Energy Consumption Evaluation of AODV and AOMDV Routing Protocols in Mobile Ad-Hoc Networks

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***Abstract*—Mobile Ad-hoc Networks (MANETs) are mobile, multi-hop wireless networks that can be set up anytime, anywhere without the need of pre-existing infrastructure. Due to its dynamic topology the main challenge in such networks is to design dynamic routing protocols, which are efficient in terms of consumption of energy and producing less overhead. The main emphasis of this research is upon the prominent issues of MANETs such as energy efficiency and scalability along with some traditional performance metrics for performance evaluation. Two proactive routing protocols used in this research are single-path AODV versus multi-path AOMDV. Extensive simulation has been done in NS2 simulator, which includes ten scenarios. The simulation results revealed that the performance of AOMDV is more optimal as compared to AODV in terms of throughput, packet delivery fraction and end to end delay. However, in terms of consumption of energy and NRL the AODV protocol performed better as compared to AOMDV.**

***Keywords*—MANETs; routing protocols; AODV; AOMDV; energy efficiency; routing performance**

I. Introduction

In Mobile Ad-hoc Networks (MANETs) the mobile nodes can connect dynamically using a variety of wireless media without any centralized infrastructure [1]. There are many advantages of MANETs as compared to the traditional network such as ease of establishment of network, reduced infrastructure cost etc. In MANETs each mobile node not solely operates as a host but additionally works as a router and has the capability to perform routing [2]. The transmission range of the mobile nodes is limited due to which the nodes frequently join and leave the network and as a result, the network topology updates again and again [3]. The mobility of the nodes in MANETs can cause the links to break due to which the nodes recalculate routing information in order to establish the links. This process consumes power, processing time, memory and produces additional traffic [4]. The potential of the Ad-hoc networks is that it can be used in the situations where infrastructure is not available and technically not possible to deploy such as disaster and military operations. The situations can also include low power sensor networks [5].

In MANETs, routing is a very critical task that should be deal with very care. To send the data between the source node and the destination as well as to establish the connection, there is a need for routing protocols. Due to dynamic and unexpected topology changes in MANETs, the design of an efficient routing protocol in terms of consumption of energy and producing less overhead is very important and it is a significant challenge for such type of networks. The routing protocols have been developed to deal with the challenges, such as security, energy and delay. However, there are shortcomings in some aspects and improvement in others. Furthermore, the cooperative routing algorithms that are associated to energy gathering are quite limited [6].

There are few studies related to energy consumption calculation of wireless network in ad-hoc mode such as the research conducted in [7] proposed an energy efficient MAC protocol having multichannel and provisioning of quality of service in MANETs. The research conducted in [8] proposed an energy efficient secure selection of MPR mechanism which considers both security metrics as well as energy metrics for the selection of MPR. More specifically, there is a lack of detailed evaluation of energy consumption of mobile ad-hoc network protocols.

We believe that energy-aware designing and analysis of known-protocols for the ad-hoc networking environment needs sensible data of the energy consumption behavior of actual wireless nodes. Additionally, it's vital to present this information in a manner that is helpful to protocol developers as well as to researchers. The main focus of this research are benchmarking performance against criteria of energy efficiency and scalability along with most traditional performance metrics for performance evaluation of two proactive routing protocols. The first one is a single path named AODV [9, 10], while the second one is multi-path called AOMDV [11, 12] respectively. This research work provides a paradigm for future studies of the development of dynamic routing protocols which are more efficient in terms of energy consumption and producing less overhead. All of which are considered to be prominent issues of MANETs. This research utilized the mendeley reference manager [13] for organizing this research, as well as for referencing.

A. *MANETs Routing Protocols*

Generally, MANETs routing protocols are often categorized into the subsequent three categories [14, 15]:

1) Proactive or Table-Driven routing protocols are based on the traditional link state and distance vector algorithms that are primarily meant for wired networks. These protocols maintained and periodically update their routing tables through interchanging the broadcast control messages.

