Volume 3, Issue 8, August 2013 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

Energy Aware Routing Protocol Based on Adaptive Transmission Range and Fuzzy Threshold Energy

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Abstract— Energy efficiency is a critical issue for battery-powered mobile devices in ad hoc networks, wherein routing based on energy-related parameters is used to extend the network lifetime. In this paper, a comprehensive energy optimized cross layer routing algorithm is proposed and is implemented with ad hoc on demand distance vector routing (AODV). 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 fuzzy threshold energy is used for routing of packets. The results are compared with the traditional AODV routing algorithm and also with power aware routing algorithm based on adaptive fuzzy threshold energy (AFTE). The proposed routing algorithm based on adaptive transmission range with AODV (ATRAODV) is able to extend network lifetime longer as compared to AODV and AFTE routing algorithms.

Keywords— MANETs, residual energy, network lifetime, threshold energy

I. INTRODUCTION

Wireless communication is one of the fastest growing fields in telecommunication industry. The communication systems, such as cellular, cordless phones, wireless local area networks (WLAN), etc., have become an essential tool for people in today's life. Using these systems and the equipments like PDA, laptops, cell phones, user can access all the required information whenever and wherever needed. All these systems need some fixed infrastructure. It involves more time and high cost to set up the necessary infrastructure. There are situations where the networking connections as desired by the users are not available in a given geographic area, and providing such connectivity and network services becomes a real challenge. So, in such situations, mobile communication network without a pre-existing network infrastructure is the best solution. The mobile ad hoc networks (MANETs) are wireless networks characterized by the absence of fixed infrastructures. The main aim of MANETs is to support robust and efficient operations in mobile wireless networks. MANET consists of mobile nodes which form a spontaneous network without a need of fixed infrastructure. It is an autonomous system in which mobile hosts connected by wireless links are free to move randomly and often act as routers at the same time. Hence, it forms a multi-hop network. The ad hoc networks are gaining more importance due to the fact that they can be easily deployed as well as reconfigured. It allows the use of this kind of network in special circumstances, such as disastrous events, the reduction or elimination of the wiring costs and the exchange of information among users independent of the environment. The applications of MANETs are ranging from large-scale, mobile, highly dynamic networks, to small, static networks that are constrained by power sources. It can be used in military communication, commercial sectors like disaster management, emergency operations, wireless sensor networks, etc. Though MANETs have very attractive applications, they also pose some problems and challenges.

As MANET is a wireless network, it inherits the traditional problems of wireless networking:

- The channel is unprotected from outside signal.
- The wireless media is unreliable as compared to the wired media.
- Hidden terminal and exposed terminal phenomenon may occur.
- The channel has time varying and asymmetric propagation properties.

Along with these problems, there are some other challenges and complexities:

- The scalability is required in MANET, because the network grows in a practical situation according to the need, and hence each mobile device must be capable to handle the intensification of network and to accomplish the task.
- MANET is an infrastructureless network. There is no central administration. Each device can communicate with every other device. Hence, it becomes difficult to detect and manage the faults. In MANET, the mobile devices can move randomly. The use of this dynamic topology results in route changes, frequent network partitions and possibly packet losses.
- Each node in the network is autonomous. Hence, the nodes have the equipment for radio interface with different transmission / receiving capabilities, which results in asymmetric links. MANET uses no router in between.

- Nodes are mobile and can be connected dynamically in an arbitrary manner. This leads to dynamic topology, which is based on the proximity of one node to another node.
- Mobile nodes rely on battery power, which is a scarce resource. Also storage capacity and power are severely limited. Lifetime of MANET depends on the lifetime of a mobile node.
- Mobility implies higher security risks such as peer-to- peer network architecture or a shared wireless medium accessible to both legitimate network users and malicious attackers. Eavesdropping, spoofing and denial-of-service attacks etc. are possible.

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. Since the devices used in MANETs are mostly battery powered, the energy is a scarce resource and, hence, power conservation is a major issue of such networks. A large volume of research has been conducted on the issue of energy efficiency for MANETs. 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 neighbour in the forward progress direction. The intuition behind this result 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 neighbourhood. 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 multihop 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. On the other hand, the transmission power determines who can hear the signal, so reducing it can adversely impact the connectivity of the network by reducing the number of active links and, potentially, partitioning the network. Thus, to maintain the connectivity, power control should be carried out while accounting for its impact on network topology.

