be set to a fixed value (fixed transmission-power control: FTPC), or it can be adjusted dynamically so that each node has similar number of neighbours (dynamic transmission-power control: DTPC). In this paper, the transmission power of a node is varied in accordance with the minimum number of neighbouring nodes in order to maintain the connectivity of the network. Further, every neighbour after receiving the route request from its previous node, checks whether its residual energy is greater than adaptive threshold energy before forwarding the route request to its next neighbour. Thus, the proposed protocol is a cross layer design technique with adaptive transmission power control at MAC layer and adaptive power aware routing at network layer. The default transmission range is usually 250 mts. The required transmission power \( p_t \) for a given transmission range \( d \) is determined by the Eq. (1).
\[ P_t = \frac{P_r \cdot d^4 \cdot L}{G_t \cdot G_r \cdot (h_t^2 + h_r^2)} \]  

Where \( P_r \) is the receiver threshold power, \( d \) is the distance (transmission range), \( L \) is the system loss, \( G_t \) and \( G_r \) are transmitter and receiver gains (usually 1), \( h_t \) and \( h_r \) are the heights of transmitter and receiver (usually 1.5 mts), respectively. The proposed method, which combines the adaptive transmission power control and the adaptive threshold energy routing, is as given below:

**Procedure: Adaptive Transmission Power Control**

1. Let \( N_n \) be the total number of nodes. Set the source node as the current node. Set the transmission power of the current node such that the transmission range \( d \) is 50 mts. (using Eq.(1))
2. Determine the number of neighbours \( N_c \) of the current node.
3. If \( N_c \geq 0.1 \cdot N_n \), then select the next node using adaptive Load Aware Energy Efficient Routing procedure and set the selected next node as the current node:
   - if the current node is the destination node then go to step 4,
   - else go to step 2;
   - else increase the transmission power such that transmission range \( d \) is incremented by 50 meters and go to step 2
4. Stop

**Procedure: Load Aware Energy Efficient Routing**

1. Let \( S \) be the source node having \( n \) neighbors with residual energy levels \( RE_i, i = 1, \ldots, n \).
2. For node \( S \), compute initial threshold \( Th \) given by
   \[ Th = \frac{1}{n} \sum_{i=1}^{n} (RE_i) \]
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 \( D \).
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.
5. Intermediate node responds by sending reply packet RREP if it has a path to destination. Go to step 7.
6. Intermediate node forwards RREQ after replacing the embedded \( Th \) value by the modified threshold value given by
   \[ Th = Th - \frac{1}{k} \left[ \frac{1}{k} \sum_{i=1}^{k} (RE_i) \right] \]
   where \( k \) is the number of neighboring nodes of the intermediate node and \( RE_i, i = 1, \ldots, k \) are their residual energy levels.
7. Repeat Steps 4 to 6 until packet sent by node \( S \) reaches the destination node \( D \).

**IV. RESULTS AND DISCUSSIONS**

The simulation experiments are carried out using NS2 simulator for different simulation times (50, ..., 600), in steps of 50. In the experiment various node densities ranging from 50 to 300 in steps of 50 are considered. The other simulation parameters are given in the Table 1. The results for node densities 50, 150, and 250 are shown in the graphical form in the Figs.1-2. Rest of the results are shown in Table 2. In Fig.1, it is observed that as the simulation time increases, the average energy consumed by the mobile nodes keeps on increasing. The proposed routing algorithm ATRATE consumes lesser energy as compared to AODV, LAEE and AFTE routing algorithms. The slope of the graph shown in Fig.1 is highest for AODV and lowest for ATRATE. It means that the rate at which the energy gets drained off is highest for AODV and lowest for ATRATE. The drain rate for LAEE and AFTE falls in between. All the nodes drain off their residual energy by 300-350 sec. for AODV protocol, for LAEE protocol it occurs at 400-450 sec., for the AFTE protocol it occurs at 500-550 sec. For the proposed ATRATE protocol, this period extends up to 600 sec.
The Fig. 2 shows the percentage of dead nodes as the simulation time varies from 50 to 600 sec. in steps of 50 sec. When the nodes lose all their residual energy, they can be declared as dead nodes. The network lifetime depends on the lifetime of the nodes. Network partitioning is usually defined [10] according to the following criteria:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation Time</td>
<td>50 sec. to 600 sec.</td>
</tr>
<tr>
<td>Terrain Area</td>
<td>500 X 500 sq. mts</td>
</tr>
<tr>
<td>Number of Nodes</td>
<td>50, 100, 150, 200, 250, 300</td>
</tr>
<tr>
<td>Node placement</td>
<td>Random</td>
</tr>
<tr>
<td>Propagation Model</td>
<td>RWP</td>
</tr>
<tr>
<td>Channel Frequency</td>
<td>2.4 G.Hz.</td>
</tr>
<tr>
<td>Routing Protocol</td>
<td>AODV, LAEE, AFTE, ATRATE</td>
</tr>
<tr>
<td>Transmission Range</td>
<td>250 mts</td>
</tr>
<tr>
<td>Initial Energy for each node</td>
<td>100 Joules</td>
</tr>
</tbody>
</table>

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

In our simulation experiment for determination of lifetime of a network we have considered three cases:

- Time at which the first node fails.
- Time at which the 50% of the nodes fail.
- Time at which all the nodes fail.