2) Reactive or On-demand routing protocols are designed to have less overhead as compared to proactive routing protocols because the connection is only established when it is required by the source. This is typically done through a two-stage process known as route discovery.

3) In order to increase the overall scalability of routing Hybrid routing protocols were introduced which includes the features of both reactive and proactive routing protocols. In hybrid routing protocols, the network is comprised of various zones. The network route within each zone is kept up proactively and the routes between zones are resolved responsively.

B. Ad hoc On-Demand Distance Vector (AODV) Routing Protocol

AODV [9, 10] is proactive, single path, loop-free distance vector routing protocol. It is based on DSR's on-demand route discovery mechanism, with the idea of destination sequence numbers from DSDV, but it is different from DSDV by using hop-by-hop routing approach. AODV maintains routes only between nodes which need to communicate with each other. Each mobile node keeps a routing table which maintains information about next-hop of a path towards the destination node. In order to transport packets correctly towards the destination, the protocol uses two procedures: Route discovery of route between the source and the destination and route maintenance. It uses route request message (RREQ) and route reply message (RREP) for route discovery, and uses Route Error (RERR) for route maintenance. Moreover, Hello messages are used to preserve the connectivity between neighboring nodes.

C. Ad hoc On-Demand Multipath Distance Vector Routing Protocol

Depending upon the distance vector idea and utilizing hop-to-hop routing concept AOMDV discover routes on-demand utilizing a route discovery technique. The primary difference between AOMDV and AODV lies within the number of routes found in every route discovery [11]. The essence of the AOMDV protocol lies on guaranteeing that multiple paths discovered will be loop-free as well as disjoint, and in effectively finding such routes utilizing a flood-based route discovery [12]. Route update runs in AOMDV are executed locally at each node which has a key part in keeping up loop-freedom and disjoint attributes.

The rest of the paper is organized as follows: Section II includes the relevant research work done. Section III contains the research methodology adopted for carrying out this research. In Section IV results generated are discussed in detail. In Section V the research work done is concluded and at the end there are references.

II. LITERATURE REVIEW

Although energy consumption is agreed to be of importance within the design of ad-hoc networks routing protocols. However, most of studies regarding performance evaluation relied on traditional performance parameters such as throughput, end-to-end delay, PDF and NRL. Moreover, there is a great need to investigate the energy consumption of known protocols in MANETs for future researches.

The research that has been done in MANETs follows two trends, The first trend is the research work related to the design of efficient ad-hoc routing protocols aiming to achieve one or a combination of the targets such as increase in the packet delivery, minimizing energy consumption, and reducing the overheads in MANETs [16]-[24]. However, there are shortcomings in some aspects and improvement in others. The second, upon which the vast majority of research focuses, is performance evaluation based on traditional performance metrics [25]-[31].

The research conducted in [16] proposed a novel fault-tolerant routing approach utilizing a stochastic learning-based weak estimation procedure. The proposed scheme aims to make routing protocol successfully operate in adversarial environment. Authors in [17] have tried to reduce the waste of the limited battery power that occur in exchanging cluster maintenance messages by assigning critical node that has highest priority to be selected as a cluster head, as a results, limited battery power is preserved.

The research conducted in [18] proposed a dynamic energy efficiency algorithm which aims to extend the network lifespan, the proposed approach used two threshold ,yellow threshold that was used to obtain some sort of local load balancing via distributing the load equally among the neighboring cluster-heads, and a red thresholds that was used to prompt local re-clustering in the network. The result obtained in this research revealed that the proposed approach achieved better efficiency than those found in existing weight clustering approach.

The research conducted in [19] proposed a Bird Flight-Inspired Routing Protocol (BFIRP), the aim was to make highly scalable, dynamic, energy efficient, and position-based routing protocol. The proposal was based on three-dimensional (X, Y, Z) to determine the source and destination location. The outcomes demonstrate that the algorithm was highly scalable, and had low end-to-end delay compared to AODV as well as more efficient than AODV in terms of energy and throughput by 20% and 15% respectively.

