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Abstract. Energy efficiency is a critical issue for battery-powered mobile devices in ad hoc networks. Failure of node or link allows re-routing and establishing a new path from source to destination which creates extra energy consumption of nodes, sparse network connectivity and a more likelihood occurrences of network partition. Routing based on energy related parameters is one of the important solutions to extend the lifetime of the network. In this paper, we are designing and evaluating a novel energy aware routing protocol called a balanced battery usage routing protocol (BBU) which uses residual energy, hop count and energy threshold as a cost metric to maximize network life time and distribute energy consumption of Mobile Ad hoc Network (MANET) based on Ad hoc on-demand Distance Vector (AODV). The new protocol is simulated using Network Simulator-2.34 and comparisons are made to analyze its performance based on network lifetime, delivery ratio, normalized routing overhead, standard deviation of residual energy of all Nodes and average end to end delay for different network scenarios. The results show that the new energy aware algorithm makes the network active for longer interval of time once it is established and fairly distribute energy consumption across nodes on the network.

Keywords: AODV, BBU-AODV, MANET, NS-2.34, Network Lifetime, energy consumption, residual energy.

1 Introduction

Recent advances in wireless communication technologies and availability of less expensive computer processing power have led to an interest in mobile computing applications. Mobile Ad hoc Network (MANET) is a special type of wireless network in which a collection of mobile entities form a temporary network without the aid of any established infrastructure or centralized administration [1]. Therefore, dynamic topology, unstable links, limited energy capacity and absence of fixed infrastructure are special features for MANET when compared to wired networks. These characteristics put special challenges in routing protocol design.

The key challenge in the design of wireless ad hoc networks is the limited availability of the energy resources. Each of the mobile nodes is operated by a limited energy battery and usually it is impossible to recharge or replace the batteries during a mission such as in battlefields and emergency relief scenarios [2, 3]. Since each mobile node in a MANET acts both as a router and host and most of the mobile nodes rely on other nodes to forward their packets, the failure of a few nodes, due to energy exhaustion, might cause the disruption of service in the entire network. Thus, researchers have focused on design of power-aware network protocols for the ad hoc networking environment to extend network lifetime and balance energy usage among mobile nodes.

In recent years, many researchers have focused on the optimization of energy consumption of mobile nodes, from different points of view. Some of the proposed solutions try to adjust the transmission power of wireless nodes; other proposals tend to efficiently manage a sleep state for the nodes [4]. Finally, there are many proposals which try to design an energy efficient routing protocol by means of an energy efficient routing metric instead of the minimum-hop count.

In this paper a new energy efficient algorithm called BBU-AODV, which maximizes the life time of a MANET by avoiding routing of packets through nodes with low residual energy and balance the total energy consumption among all nodes in the network while selecting a route to the desired destination, is proposed. BBU routing protocol is developed on top of the popular AODV routing protocol.

The remainder of the paper is organized as follows. In section 2, we describe MANET routing protocols. In Section 3, we review some of the proposed energy-aware routing protocols for MANETs. We explain in detail our proposed work and its integration with AODV in Section 4. In Section 5, we compare the performance of our protocol with that of AODV via Network simulator NS-2.34 simulations for a variety of network scenarios, and finally, we conclude the paper in Section 6.

2 MANET Routing Protocols

In this section we describe routing protocols in MANET and the basic operation of the reactive AODV routing protocol. MANET routing protocols could be classified into three categories based on the routing information update mechanism: proactive (table-driven), reactive (on-demand) and hybrid [5].

Proactive routing protocols require nodes to exchange routing information periodically and compute routes continuously between any nodes in the network, regardless of using the routes or not. This means a lot of network resources such as energy and bandwidth may be wasted, which is not enviable in MANETs where the resources are constrained. On the other hand, reactive routing protocols do not exchange routing information periodically. Instead, they discover a route only when it is needed for the communication between two nodes. Proactive protocols inherently consume more energy than the Reactive ones; hence most of the research works involve modifications to reactive protocols. The last category which is Hybrid routing protocols combine the basic properties of the first two classes of protocols. That is, they are both reactive and proactive in nature. It uses the route discovery mechanism of reactive protocol to determine routes to far away nodes and the table maintenance mechanism of proactive protocol to maintain routes to nearby nodes.