Considering the first node failure, it can be seen that in case of AODV protocol the network partitioning occurs at 210 sec., for LAEE protocol, the network partitioning occurs between 300 to 350 sec. for 50 and 250 nodes and between 350 to 400 sec. for 200 nodes, for AFTE protocol, it occurs between 350 to 400 sec. for 50 and 150 nodes and between 400 to 450 sec. for 250 nodes. For the proposed ATRATE protocol it occurs 350-400 sec. The residual energy of all the nodes for AODV becomes zero at simulation time 300 to 350 sec. for all node densities. It can also be seen that the residual energy of all the nodes becomes zero at simulation time t=500, at t=450 and at t=400 correspondingly for n= 50, n=150 and n=250 for the LAEE protocol. For AFTE protocol it occurs at t=500, at t=600 and at t=550 sec. For the proposed ATRATE protocol the residual energy for all the nodes becomes zero at 600 for all node densities. Further the nodes lose all their residual energy (thus become dead) rapidly in case of AODV, LAEE and AFTE protocol as compared to ATRATE protocol. Hence, the ATRATE protocol consumes less energy and is able to provide more lifetime for the network. The results of simulation for all nodes ranging from 50 to 300 in steps of 50 are given in the Table 2. From the Table 2, it is observed that, for a smaller number of nodes (50), considering the network partitioning due to a single node failure, ATRATE protocol is more efficient as it provides 26.8%, 14.6% more lifetime as compared to LAEE and AFTE routing protocols respectively. For medium density of nodes (100-150 nodes), considering network partitioning due to 50% node failure, ATRATE is more advantageous as it achieves 14% to 16% more lifetime as compared to LAEE. When 100% node failure is considered, ATRATE achieves 20% to 33% extra lifetime than LAEE, up to 10% more lifetime as compared to AFTE. For more denser networks (200-300 nodes), ATRATE is advantageous under all circumstances. Considering network partitioning due to single nodes failure, ATRATE achieves 13 to 33% more lifetime as compared to LAEE. Similarly, considering network partitioning due to failure of 50% nodes, it provides 24% to 30% more lifetime as compared to LAEE and up to 17% as compared to AFTE. Finally, considering 100% nodes failure, ATRATE outperforms all the protocols.

V. CONCLUSION

In this paper, a cross layer design of energy conservation protocol, based on adaptive variation in transmission power in MAC layer depending on node density and a power aware routing based on average threshold energy in network layer, has been proposed. The proposed protocol, namely, adaptive transmission range with adaptive threshold energy (ATRATE), is able to achieve energy conservation and to extend network lifetime. The simulation experimental results are compared with AODV, LAEE and AFTE routing protocols. It is observed that, in general, ATRATE is able to extend network lifetime by 90 to 100% as
compared to AODV and 15 to 33% as compared to LAEE and 10 to 22% as compared to AFTE routing protocols.

Figure 1. Simulation time v/s Average energy consumed

Figure 2. % of dead nodes vs. simulation time

| Table II. Performance Comparison of AODV, LAEE, AFTE and ATRATE Routing Protocols for Different 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 | LAE | AFE | ATRATE | AODV | LAE | AFE | ATRATE | AODV | LAE | AFE | ATRATE |
| 50                             | 212  | 320 | 354 | 406    | 232  | 423 | 426 | 472    | 350  | 500 | 500 | 550    |
| 100                            | 220  | 362 | 364 | 405    | 228  | 425 | 476 | 492    | 350  | 500 | 600 | 600    |
| 150                            | 210  | 360 | 364 | 372    | 230  | 422 | 482 | 482    | 300  | 450 | 600 | 600    |
| 200                            | 212  | 362 | 410 | 410    | 240  | 392 | 490 | 497    | 350  | 450 | 550 | 600    |
| 250                            | 213  | 308 | 405 | 413    | 232  | 383 | 476 | 501    | 300  | 400 | 550 | 600    |
| 300                            | 210  | 260 | 308 | 345    | 238  | 372 | 422 | 495    | 300  | 400 | 500 | 600    |
REFERENCES