The research conducted in [20] proposed learning automata based fault-tolerant routing algorithm which is able to perform routing in the existence of faulty nodes in MANETs. To achieve the optimize selection of paths, decrease the overhead in the network, and for learning about the faulty nodes existence in the network, they have utilized the theory of Learning Automata. The outcomes demonstrate that the packet delivery ratio increased and the overhead decreased as compared to the AODV protocol.

The research conducted in [21] proposed energy efficiency algorithm for a communication network in MANETs. The proposal aims to optimize energy consumption through selecting the best path in terms of energy for transferring data after computing the energy required for each available path.

The research conducted in [22] proposed Ant-Colony Optimization (ACO) approach for selecting the optimal cluster heads. The aim was optimization of energy consumption as well as stability of the node. The probability function was used to compute the parameters like residual energy, energy drain rate and mobility factor. Node that has the highest value for the probability function will be selected as a cluster-head. The overall workload of communication is computed periodically. The cluster head is reset, if its value is high. The outcome shows that the approach has energy efficiency and clusters stability.

The research conducted in [23] attempted to decrease energy consumption and delay in MANETs. The proposed approach computed the important matrices such as Residual Energy, Node connectivity and Available Bandwidth for election of the cluster head efficiently. A conscious cluster routing algorithm was proposed by using constructed shortest path multicast tree that pick a cluster head as group leader and cluster members as leaf nodes. The most proposed approaches are extension of some of the current protocols which are either reactive protocols such as AODV and DSR or proactive protocols such as OLSR and DSDV.

The research conducted in [24] proposed the AOMDV-ER for improving of network lifetime and reduce routing overhead by using recoil off time technique based on their geographical location in order to reduce the number of transmissions. The outcomes show that the proposed scheme such as AOMDV-ER was able to save energy consumption up to 16%, and 12% reduction in routing overhead.

The second working trend are research on benchmarking and performance analysis of known network protocols, focused on traditional performance metrics such as PDF, throughput and End-to-End delay; or survey studies.

AODV and AOMDV in [25], [26] are compared with connections up to 50. They have concluded that AOMDV has more routing overhead and delay as compared to AODV, but it has better efficiency in packet drop and PDF.

The research conducted in [27] evaluated the performance of DSR, AODV and AOMDV routing protocol in MANETs by comparing the PDR, throughput, and end-to-end delay. They observed that in a network with increased number of nodes up to 20 nodes, PDF and throughput in AOMDV and DSR routing protocols are better as compared to AODV whereas the delay is less in AOMDV as compared to DSR and AODV.

The survey conducted in [28] reviewed typical reactive routing protocols and revealed the characteristics and trade-offs of AODV, AODV-UU, AOMDV, DSR and DYMO. They have concluded that each of the protocol in the conducted research performs well in some cases and has certain drawbacks in others scenarios.

The performance of AODV, AOMDV, DSR and DSDV were evaluated in [29] through comparing the PDR, packet loss ratio, and end-to-end delay performance matrices for wireless networks. They observed that the performance of AODV is best as compared to AOMDV, DSDV and DSR and therefore the performance of DSR is best as compared to AODV, AOMDV and DSDV in TCP connection type as well as in CBR connection type.

The research conducted in [30] compared and analyzed the performance of AODV and AOMDV routing protocols in MANETs relying on the traditional performance metrics like throughput, end-to-end delay, PDF. They have observed that AOMDV performs well as compared to AODV in terms of PDF and throughput, however, AOMDV incurs a lot of delay in comparison to AODV.

The research conducted in [31] includes AODV, AOMDV, DSDV and DSR. They examined the effect of dynamic change in network topology on the performance based on traditional metrics such as PDR, end-to-end delay and NRL. They observed that AOMDV and DSDV are not suitable when the network topology updates again and again, while AODV and DSR are suitable in such scenario. DSR and DSDV performed better as compared to other protocols in terms of packet delivery ratio, end-to-end delay and NRL. AOMDV had less end-to-end delay but when the network topology changes more frequently, the PDF and NRL are worst as compared to other protocols.