II. RELATED WORK

Transmission power control is a prototypical example of a cross-layer design problem. The transmission power level affects signal quality and, thus, impacts the physical layer. Further, it determines the neighbouring nodes that can hear the packet and, thus, the network layer experiences interference which causes congestion in the transport layer. It is also the key to several performance measures such as throughput, delay, and energy consumption. The challenge of locating the power control problem in the architecture is discussed in [1]. It also discusses about the determination of the appropriate power level depending upon its impact on several performance issues relating to the multiple effects of transmission power control. A novel energy-efficient route discovery scheme with transmission power control for ad hoc networks has been proposed in [2]. When a node receives a RREQ, it calculates the routing-level back-off time as being inversely proportional to received power of RREQ. After route discovery, source and intermediate nodes transmit packets by power controlled medium access control (MAC) protocol. It also presents the extended version of the scheme for discrete power control devices. The DPAECR [3] uses per packet power calculation of the links and updates the sender with the required transmission power. Then, the sender updates its transmission power and sends the data packets using that power. After receiving the data packet, each of the nodes calculate the required transmission power and update the sender by sending a reply packet. As the sender updates the required transmission power, the energy utilization will be reduced. A scheme that takes into consideration the power awareness during route selection has been proposed in [4]. This scheme observes power status of each and every node in the topology and further ensures the fast selection of routes with minimal efforts and faster recovery. The scheme is incorporated with the AODV protocol and the performance has been studied through simulation over NS-2.

The main goal of minimum energy routing (MER) protocol [5] is not to provide energy efficient paths but to make the given path energy efficient by adjusting the transmission power just enough to reach to the next hop node. Transmission power control provides an opportunity to save energy by utilizing intermediate nodes between two distant nodes. However, the resultant path with many short-range links may perform worse than a path with fewer long-range links in terms of latency as well as energy consumption. This is because the path with many short-range links would cause more link errors that would result in more retransmissions. To deliver packets with minimum energy, the transmission power control approach adjusts each node's radio power and allows different transmission power levels at different nodes. The impact of individual variable-range power control on the physical and network connectivity, network capacity, and power savings of wireless multihop networks such as ad hoc and sensor networks has been investigated in [6]. The presence of an optimum setting for the transmission range, not necessarily the minimum, which maximizes the capacity available to nodes in the presence of node mobility has also been shown. 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 problem of power control when nodes are non-homogeneously dispersed in space is considered in [8]. In such situations, one seeks to employ per packet power control depending on the source and destination of the packet. This gives rise to a joint problem which involves not only power control but also clustering. An overview of various power control approaches that have been proposed in the literature are discussed in [9]. The factors that influence the selection of the transmission power, including the important interplay between the routing (network) and the medium access control (MAC) layers have also been discussed. A power-aware routing optimization (PARO) that helps to minimize the transmission power needed to forward packets between wireless devices in ad hoc networks is presented in [10]. One or more intermediate nodes called "redirectors" elects to forward packets on behalf of source-destination pairs thus reducing the aggregate transmission power consumed by wireless devices. PARO is applicable to a number of networking environments including sensor networks, home networks and mobile ad hoc net-works. The two important multi-hop ad hoc network scenarios: Node Mobility Scenario and Transmission Range Scenario are analysed and their impact on the performance of various back off algorithms have been evaluated in [11]. A power aware routing, which minimizes the total transmit power, with BASIC-like power control, which is a simple modification of IEEE 802.11, has been discussed in [12]. It uses Power Aware Routing Optimization (PARO) as an example. It has been shown that the power aware routing with BASIC-like power control is not energy efficient; it may even consume more energy as compared to IEEE 802.11 without power control. Transmission power control has the potential to increase a network's traffic carrying capacity, reduce energy consumption [13]. A power aware routing protocol based on adaptive fuzzy threshold energy is presented in [14].

III. PROPOSED WORK

When a node's radio transmission power is controllable, its direct communication range as well as the number of its immediate neighbours are also adjustable. While stronger transmission power increases the transmission range and reduces the hop count to the destination, weaker transmission power makes the topology sparse which may result in network partitioning. The transmission power control approach is not only energy efficient, but it also reduces the interference in the transmission ranges of the different nodes, which certainly leads to increase in the throughput of the network. In this paper, the objective is to propose a new adaptive transmission power control based on the number of neighbouring nodes. It also incorporates load balancing by using adaptive fuzzy based threshold energy (AFTE) technique [14]. 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 power control approach consists of adjusting the transmission range of a node depending on the number of neighbouring nodes to ensure network connectivity. The default transmission range is usually 250 mts. The required transmission power (Pt) for a given transmission range (d) is determined by the Eq. (1).