Among reactive protocols, AODV is considered potentially the most energy efficient routing protocol. Hence many research studies have focused on making AODV routing protocol more energy efficient [6].

Ad hoc On-demand Distance Vector (AODV): When a node wants to find a route to a destination and does not have a valid route to that destination, it will initiate a path discovery process. Path discovery process is initiated by broadcasting a route request packet (RREQ) to its neighbors. When a node receives RREQ in case it has routing information to the destination, it sends a route reply (RREP) packet back to the source. Otherwise, it rebroadcasts RREQ packet further to its neighbors till either the destination is reached or another node is found with a fresh enough route to the destination. Nodes that are part of an active route keep its connectivity by broadcasting periodically local Hello messages to its neighbors. If Hello messages stop arriving from a neighbor beyond some time threshold, the connection is assumed to be lost. When a node detects that a route to a neighbor node is not valid it removes the routing entry and sends a route error (RERR) message to neighbors that are active and use the route. This procedure is repeated at nodes that receive RERR messages till it reaches to the source node. A source that receives an RERR can reinitiate a route discovery by sending a RREQ Packet. In AODV, the routing process will not consider about the energy of the node rather it considers only minimum hop-count along the paths [7]. Hence AODV algorithm may result in a quick depletion of nodes battery along the most heavily used routes in the network.

3 Related Works

Routing is one of the important solutions to the problem of energy efficiency in Mobile ad hoc network. In the recent past years energy efficient routing in Ad hoc network has been addressed by many research works which has produced so much innovation and novel ideas in this field. The majority of energy efficient routing protocols for MANET try to reduce energy consumption by means of an energy efficient routing metric instead of the minimum-hop metric. Each and every protocol has some advantages and shortcomings. None of them can perform better in every condition. It depends upon the network parameters which decide the protocol to be used. This section reviews some of the many energy efficient schemes based on AODV developed by researchers in the field.

In Zhaoxiao et al. [8], to mitigate the energy saving problem, an energy-aware routing named EAODV for Ad Hoc networks is proposed. The algorithm selects routing according to the dynamic priority-weight (β) and takes the hop count as an optimization condition. The dynamic priority weight is determined using the square of the ratio of residual battery energy(R) and consumed energy(C) of a node at time t as shown below.

$$\beta_i(t) = \left(\frac{R_i(t)}{C_i(t)}\right)^2$$

The destination node selects two maximum summation of priority-weight which spends less energy and owns larger capacity based on synthetic analysis among possible routes and propagates the route reply (RREP) messages to the source node. The second path will be used when the primary path fails. Since the work considered the summation of priority-weight, the selected path for data transmission might contain a node which has less remaining energy.

Jie et al [9] propose a PS-AODV routing protocol based on load conditions of a node to balance uneven nodes energy consumption of the traditional AODV. They made an improvement in route discovery process. Node checks its load value when received a RREQ packet before forwarding RREQ packets. If the node load is too high, it refuses to forward the RREQ packet until the load is reduced. However queue load condition could not give guarantee to protect nodes with little battery capacity which decreases network life time.

Lei and Xiaoqing [10] propose an improved energy aware AODV strategy to extend network life time. The improvements made by the authors are on route request packets and hello mechanisms of AODV. However the algorithm did not consider fair distribution of energy usage across nodes on the network.

Patil et al. [11] introduce an algorithm which combines Transmission Power and Remaining Energy Capacity and integrates these metrics into AODV so that the Ad hoc network has a greater life time and the energy consumption across the nodes is reduced. During route discovery from source to destination the transmission and remaining energy values along the route are accumulated in the RREQ packets. At the destination or intermediate node (which has a fresh enough route to the destination) these values are copied into the RREP packet which is transmitted back to the source. The source alternates between the maximum remaining energy capacity route and minimum transmission route every time it performs route discovery. Since hop count did not consider as a cost metric and transmission power is used for route selection, the selected link for data transmission might be frequently broken which creates more energy consumption and shorten life time of network.