III. Research Methodology

This research is based on evaluating the performance of AODV and AOMDV routing protocols in varied aspects, especially in energy consumption. To evaluate the performance, these protocols are simulated using NS-2 version 35 (The Network Simulator - ns-2, https://www.isi.edu/nsnam/ns) [32]. The simulation workflow is shown in Fig. 1.

A. Simulation Environment

NS2.35 is an object oriented simulator, which is built by combining the advantages of C++ with an OTcl languages. NS2 has full supports for multi-hop wireless ad-hoc environment integrated with physical, data link, and medium access control (MAC) layer model [33]. This research utilized these advantages of NS simulator to set and configure the environment for this research. The protocols have a send buffer of 64 packets to maintain the data packets start with route discovery phase, which are waiting to get the route that has not yet arrived. The mechanism that prevents unlimited buffering is to drop packets in buffer that took longer than 30 seconds. The interface queue that has a maximum size of 50 packets is used to maintain the routing layer packets that are sent until the MAC layer transmits them. The interface queue has two priorities for packets, each perform FIFO order mechanism. The higher primacy is given to routing packets as opposed to data packets [34].

The evaluations in this research depends on the simulation of 10, 20, 30, 40 and 50 wireless nodes for each protocol, moving randomly along a simulation area (800m x 800m) flat grid for 100 seconds simulation time. A square field grants nodes to move freely with a similar density. For the sake of a fair comparison between the two protocols, we have made the same environment and the same parameters for both protocols mentioned in Table I. Fig. 2 shows the simulation environment setup and configuration.

