Enhancing AODV Routing Protocol for Better Energy Utilization and Packets Delivery In MANETs

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Abstract

A Mobile Ad hoc NETwork (MANET) is a collection of wireless nodes communicating with each other without any predetermined topology. In recent years, application domains of wireless ad hoc networks highly affected military and non-military organizations. In this paper, a comparison using NS2 for AODV, DSDV and CBRP is conducted. Metrics of packet delivery fraction and the energy behavior of topology nodes are considered to nominate a protocol suitable for such networks. Since AODV recorded better results the paper proposes enhancements on AODV, namely, AODV-DRT and AODV-PE in term of energy preservation and packet delivery fraction (PDF) fraction. Experimental results show that AODV-PE outperforms both AODV and AODV-DRT in term of packet delivery fraction with comparable results in term of energy preservation.

Keywords: *MANET, NS-2, Adhoc, AODV, CBRP, DSDV, AODV enhancement*

1. Introduction

The set of applications for MANETs ranges from large-scale, mobile, highly dynamic networks, to small, static networks that are constrained by power sources. MANETs are used in Military battlefield operations, where most communication devices are installed in mobile vehicles, tanks, trucks or may be a soldier carrying a telecomm device. MANET could also be used in rescues missions for firemen or overseas rescue teams. Another application of MANETs is road status detection, as cars are equipped with wireless transceivers that spontaneously form wireless ad hoc networks. By this, cars can talk to the road, to traffic lights, and to each other, forming ad-hoc networks of various sizes. Routing protocols for mobile ad hoc networks have different features. Regarding the way to exchange routing information, the main difference is between reactive and proactive routing protocols. A reactive (or on-demand) routing protocol determines routes only when there is a need to send data. In contrary, a proactive routing protocol attempts to maintain routes to all destinations. The present paper has two objectives. The first is to nominate a protocol suitable for MANETs and their distinguished features. So, a comparative study between three routing protocols reactive, proactive, and reactive clustered which are represented by AODV (Ad Hoc On-Demand Distance Vector), DSDV (Destination -Sequenced Distance-Vector) and CBRP

(Cluster based routing protocol), respectively. The second objective is enhancing AODV as the winner in terms of packet delivery fraction and node energy saving. Consequently, AODV-DRT (AODV Drop Request at Threshold) and AODV-PE (AODV path energy metric) protocols were proposed and tested in the present paper. The paper is organized as follows, in section II related work in literature is presented. The three routing protocols used in the comparison are briefly discussed in section III. In section IV the comparative study is presented. Later in section V the proposed enhancements AODV-DRT and AODV-PE are developed. Experimental results of enhancements compared with the traditional AODV are presented in section VI. Finally, section VII has the conclusion and future work.

2. Related Work

Many researches were carried out in the field of ad-hoc network routing. In one end lies a comparison among different acting protocols. Meanwhile, tuning acting protocols covers the far end where researches join network performance and energy consumption. Considering On-demand protocols, AODV and DSR outperform the table-driven DSDV protocol [HYPERLINK \l "Sha08" 1]2]. In terms of end-to-end packet delay, AODV's shows a shorter delay than DSR and CBRP [HYPERLINK \l "BOU04" 3]. A Simple Load Balancing Approach (SLBA) was presented in 4] to improve AODV performance via minimizing the traffic concentration. Meanwhile, PIFA prevented MANET from being partitioned or degraded in performance due to the effect of selfish nodes. Further enhancements were proposed in [HYPERLINK \l "Gwa03" 5] where AODV-PA (AODV with path accumulation) optimizes AODV to perform effectively in terms of reducing routing overhead and delay during high load. Enhancing AODV to improve MANET's lifetime by applying Energy Mean Value was proposed in 6]. An ER-AODV (Energy Reverse Ad-hoc On-demand Distance Vector routing) was presented in [HYPERLINK \l "Khe10" 7] where a mechanism tries multiple route replies in order to obtain a routing path with less RREQ messages. Later, 8] proposed ECNC_AODV (Energy Constraint Node Cache). This algorithm aimed at increasing the network lifetime based on reducing the number of routing packets, generated due to flooding.