Kim and Jang [12] propose an enhanced AODV routing protocol to maximize networks lifetime in MANET using an Energy Mean Value algorithms. Here, energy remaining of each node in the path between source and destination is accumulated and delivered to the destination by adding a field on a RREQ message. The destination node does not give a RREP reply immediately to the first RREQ, rather it waits for 3 * NODE_TRAVERSAL_TIME to receive additional RREQ packets destined for the node. Then the destination node adds the accumulated residual energy of each path and divides by the number of hops along the paths to obtain the mean energy of network. Finally the destination node unicasts RREP messages along the reverse path of the RREQ message received first and nodes hearing the RREP message store the mean energy. When a new path is discovered, the mean energy stored in each node is compared with the residual energy in the node. If the residual energy is less than the mean energy, the delay time of RREQ message is set to be 0.5ms otherwise the delay time of RREQ message is set to 0.05ms.Since the nodes are mobile, cumulative delay of each node affect the relay node out its position during data transmission which minimizes network lifetime and consumes battery.

Liu et al. and Sara et al. [13,14], propose a multipath mobile ad hoc routing protocol which extends the Ad Hoc On-demand Multipath Distance Vector routing protocol . The protocol finds the minimum remaining energy of each route and sort multi-route by descending nodal residual energy. Once a new route with higher nodal residual energy is emerging, it is reselected to forward rest of the data packets.

The work done in Tie et al. [15] proposes ALMEL-AODV which considers node remaining energy as a routing metric to balance and extend the survival time of the nodes in the network. The proposed algorithm chooses two highest summations of residual energy routes for data transmission. The second route will be used as a backup. Although the metric used is important, a node which has very low residual energy might be included during message transmission as they centered on maximum summation of remaining energy irrespective of nodal residual energy. Hence the remaining capacity of each host should be consider as a metric to prolong the life time of the network.

Kim et al. [16] introduce an energy drain rate metric, which represents the rate of battery consumption. It estimates the lifetime of a node; therefore, if the estimated value is below a threshold, the traffic passing through it can be diverted in order to avoid node failure due to battery exhaustion. The cost of a node i is calculated as the ratio between the Remaining Battery Power (RBC) and the Drain Rate (DR):

$$C = RBC / DR$$

C-K Toh [17] proposes a routing algorithm called Minimum Total Transmission Power Routing (MTPR) based on minimizing the amount of energy required to get a packet from source to destination. The problem is mathematically stated as:

$$\underset{\Pi}{Min} \left\{ \sum_{(i,j)\in \Pi} T_{ij} \right\}$$

Where Tij denotes the energy consumed in transmitting between two consecutive nodes i and j in route ∏. Although the MTPR can reduce the total energy consumption of the overall network, it does not reflect the lifetime of each mobile entity.

Singh et al. [18] propose the Minimum Battery Cost Routing (MBCR) which used the remaining energy capacity as a cost metric, and the cost function is defined as:

$$C_R = \sum_{i=1}^{k-1} f(E_r^i(t))$$

$$\text{where} \quad f(E_r^i(t)) = \frac{1}{E_r^i(t)} \; ; \; E_r^i(t) - \text{remaining energy of node } i \text{ at time } t$$

MBCR selects routes with a minimum cost value to choose the route with the maximum remaining energy capacity. However, MBCR only considers the summation of the inverse of residual battery capacities for all nodes along the path. Thus, routes containing small energy capacity nodes can still be chosen.

Local Energy-Aware Routing Protocol is proposed by works in [19][20][21][22][25]. When a node receives a RREQ message at time t, it compares its current remaining energy capacity with the predefined threshold value or computed value. If the residual energy is less than the threshold or computed value, the RREQ message is dropped. Otherwise, the message is processed and forwarded. However, the destination will receive a route request message only when all intermediate nodes along the route have enough battery levels. If all the paths to destination have small residual energy, the RREQ message will not be reached at the destination.

Kumar and Banu [23] present an E2AODV scheme to balance load distribution of nodes. A threshold value is used to judge if intermediate node was overloaded or not. Here, an intermediate node receiving the RREQ will compare its current queue length with its threshold before rebroadcasting it. If queue length is greater than the threshold, the RREQ will be dropped. Otherwise, the node will broadcast it. In their scheme, the threshold value plays the key role in selecting nodes whether or not to forward RREQ. Every time an intermediate node receives a RREQ, it will recalculate the threshold according to the average queue length of all the nodes along the path to the node itself. Therefore, the threshold is variable and changing adaptively with the current load status of network.