$$Pt = \frac{Pr*d^4*L}{Gt*Gr*(ht^2*hr^2)} \qquad (1)$$

where, Pr is the receiver threshold power, d is the distance (transmission range), L is the system loss, Gt and Gr are transmitter and receiver gains (usually 1.0), ht and hr 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 fuzzy threshold energy routing, is as given below:

```
Procedure Adaptive Transmission Power Control:
1. Let  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 of the current node.
3. If $N_C >= 0.1 N_0$ ,
        then select the next node using adaptive fuzzy threshold energy routing method 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 50mts
        and go to step 2.
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4. Stop.

Procedure *Adaptive Fuzzy Threshold Energy (AFTE) Routing*:

Let , i = 1,2, …… , n , be the residual energies of the n neighbouring nodes of a transmitter node. Let minRE = min{ } , maxRE = max { } and midRE = (minRE + maxRE) / 2. We define the three fuzzy subsets of these neighboring nodes with low, medium and high residual energies, whose membership functions μ_{low} , μ_{medium}, and μ_{high} , respectively, are given below (Fig 1).

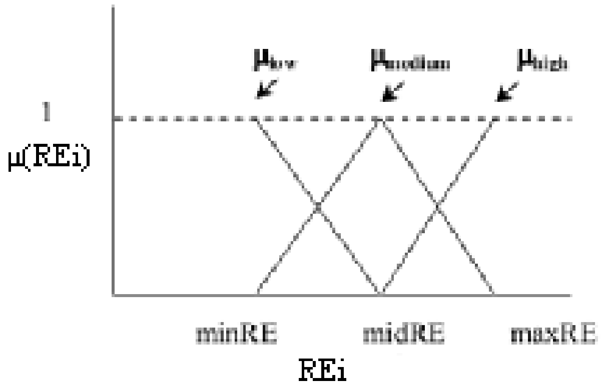


Fig.1. Membership functions for nodes with fuzzy RE levels.

$$\mu_{low}(RE_i) = \begin{cases} \dfrac{RE_i \text{ - midRE}}{\text{min RE - midRE}} & , \text{ min RE} \le RE_i \le \text{max RE} \\ 0 & , \text{ midRE} \le RE_i \le \text{max RE} \end{cases}$$

$$\mu_{medium}(RE_i) = \begin{cases} \dfrac{RE_i \text{ - midRE}}{\text{min RE - midRE}} & , \text{ min RE} \le RE_i \le \text{midRE} \\ \dfrac{RE_i - \text{max RE}}{\text{midRE} - \text{max RE}} & , \text{ midRE} \le RE_i \le \text{max RE} \end{cases}$$

$$\mu_{high}(RE_i) = \begin{cases} 0 & , \text{ min RE} \le RE_i \le \text{midRE} \\ \dfrac{RE_i - \text{midRE}}{\text{max RE} - \text{midRE}} & , \text{ midRE} \le RE_i \le \text{max RE} \end{cases}$$

Then the membership value μ of RE $_i$ for the ith node is given by:

$$\mu_i(RE_i) = \max\left\{\mu_{low}(RE_i), \mu_{medium}(RE_i), \mu_{high}(RE_i)\right\}$$

Let RE_{TH} be the value of RE_i for which the membership value is minimum among the neighbouring nodes, i.e,