3. Ad hoc Network Protocols

3.1. Ad Hoc On-Demand Distance Vector (AODV)

AODV uses traditional routing tables, one entry per destination. When a source node needs to send a data packet to a destination node and its table does not contain any route to the destination, the source broadcasts a route request (RREQ) packet to its neighbors containing the address of the source, and the address of the requested destination. A sequence number is used to determine the relative freshness of routing information generated by two nodes for the same destination. When a node receives a RREQ, the node either drops the request if it was received before or accepts it for further processing. The node also checks if it has a fresh route to the destination. If such a route is found, the node responds a route reply (RREP) packet to the source. Otherwise it rebroadcasts the RREQ to its neighbors after incrementing the hop count

3.2. Destination -Sequenced Distance-Vector (DSDV)

DSDV requires each node to maintain a routing table that lists entries to all available destinations. Each table's entry contains the number of hops to the destination, the address of the next-hop, and a sequence number. To maintain the consistency of the routing tables each node updates neighbors periodically and when significant new information are available such as link breakage. Modes of updates are either "full dump" of all available routing information or "incremental" where only changed information since the last "full dump" is sent to neighbors. Due to network-wide periodic and triggered update requirements, DSDV introduces excessive communication over head. Such problem can become unacceptable if network size or node mobility increases.

3.3. Cluster Based Routing Protocol (CBRP)

In the CBRP protocol, mobile hosts form clusters. The head of a cluster knows the addresses of its members. Hence, broadcasting route requests only to the cluster heads is equivalent to broadcasting to every host in the network. The diameter of a cluster is only two hops and clusters can overlap. At any time, a node is in one of the three states: a cluster member, a cluster head, or undecided, meaning still searching for its host cluster. When a cluster head receives a hello message from an undecided neighbor, it sends out a triggered hello message which notifies that neighbor about the existence of the cluster. Upon receiving the triggered hello message from a cluster head, the undecided node changes its state to a member and records the cluster head's address. The adjacent cluster head discovery is done by having each cluster head maintains a cluster adjacency table, which stores the addresses of the neighboring cluster heads and the gateway node through which that head can be reached. A route discovery starts with the source host broadcasts a route request to its neighbors, one of which is the cluster head. Subsequently, the request is flooded to the neighboring cluster heads though the gateway nodes, until the request reaches the cluster head of the destination host which uni-casts the request to the destination. The route request records only the past cluster heads. The actual route is calculated during the returning of the route reply.

4. A Comparative Study

A comparative study between AODV, DSDV, and CBRP is carried out and the energy behavior of nodes and the packet delivery fraction are recorded for analysis. Four scenarios are considered for large and small networks where the number of nodes varies from 50 to 20 and moving randomly according to the Random Way Point Mobility [HYPERLINK \l "Kum09" 9] model with max nodes' speeds ranging from 20 to 50 meter/s in an area of 800X800 meters during 700 seconds simulation period. The initial node energy is 50 Joule while communication parties are selected randomly to send and receive Constant bit rate (CBR) packets over the simulation period. Configuration parameters are shown in "table 1".

Table (1): Summary of all Experiment parameters

Parameters	Case study (1)	Case study (2)	Case study (3)	Case study (4)
max speed	50ms	20ms	50ms	20ms
Pause	1s	2s	1s	2s
No. of nodes	50	50	20	20
src/conn.	25/40	25/40	11/16	11/16
send rate	3 packet/sec	3 packet/sec	4 packet/sec	4 packet/sec

The nodes energy behavior over the simulation time as well as the packet delivery fraction are recorded and analyzed, for the different scenarios, in the following subsections.

Simulation results

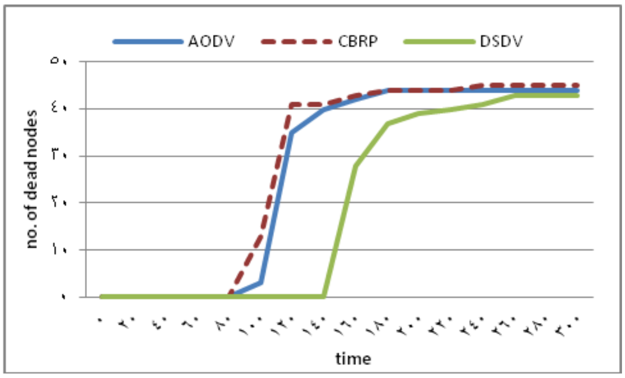
The computed results of the comparative cases (case 1-case 4) are shown in "figures 1-8". "Figures 1,3,5, and 7" display the energy behaviour of dead nodes while "figures 2,4,6, and 8" presente the packet delivery fractions of communication sessions.