4 The Proposed Work

The main aim of this work is to propose a routing protocol that increase the life time of network and fairly distribute an energy consumption of hosts in MANET. The algorithm which we propose combines threshold, summation of residual energy, min residual energy and hop count as a cost metric and integrates these metrics into AODV in an efficient way. This metrics ensure that all the nodes in the network remain up and running together for as long as possible.

4.1 Modification on RREQ Packet

The proposed energy aware AODV modifies route request (RREQ) packet for route discovery process as shown in Figure 1. We modified the fields in the RREQ packet by adding minimum residual energy (MRE) and sum of residual energy (SRE) which keeps the minimum remaining energy and sum of remaining energy along the path respectively. An EnergyDifference (D) field, which stores the difference between either average minimum residual energy (AME) and threshold (Th) or average sum of residual energy (ASE) and threshold (Th), is also added on the routing table at a destination node.

In BBU-AODV, when all nodes in some possible routes between a source-destination pair have large remaining energy than the threshold then a route with maximum of the difference of average sum of residual energy and threshold among the routes is selected. Otherwise the maximum difference of the average minimum residual energy and threshold among the routes is selected.

TYPE	**Reserved**	**Hop Count**
Broadcast ID		
Destination IP Address		
Destination Sequence Number		
Source IP Address		
Source Sequence Number		
Minimum Residual Energy(MRE)		
Sum Residual Energy(SRE)		

Fig. 1. Modified RREQ Packet format

4.2 Mathematical Model of BBU-AODV

If we consider a generic route $r_j = n_0 , n_1 , n_2 , \dots , n_d$, where n_0 is the source node and n_d is the destination node , h is the number of hop between n_0 and n_d and a function $r(n_i)$ denotes the residual energy of node n_i then the average minimum residual energy(AME) and average summation of residual energy(ASE) for the route r_j is calculated as:

$$\text{AMR}(r_j) = (\min_{\forall n_i \in r_j} r(n_i)) / h$$

$$\text{ASR}(r_j) = (\sum_{\forall n_i \in r_j} r(n_i)) / h$$

The BBU-AODV algorithm selects an optimal route k O_k (D) which verifies the following condition:

If (minimum residual energy along a path is greater than or equal to the threshold i.e.

$$\underset{r_j \in A}{AMR}(r_j) \times h >= Th)$$

Choose a route which has the maximum of the difference of average residual summation and threshold i.e.

$$O_k(D) = \max_{r_j \in A} (ASR(r_j)) - Th$$

Else

Choose a route with maximum difference of average minimum residual energy and threshold i.e.

$$O_k(D) = \max_{r_j \in A} (AMR(r_j)) - Th$$

Where A is the set of all routes under consideration and Th is a predefined energy threshold.

4.3 Algorithm for RREQ Handling

The pseudo code in Figure 2 shows the algorithm used to search for the desired path and the flow chart of RREQ handling at the intermediate and destination node for BBU-AODV is as shown in Figure 3.

The intermediate nodes process RREQ as follows:

Step 1: It checks whether RREQ is new by looking up the source node id and broadcast ID in a routing table

Step 2: If RREQ is the first or greater Destination Sequence Number, a node updates additional MRE and SRE fields of RREQ as follow, then rebroadcast RREQ.

MRE=min (residual energy of current node, MRE of RREQ received)

SRE= (residual energy of current node + SRE of RREQ received)

Step 3: If RREQ is not the first or Destination Sequence Number is not greater than the sequence number in the routing table, then the coming RREQs is discarded.

The destination node processes RREQ as follows:

Step 1: The node checks whether RREQ is first arrived by looking up the source node id and broadcast ID in a routing table.

Step 2: If RREQ is first arrived, it calculates an EnergyDifference(D) value as shown below and waiting time (δ) for additional RREQ's packet and keeps it on a routing table for additional RREQ.

Let threshold (Th) = some constant energy E

If (MRE >= Th)

D= ((SRE/hopcount) - Th)

Else

D= ((MRE/hopcount) - Th)

Step 3: If RREQ is not the first, then the node checks its waiting time δ.