$$\mu_{Th}(RE_{TH}) = \min_{1 \le i \le n}\left\{\mu_i\left(RE_i\right)\right\}$$

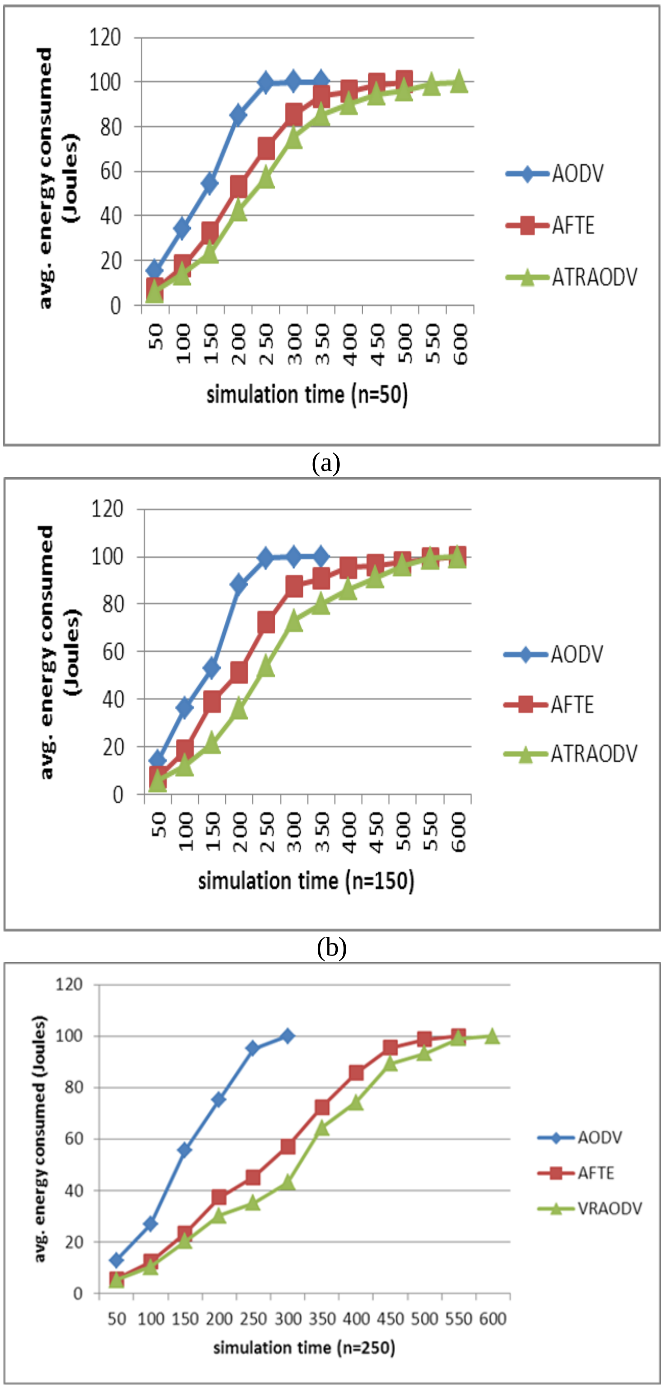
If there is a tie, it is broken by selecting the node with min RE among the nodes with the same minimum membership value . Then RE_{TH}, obtained by this defuzzification process, is used as the threshold energy value, which is transmitted in RREQ packet to the neighbouring nodes. Every intermediate node i, after receiving RREQ packet, checks if $RE_i > RE_{TH}$, where, RE_i is the residual energy of node i, then the node will forward the route request to its next hop. Otherwise, the node simply drops the route request packet.

IV. RESULTS AND DISCUSSIONS.

The proposed protocol is implemented using NS2 simulator, for different simulation times (50,100,.., 600) in steps of 50, for different number of nodes (50,100,…, 300) in steps of 50. The other parameters used for simulation are given below in the Table I. The simulation results for 50,150 and 250 nodes are shown in the Figs. 2–3. The complete simulation results are given in the Table 2. The results are compared with the performance of the on-demand routing protocol AODV and AFTE.

TABLE I
SIMULATION PARAMETERS

Parameter	**Value**
Simulation Time	50 sec. …. 600 sec.
Terrain Area	500 X 500 sq. mts
Number of Nodes	50,100,…300
Node placement	Random
Propagation Model	RWP
Channel Frequency	2.4 G.Hz.
Routing Protocol	AODV,AFTE,ATRFTE
Transmission Range	50…250mts
Initial Energy for each node	100 Joules

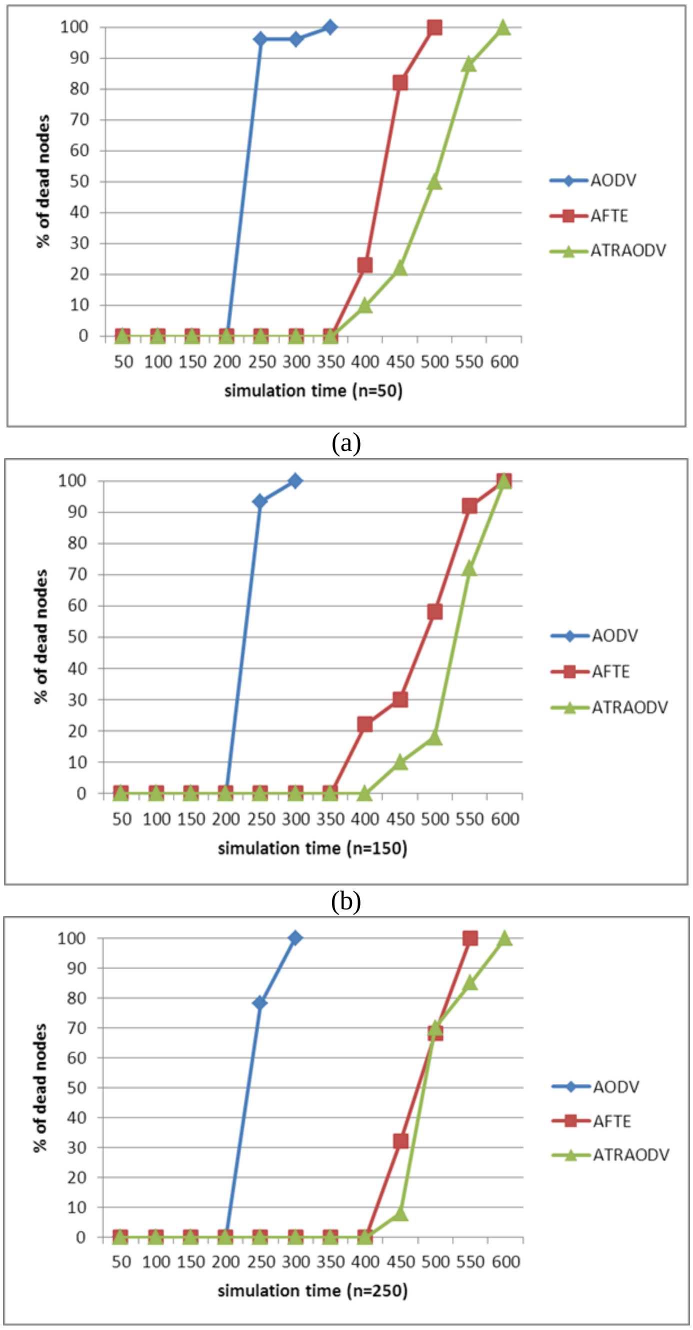


(a)

(b)

(c)

Fig. 2. Average energy consumed vs. simulation time for simulation runs up to 50,150 and 250 secs. using AODV, AFTE and the proposed ATRAODV.



(a)

(b)

(c)

Fig. 3. .The % of dead nodes vs. simulation time for simulation runs up to 50, 100, and 250 secs. using AODV, AFTE and the proposed ATRAODV

From the Fig.2, it is observed that as the simulation time increases, the average energy consumed by the mobile nodes keeps on increasing. The proposed algorithm ATRAODV consumes less energy as compared to AODV and AFTE. All the nodes drain off their energy by 350-400 sec. for AODV, by 500-600 for AFTE. But for ATRAODV all the nodes drain off their energy by 600 sec. From the