Case Study (1): DSDV has a low packet delivery fraction as a result of the low contribution of its nodes in the packet delivery process, "figure 2". Consequently, nodes preserve their energy as indicated in "figure 1". CBRP and AODV show a high PDF over early simulation periods, "figure 2", but both loose this advantage during later periods as most of the nodes ran out of their energy and became unable to either route or forward more packets, "figure 1". It is worth to be noted that during early stages of the simulation AODV nodes sustain with more energy than those of CBRP, as some cluster heads lost their energy, being masters in most routing and forwarding of packets to other network nodes, "figure 1".

Case Study (2): DSDV routing protocol remains having the lowest PDF, "figure 4", even though its recorded results are relieved compared to those previously recorded in case 1. Reducing nodes' speed offers better stability for DSDV cluster heads and the packet delivery ratio gets better. Meanwhile, both AODV and CBRP remain offering a comparable high PDF at early stages. Later both protocols suffers a higher number of nodes compared those in the corresponding intervals of case 1. In return, more packets delivery fraction is attained. So, as the nodes' speeds are slowed down, the packets loss is reduced and the energy consumed in packets delivery is increased, "figures 3& 4".

Case Study (3): in this case 20 nodes are moving at 50ms. "Figure 5", shows that DSDV continue offering low PDF while AODV and CBRP show high PDF with superiority of AODV. "Figure 6" shows that although AODV loses more energy than CBRP at the beginning, it outperforms CBRP in sustaining nodes' energy during the remaining intervals.

Case Study (4): where a small network with 20 nodes moving at 20ms. "Figures 7 & 8" show nearly the same results that was previously given in "figures 1 & 2" of case 1.



Figure(1): nodes energy behavior (case study 1-[50n, 50m/s])

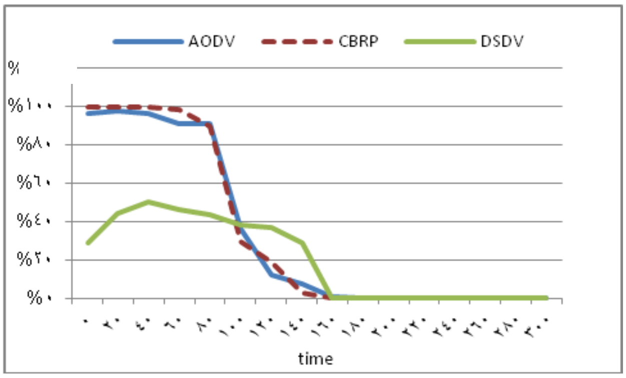
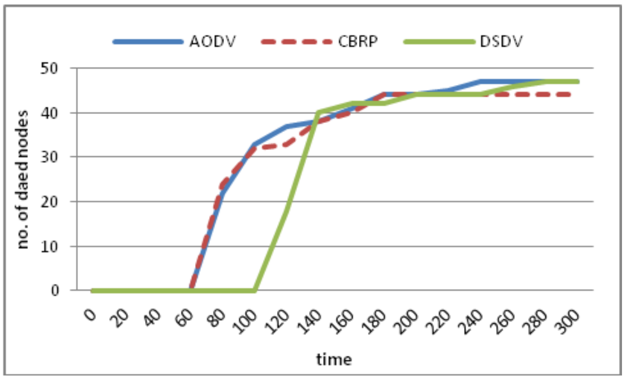
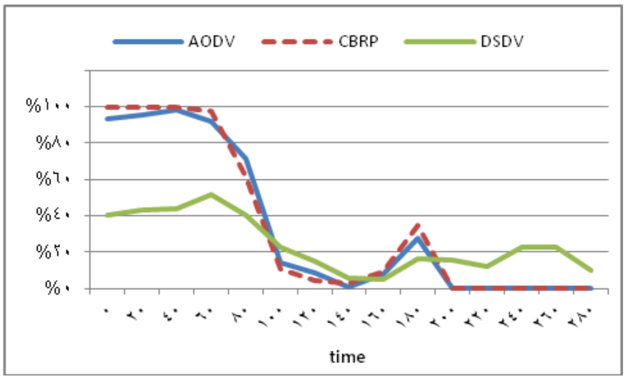