Step 4: If RREQ is not expired, then the algorithm calculates an energyDifference (routing cost) for the new RREQ and compares it with an EnergyDifference value on the the routing table. If the route cost (D) of the incoming RREQ is greater than an EnergyDifference (D) in the routing table, then the destination node replaces the routing table entry of an existing RREQ by the incoming copies of RREQ otherwise the incoming RREQ is discarded.

Step 5: If the node receives another copy of RREQ, it executes step 4 till its waiting time expires.

Step 6: If waiting time expires a destination node sends an RREP on the reverse path which has large value of EnergyDifference to a source node.

Fig. 2. Pseudo code on how node process RREQ

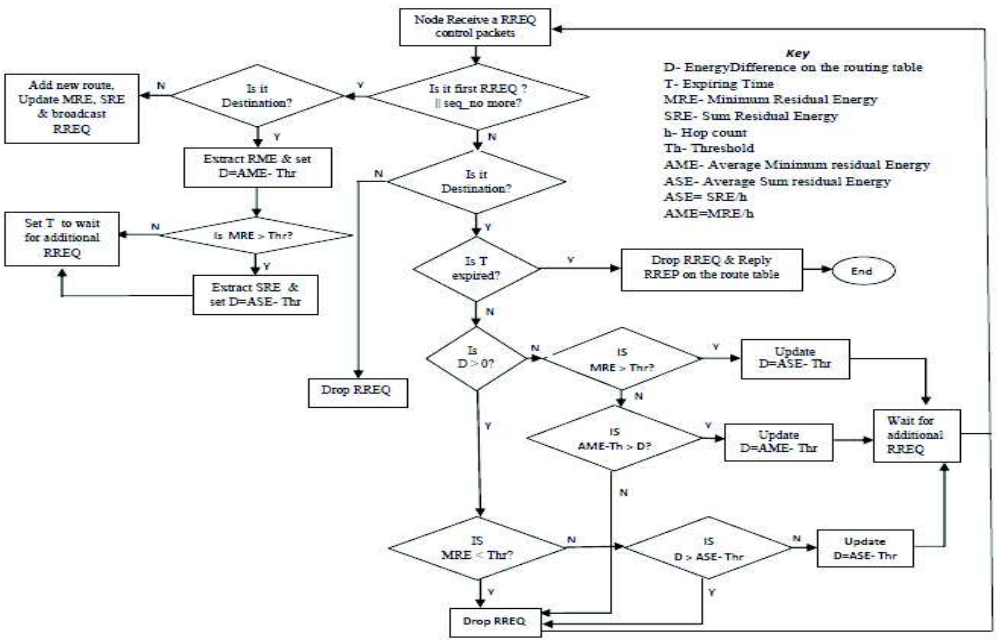

Fig. 3. The flow chart of RREQ handling by BBU-AODV

4.4 Comparison of Routing Protocols

To understand the operations of the proposed protocol, we consider three different routing protocols namely AODV, ALMEL-AODV and BBU-AODV. In Fig.4, the number written above a node corresponds to the value of residual node energy during RREQ received and inside a node indentifies a particular node. We have also used 10 joule as an energy threshold for the network.

Case 1: Choose a route with minimum hop count between source and destination (AODV routing protocol). AODV selects route < S-6-7-8-D > which has the smallest hop count of 4.

Case 2: Choose a route with largest Summation of residual energy. (Max_Sum Energy (ALMEL-AODV) routing protocol. The ALMEL-AODV algorithm selects route <S-1-2-3-4-5-D> which is the largest summation of residual energy.

Case 3: Choose a route with large summation of residual energy and less hop count if possible; otherwise choose a route with largest minimum residual energy and less hop count (proposed routing protocol i.e. BBU-AODV). Our proposed model selects a route with largest value of EnergyDifference (D). Thus route <S-9-10-11-12-D> which has largest D value of 6.6 is selected.