figure it can also be seen that energy drain rate for ATRAODV is more gradual as compared to AODV and AFTE. It can also be seen that for ATRAODV, as the node density increases the average energy consumed decreases. The Fig. 3 shows the percentage of dead nodes as the simulation time increases from 50 to 600 in steps of 50. It can be seen that the ATRAODV is able to attain more network life time as compared to AODV and AFTE protocols. The ATRAODV protocol achieves 42% and 32% more lifetime for lower node density and 100% and 20% for higher density, as compared to AODV and AFTE, respectively. From the Table II, considering network partitioning due to first node failure, it can be seen that ATRAODV is able to prove 70% to 100% more lifetime as compared to AODV, it is able to extend network lifetime by 5 to 36% as compared to AFTE. Considering 50% node failure, ATRAODV is able to achieve more than 100% network lifetime as compared to AODV, whereas it extends network lifetime by 2 to 17% as compared to AFTE. Considering 100% node failure, ATRAODV is able to provide 83 to 100% more network lifetime as compared to conventional AODV, whereas it is able to extend network lifetime by 9 to 20% as compared to AFTE.

TABLE II.
PERFORMANCE COMPARISON OF AODV,AFTE AND ATRAODV 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	**AFTE**	**ATRAODV**	**AODV**	**AFTE**	**ATRAODV**	**AODV**	**AFTE**	**ATRAODV**
50	212	354	372	232	426	500	350	500	600
100	220	364	422	228	476	490	350	600	600
150	210	364	410	230	482	532	300	600	600
200	212	410	442	240	490	545	350	550	600
250	213	405	422	232	476	485	300	550	600
300	210	308	418	238	422	486	300	500	600

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 fuzzy based threshold energy routing in network layer, has been proposed. The proposed protocol, namely, adaptive transmission range with AODV (ATRAODV), is able to achieve energy conservation and to extend network lifetime. The simulation experimental results are compared with AODV and AFTE routing protocols. It is observed that, in general, ATRAODV is able to extend network lifetime by 90 to 100% as compared to AODV and 20 to 35% as compared to AFTE.

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