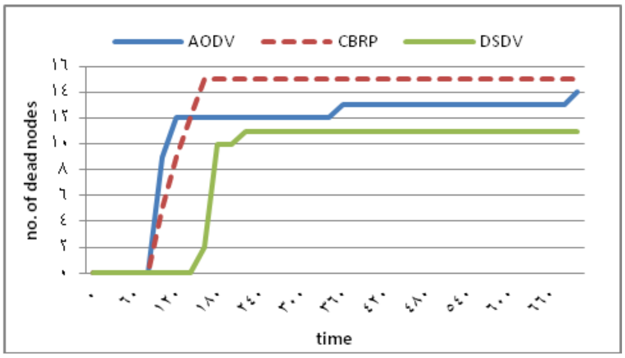
Figure (2): data connections PDF (case study 1 - [50n, 50m/s])



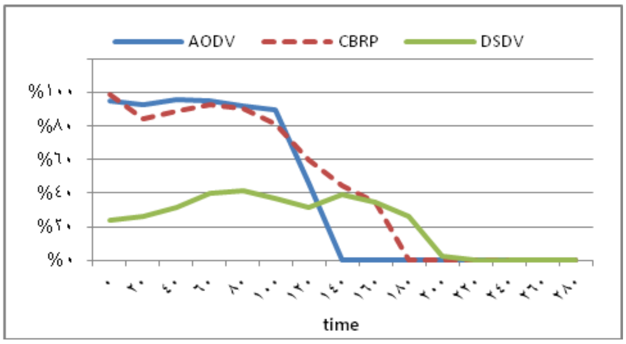
Figure(3):nodes energy behavior (case study 2-[50n, 20m/s])



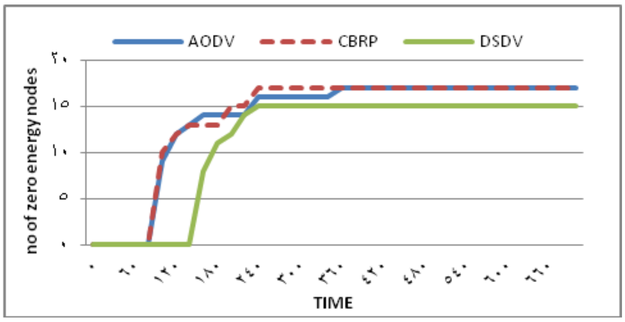
Figure(4): data connections PDF (case study 2 - [50n, 20m/s])



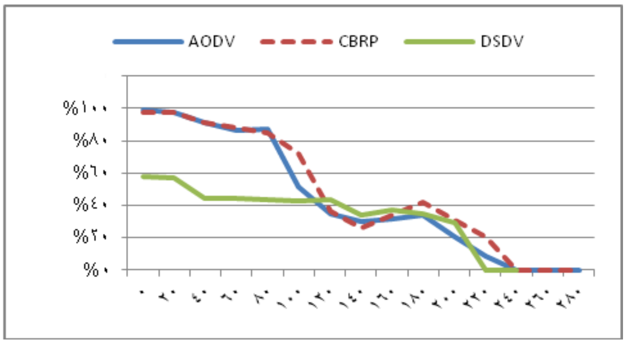
Figure(5): nodes energy behavior (case study 3-[20n, 50m/s])



Figure(6): data connections PDF (case study 3 - [20n, 50m/s])



Figure(7): nodes energy behavior (case study 4-[20n, 20m/s])



Figure(8): data connections PDF (case study 4 - [20n, 20m/s])

Discussion

As previously discussed, DSDV preserved nodes' energy, by dropping more packets, and offered a low PDF. In contrary, AODV and CBRP behave nearly the same with superiority of AODV protocol. It is also worth to be noted that the PDF, for all protocols, is proportional with the nodes' speed. Based on the result recorded from the previous cases, an average of PDF for AODV, CBRP, & DSDV are given in "figure 9" and AODV is nominated for further enhancements.