Case 1 selects the shortest path without considering remaining energy of nodes. Thus, case 1 does not give guarantee for long network lifetime. Case 2 selects a route with largest summation of residual energy but it has serious problem in terms of life time and hop count as it may still choose a route with nodes containing small remaining battery capacity as shown in Figure 4. Case-3 improves the drawbacks of Case 1 and Case-2 by considering both residual energy and hop count as a cost metric. Based on our algorithm the cost function (D) for path S-1-2-3-4-5-D, S-6-7-8-D, S-9-10-11-12-D and S-13-14-15-16-17-18-D is -9.5, -9.25, 6.6 and 5.4 respectively as shown in Figure 4. Hence BBU-AODV selects path S-9-10-11-12-D which is the largest value of D i.e. 6.6 for data transmissions. So the proposed algorithm always chooses a route which extends network lifetime by taking energy capable nodes and distributes load among mobile nodes as well by taking either large summation of residual energy or maximum residual energy.

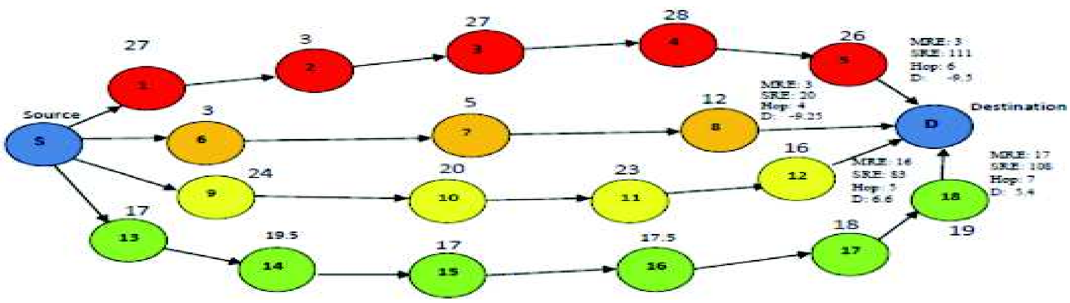

Fig. 4. BBU-AODV route setup from node S to node D

5 Simulation and Results

5.1 Simulation Environment

In this paper the simulations are carried out using Network Simulators-2 version 2.34 [24] to evaluate the performance of the proposed energy efficient routing protocol against AODV and ALMEL_AODV. We used Wireless Channel/Wireless Physical, Propagation model is Free Space Propagation Model, Queuing model is Drop Tail/Priority Queue, Mobility model is Random Waypoint model and MAC protocol is 802.11. The simulation setup consists of an area of 500m X 500m with different number of nodes ranging from 100 to 200 for each simulation. Each packet starts travelling from a random location to a random destination with a randomly chosen speed. When a node reaches a destination, it moves to another randomly chosen destination after a pause. To emulate the dynamic environment, all nodes move around in the entire region with maximum speed of 20m/sec. Constant Bit Rate (CBR) traffic source with packet size of 512 bytes is used. Traffic scenarios with 15 source-destination pairs were used to establish the routes. All the simulations were run for a period of 500 sec. The initial energy of each node was set as 100 Joule with transmission and reception power of 1 W and 0.5W respectively. The Energy threshold value for the simulation is set to 30 Joule and the expiration time of D at the destination routing table is set to 0.1sec. Identical movement and traffic scenarios are used across all protocols.

Once the trace file is generated, a Perl and AWK scripts are used to analyze the information from the trace file. Based on the output of these scripts, graphs are plotted for network lifetime v/s number of nodes, delivery rate v/s number of nodes, normalized routing overhead v/s number of nodes, standard deviation of residual energy of all nodes v/s number of nodes and average end to end delay v/s number of nodes. The parameters used in the simulation are listed in Table 1.

Table 1. Simulation Parameters

Simulation Parameters	Values
Number of Nodes	100 to 200
Geographical areas(m^2)	500mX500m
Packet Sizes(Bytes)	512
Traffic Type	CBR
Pause time(sec)	40
Mobility Model	Random way Point
Simulation Time(sec)	500
Initial Energy(Joule)	100
Transmission Energy(Watt)	1
Reception Energy(Watt)	0.5
Traffic Sources	15
Maximum Speed(m/s)	20
Threshold(Joule)	30
Expire-Time(T) of D(sec)	0.1

5.2 Performance Metrics

The following performance metrics are used to evaluate our algorithm against AODV routing protocol.

Network lifetime: the time it takes for the first node to deplete its energy.