Table (2): average PDF of three protocols

Routing protocols	**AODV**	**CBRP**	**DSDV**
PDF (Average)	78.35%	77.31%	39.88%

5. The Proposed AODV Enhancements

Two alternative enhancement algorithms, namely, AODV-DRT and AODV-PE are developed. In AODV-DRT, a node drops some of the received request control packets when its energy level drops to a pre-specified level (threshold). The goal is to help nodes sustain sharing with others in packets transfer. On the other hand, AODV-PE helps using different routes other than the shortest routes that are normally loaded with packets traffic. The nodes in such routes rapidly lose their energy and become a bottleneck that lowers the network performances by congestion and larger delays [HYPERLINK \l "Sou09" 10]. As previously discussed, AODV considers the hop count to the destination as a main metric for route selection which may not be a suitable choice for MANETs [11]. The proposed AODV-PE algorithm adds the nodes energy in a route as an additional metric, where a route with the less number of nodes that have lowest residual energy levels is preferred. In a case where two routes are even, the route with a lower hop counts is preferred. The next subsections include the description of each proposed algorithm along with its pseudo code.

5.1. AODV-DRT

In AODV-DRT a node drops some of the received request control packets as its energy level drops ½ of its original (starting) level. Reaching this state the node can discard half of its received requests to sustain sharing remaining nodes in packets forwarding for a longer period of time. The pseudo code of the algorithm is shown in "figure 9".

Pseudo code for dropping the requests

```
PROCEDURE recRequest (Packet p)
      BEGIN
IF (this is source node) {
  Drop the request packet
  END
  }
IF (this request heard before){
  Drop the request packet
  END
  }
Cash the broadcast ID in the broadcast cash list
Current energy level = Call (get_energy()/Initial energy)
IF (current energy level < 50%){
   IF (previous_req_drop_flag = false){
     Drop the request packet
     Invert previous_reqt_drop_flag
     END
    }
  Else {    Invert previous_reqt_drop_flag    }
}
```

Figure (9): Pseudo code for dropping the requests

5.2. AODV-PE (AODV Path Energy metric)

The algorithm modifies traditional AODV by adding the energy levels of nodes comprising a route as an additional metric to hop count for route selection. To implement such modification, a field in each of AODV request and reply control packets as well as a node routing table is used to store the path_energy metric. The path_energy field is 16- bits long divided into 4 equal nibbles of 4-bits each. Each nibble has the number of nodes in the route that belong to one of the four categories, shown in "table 3". Categories are classified based on the percentage of remaining energy in a node, with category_1 having the lowest node remaining energy (0-25%). The count of category_4 nodes is recorded in lowest significant nibble in the path_energy field while that of category_1 nodes is kept in highest significant nibble in the same field. The remaining two nibbles are assigned to categories 2 & 3, respectively. The power energy metric for a route is the decimal value of the binary representation in the path_energy field which is calculated by equation (1) where the route with the minimum value is recommended.

Table (3): AODV-PE categories

	energy Category	**Remaining energy (%)**	**increment in decimal**
Category_1	Critical	(0 - 25)%	$2^0 = 1$
Category_2	Low	(25 - 50)%	$2^4 = 16$
Category_3	Medium	(50 - 75)%	$2^8 = 256$
Category_4	High	(75-100)%	$2^{12} = 4096$

$$\textbf{Path Energy} = 2^0 * \sum_{k=0}^{n} \text{node}_{\text{category\_4}} + 2^4 * \sum_{k=0}^{n} \text{node}_{\text{category\_3}} + 2^8 * \sum_{k=0}^{n} \text{node}_{\text{category\_2}} + 2^{12} * \sum_{k=0}^{n} \text{node}_{\text{category\_1}} \quad (1)$$

AODV-PE illustrative example

"Figure 10" shows a scenario from node S initiating a request to the destination node M**.** Assume that node S received four routes namely A, B, C, and D that reach the destination node M.