Delivery ratio: the ratio of data packets reaching the destination node to the total data packets generated at the source node.

Standard deviation of residual energy of all Nodes: shows how much remaining energy variation or "dispersion" exists from the average.

Normalized routing overhead: the total number of routing packets transmitted per data packets delivered at the destination.

Average End-to-End Delay: the interval time between sending by the source node and receiving by the destination node, which includes the processing time and queuing time.

5.3 Simulation Results

The following results show that how BBU-AODV improves the performance of a MANET.

Network lifetime

Our modified energy aware algorithm outperforms both AODV and ALMEL-AODV by achieving long duration of time for the first node exhausts its energy on the network during the simulations as illustrated by Fig. 5. The improvement in network life time is due to the fact that our enhanced energy aware AODV prevents small residual energy nodes as a relay node or selects a path which has long duration than shorter path between source and destination.

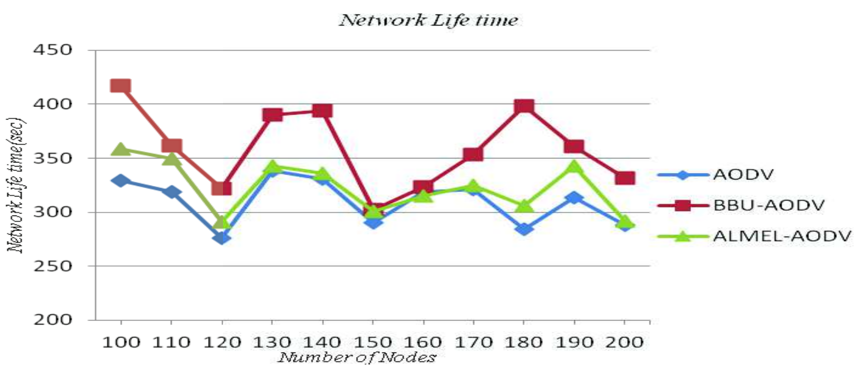

Fig. 5. Network life time with different number of nodes

Standard deviation of residual energy of all Nodes

In our energy aware AODV as the value of residual energy of each node on the path is above the threshold maximum summation of energy path with less hop count will be used. This technique protects nodes at the early stage before they exhaust their battery capacity (i.e. the battery will be used more fairly) and thus the standard deviation of residual energy of the enhanced energy aware AODV algorithm is smaller than AODV and ALMEL-AODV as shown in Fig.6.

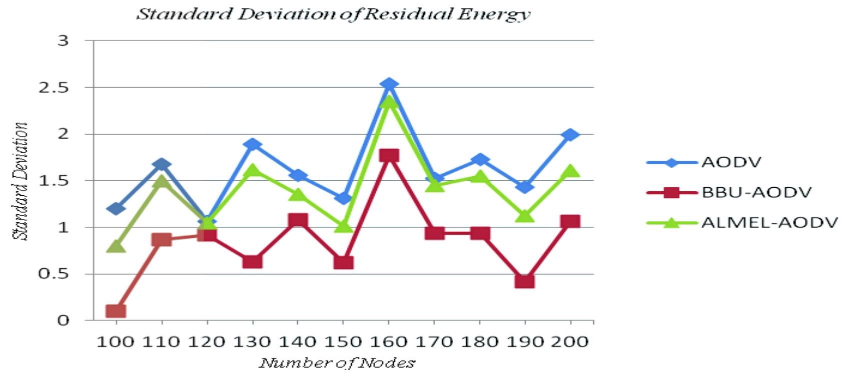

Fig. 6. Standard deviation with different number of nodes

Delivery Ratio

Fig.7 shows that the proposed scheme provides higher delivery ratio than AODV and ALMEL-AODV. This is due to the fact that our algorithm selects energy capable path which is active for longer duration of time.