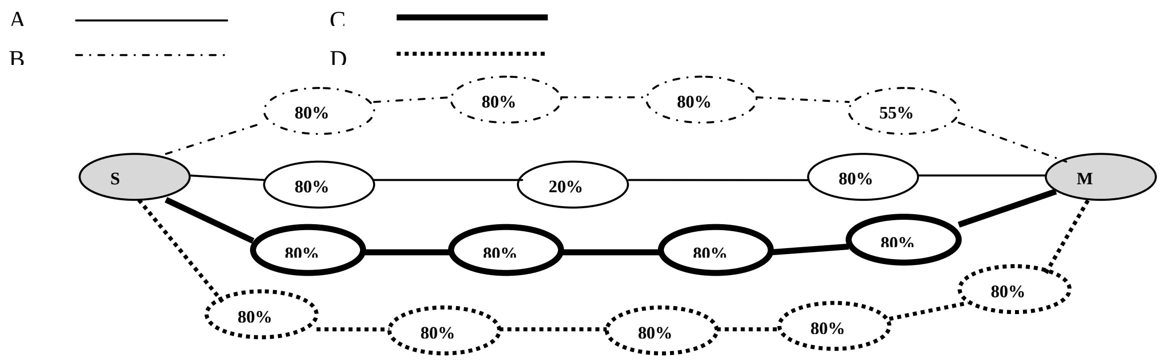


Figure (10): AODV-PE scenario Example

In "figure 10", nodes are represented by circles where encircled numbers represent the percentage of the remaining energy in each node. "Table 4" shows the binary value in the path_energy field for nodes on the routes A, B, C, and D and the corresponding decimal value of the metric along with the number of hops in each route.

Table (4): received routes at source node S for AODV-PE

Receiving Order	Route	Hop count	*Path_energy* Metric Received	
			Binary	*Decimal*
1	A	3	0001 0000 0000 0010	4098
2	B	4	0000 0000 0001 0011	19
3	C	4	0000 0000 0000 0100	4
4	D	5	0000 0000 0000 0101	5

In "table 4", every route is represented by a row. For example, route A has three nodes (hops). According to the remaining energy categorization, route A has two nodes in category_4 and one node in category_1 which are represented by the binary count 0010 and 0001 in the LSB and MSB of the path_energy field, respectively. The decimal equivalent of the path energy metric for route A equals 4096 + 2 = 4098 (equation (1)). Similar calculations for routes B, C, and D are feasible. Based on the proposed metric, route C will be elected for packets transfer since it has a minimum consumed energy in its nodes with a minimum number of hops to the destination.

AODV-PE development

To implement the AODV-PE, a new metric field is appended to the routing table. A new field, in the control packet header, is added to help nodes update and exchange the ***path_energy*** metric. AODV functions are also upgraded such as: “Generating a new request”, “Generating a new reply”, “Receiving a request”, “Receiving a reply”, “Forwarding a request”, and “Forwarding a reply”. The following sub sections elaborate more about the upgraded AODV operations.

The ***sendRequest(..)*** is used whenever a node needs discovering a route to a destination. The function initiates a request packet with the current node’s energy category along with the hop count set to one. The ***sendReply()*** function generates a reply packet when the node is either the desired destination or it is an intermediate node with a fresh enough route to the requested destination. In either cases, the path energy metric is copied from the routing table or initialized for the node generating the reply. The ***recvRequest()*** function is triggered upon receiving a request packet to update the route entry to the source of the communication and forward the request to neighbor nodes or generates a reply to the source node of the communication. A Pseudo code description of the ***recvRequest()*** function is shown in “figure 11”.

The ***recvReply()*** function is executed upon receiving a reply packet . Each node updates the route entry to the destination of the communication, and forwards the reply to the source node of the communication. The Pseudo code for the ***recReply()*** function is shown in “figure 12”. A newly added function, ***add_energy_cat(…),*** that updates the path_energy field with the current node category as described in “table 3” and equation (1). The operation of such function is described in “figure 13”.

```
Pseudo CODE
PROCEDURE recRequest(Packet p)
BEGIN
IF (this is source node){
   Drop the request packet
   END
 }
IF (this request heard before){
   Drop the request packet
   END
 }
Cash the broadcast ID in the broadcast cash list
IF (no rout in routing table to the source node)   Create a route to the source of the request
IF (seqno. and path_energy of recived request is better than in route table)
   Update the routing table entry to source
IF (exists buffered packet to source)   Send buffered packets
IF (this node is the destination to request)
   Call SendReply(initial values, add_energy_cat(0) ,to source)
ELSE IF (this node have a fresh rout to destination){
   Call SendReply(values in the fresh route, add_energy_cat(path_energy in route), to source)
   Call SendReply(value of route to source, add_energy_cat(path_energy in route), to destination)
}
ELSE{
   Update packet parameters
   Request Path_energy = add_energy_cat(request path_energy)
   Call Farward(request packet)
 }
END
```

Figure (11): A Pseudo code description recvRequest() function

```
Pseudo Code
PROCEDURE recReply(Packet p)
BEGIN
IF (no rout in routing table to the source of replying node)
  Create a route to the source of the replying node
IF (seqno. and path_energy of recived replyis better than in route table)
  Update the routing table entry to the replying node
IF (exists buffered packet to source)   Send buffered packets
IF (this node is the destination to the replying node) Discard the packet
ELSE IF (could forward and rout exists){
  Reply hop_count += 1
  Reply src = this node;
  Reply path_energy=add_energy_cat(reply path_energy);
  Call forward(reply packet)
}
ELSE
  Drop the reply packet
END
```

Figure (12): The Pseudo code for the recReply() function.

```
Pseudo Code
PROCEDURE add_energy_cat(current_cat)
BEGIN
Node energy= Call Get_energy()
Node cat = node energy/intial energy
        IF (node cat >= 0.75)
                Return current_cat+1
        ELSE IF (node cat >=0. 50)
                Return current_cat+16
        ELSE IF (node cat >=0. 25)
                Return current_cat+256
        ELSE
                Return current_cat+4096
END
```

Figure (13): The Pseudo code for the Add_energy_cat () function

Finally, the comp_new_metric() function compares the existing and the recently received energy_path metrics and returns either “True” if the recent energy_path metric is better than the existing metric or return “False”, otherwise.

Simulation results for AODV, AODV-DRT, and AODV-PE

Experiments using AODV-PE, AODV-DRT, and traditional AODV protocols were repeated several times. A network with 50 nodes performing a constant bit rate communications were considered with nodes' speeds vary from 10ms, 40ms, and 70ms, moving randomly according to the Random Way Point Mobility in an area of 800mX800m . the intial nodes energy is 50 jule and the simulation period was 700s. Each experiment was repeated 10 times and the averages packets delivery fraction (PDF) as well as the number of dead nodes were calculated for each protocol and are shown in "figures 14 -17".

"Figure 14", shows that the proposed AODV-PE outperforms the other two protocols in packets delivery fraction. The AODV-DRT protocol shows comparable results with AODV only at lower speeds of nodes' movements. However, with larger speeds, AODV-DRT allows some nodes to drop some route discovery packets which greatly affect the packets delivery fraction.