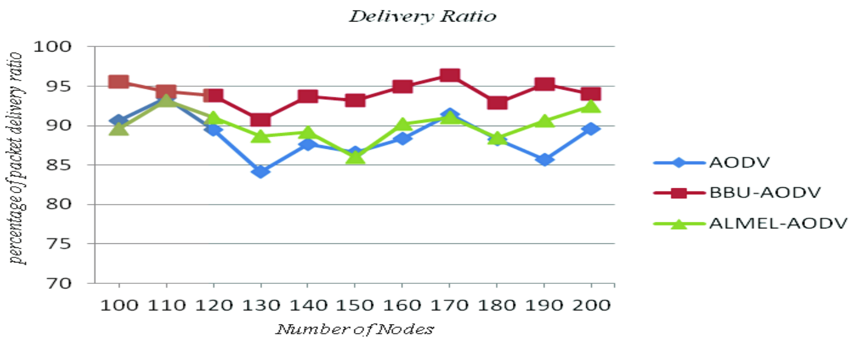

Fig. 7. Delivery ratio with different number of nodes

Normalized Routing Overhead

Fig.8 shows the normalized control packet overhead required by the transmission of the data packets. AODV and BBU-AODV has less normalized control packet overhead than ALMEL-AODV. The reason is that both schemes consider hop count as a cost metric unlike ALMEL-AODV. Thus ALMEL-AODV uses more number of hops as a relay node which creates additional number of route reply message and link failure.

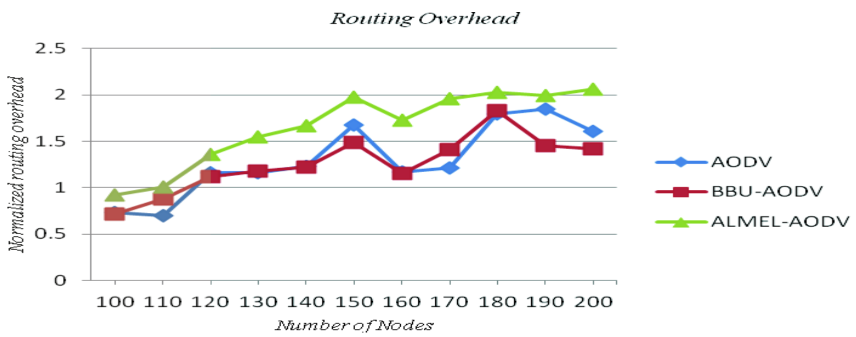

Fig. 8. Normalized routing overhead with different number of nodes

Average End to End Delay

In Fig. 9, we observe that the average end to end delay of AODV is smaller than both BBU-AODV and ALMEL-AODV. The reason is that AODV only finds shorter routes during route discovery irrespective of other parameters. Furthermore, the average end to end delay of ALMEL-AODV is higher than BBU-AODV. This is because ALMEL-AODV doesn't consider hop count as a cost metric. Hence the probability that longer paths will be selected increases.

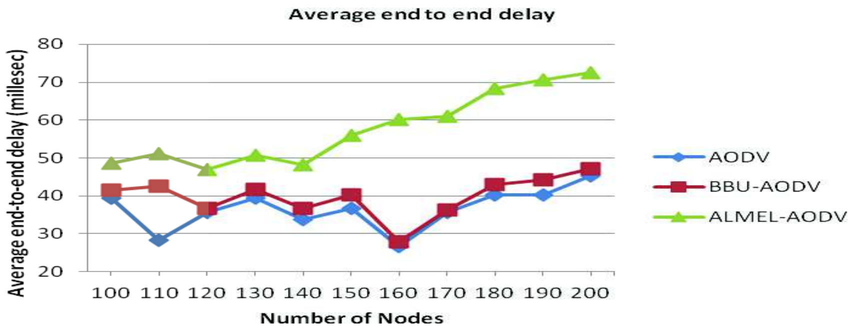

Fig. 9. Average end to end delay with different number of nodes

6 Conclusion

Maximum network life time and fair utilization of energy usage is very important in a MANET as a new route discovery process has to be reinitiated if less energy capable path is selected which creates extra energy consumption of nodes and affects delivery ratio of the network. To overcome these problems, a BBU-AODV algorithm is proposed. The simulation results show that BBU-AODV has better network lifetime, delivery ratio and reasonable distribution of energy consumption across nodes than both ALMEL_AODV and classical AODV. But AODV has relatively low normalized overhead and average end to end delay than the modified one. Now we are working on to examine the effect of various mobility and traffic models on BBU-AODV algorithm. We are also looking forward to minimize routing overhead of both AODV and BBU-AODV.

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