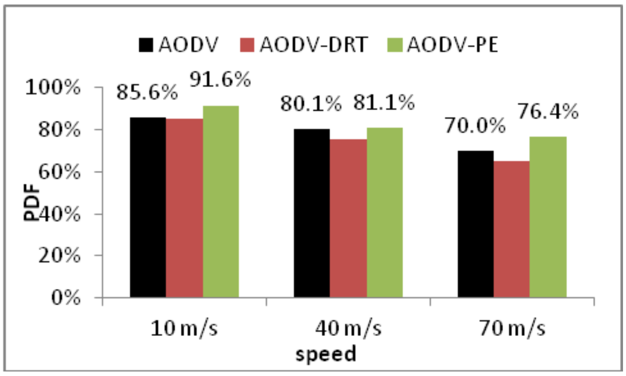


Figure (14): AODV, AODV-DRT, and AODV-PE packet delivery fraction

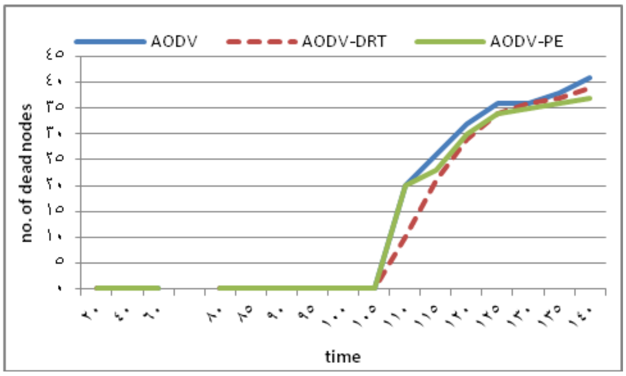


Figure (15): Dead nodes over time (AODV, AODV-DRT, AODV-PE) - 10ms

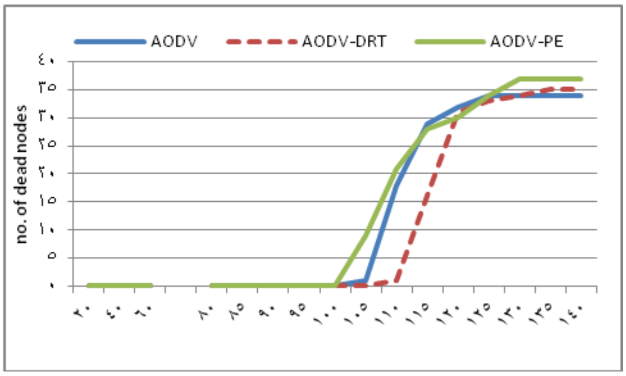


Figure (16): Dead nodes over time (AODV, AODV-DRT, AODV-PE) - 40ms

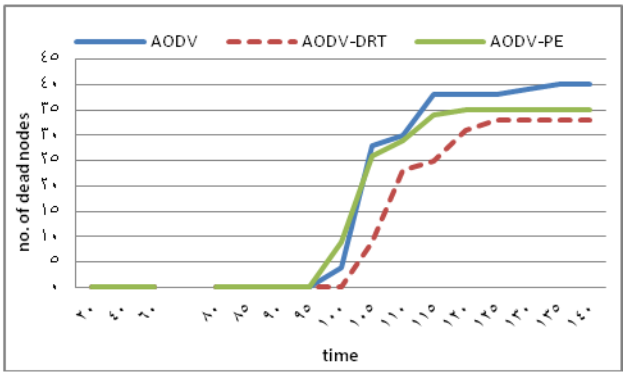


Figure (17): Dead nodes over time (AODV, AODV-DRT, AODV-PE) - 70m/s

"Figure 14" also shows that, for all protocols, the performance of packets delivery declines with increasing the nodes speeds. This could be due to the frequent change in the network topology, with faster nodes, that causes an increase in the number of link breaks [HYPERLINK \l "Par10" 12].

"Figure 15", shows that AODV-DRT outperforms other protocols in preserving nodes' energy. AODV-PE catches AODV and both recorded comparable results. However, these results are behind the results recorded by AODV-DRT, "figures 16, 17".

6. Conclusion and Future work

A comparative study was conducted to nominate one of the three considerate protocols, namely, the AODV, CBRP, and DSDV for MANETs. AODV recorded the best results in term of packet delivery fraction (PDF) and comparable results in terms of preserving nodes' energies. The nominated AODV was enhanced by developing two new protocols, namely, AODV-PE and AODV-DRT. Results indicated that AODV-PE outperformed AODV and AODV-DRT in terms of packets delivery fraction for variable nodes speeds. Meanwhile, it offered a comparable energy utilization of nodes with respect to AODV. Recorded results also indicated that AODV-DRT preserved more sustainable nodes in case of energy considerations than the other protocols. So, AODV-DRT could fit applications in which packet delivery fraction is sacrificed for long lasting nodes.

A future work is to investigate other protocols that may be used in the vast MANETs area and conduct further comparisons with the herein mentioned AODV, DSDV and CBRP routing protocols. Security issue is also a fertile area for future investigations. Improving and reducing the routing overheads remain an open area for further research. At least not last, relying on historical background information in setting up new MANETs' structures, such as clusters, may open a new area of research interest.

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