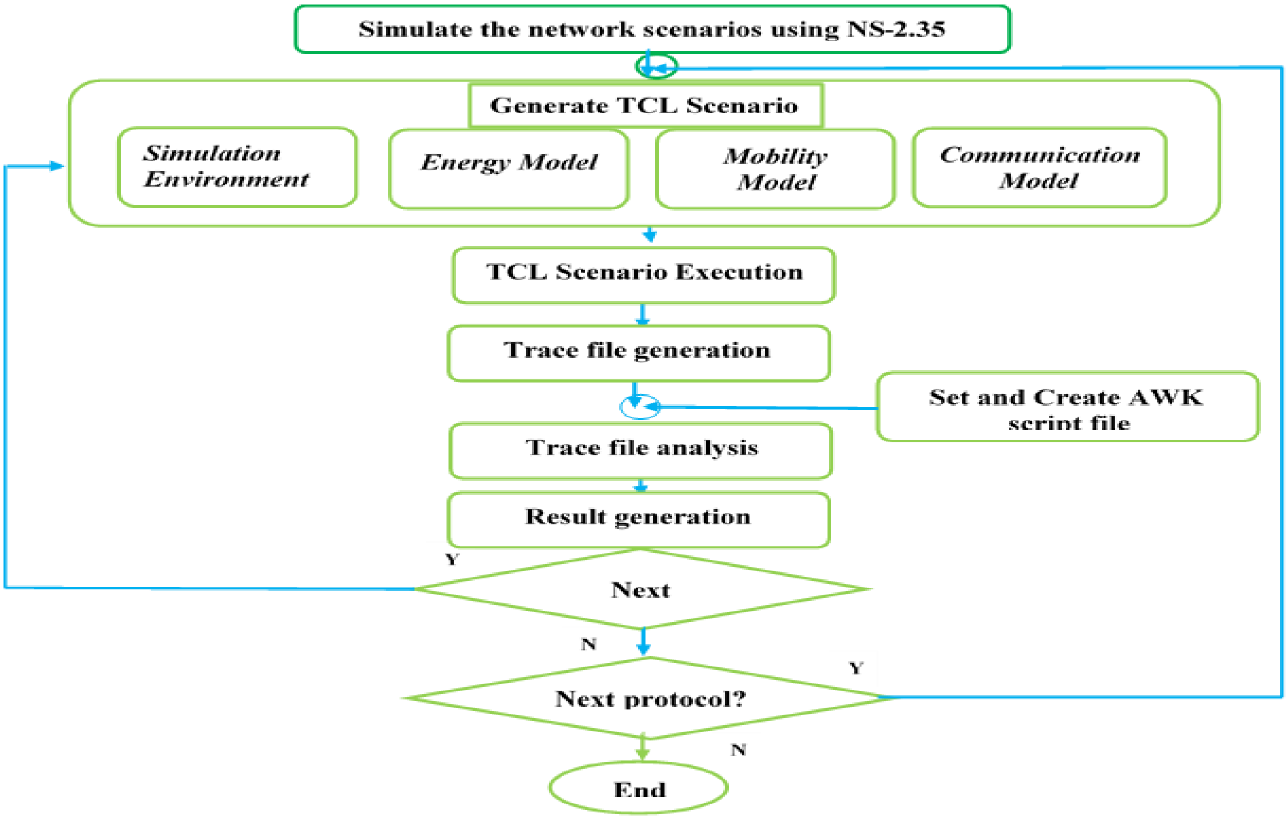

Fig. 1. Simulation Workflow.

```
set val(chan) Channel/WirelessChannel ;          # channel type
set val(prop) Propagation/TwoRayGround ;         # radio-propagation model
set val(ant) Antenna/OmniAntenna    ;            # Antenna type
set val(ll) LL ;                                 # Link layer type
set val(ifq) Queue/DropTail/PriQueue ;           # Interface queue type
set val(ifqlen) 50 ;                             # max packet in ifq
set val(netif) Phy/WirelessPhy ;                 # network interface type
set val(mac) Mac/802_11 ;                        # MAC type
set val(nn) 50 ;                                 # number of mobilenodes
set val(rp) AOMDV ;                              # routing protocol
set val(x) 800                                   #Simulation area_X
set val(y) 800                                   #Simulation area_Y
set opt(energymodel)    EnergyModel    ;         # Energy Model
set opt(initialenergy)  100 ;                    #initial energy in joules
set ns [new Simulator]
set f [open aomdv_50.tr w]                       #trace file
$ns trace-all $f
set namtrace [open aomdv_50.nam w]               #nam file
$ns namtrace-all-wireless $namtrace $val(x) $val(y)
set topo [new Topography]
$topo load_flatgrid 800 800
create-god $val(nn)
```

Fig. 2. Simulation Environment Configuration.

B. Energy Model

The parameters of energy model used in this research are mentioned in Table I and its detail is reflected in Fig. 3. The energy model is used to measure the power consumed in each scenario. The node consumes the available energy (initial energy) based on the following parameters: (1) Transmission (Tx) (2) Reception (Rx) (3) Idle (4) Sleep (5) TransitionPower and (6) TransitionTime states. Transmission manner indicates the energy consumed (Watt) for transferring each packet, reception manner indicates the energy consumed (Watt) for receiving each packet, idle manner indicates the energy consumed (Watt) when the node is in idle mode, sleep manner indicates the energy consumed (Watt) when the node is in sleep mode, TransitionPower indicates the energy consumed (Watt) in case of transition from sleep to idle. TransitionTime indicates the time (second) which is used in case of transition from sleep to idle.

TABLE I. SIMULATION PARAMETERS

Parameter	**Value**	**Parameter**	**Value**
Network Simulator	NS2.35	Transition Power	0.2 W
Type of Channel	Wireless Channel	Transition Time	0.005 S
Radio Propagation Model	Two Ray Ground	Routing Protocols	AODV, AOMDV
Type of Antenna	Omni Antenna	Mobility Model	Random Waypoint
Type of Interface queue	DropTail/PriQueue	Simulation Time	100 seconds
Max Packet in Ifqueue	50	Number of Scenarios	10 (5x2)
Type of Network Interface	Phy/WirelessPhy	Number of Nodes	10,20,30,40,50

Type of MAC layer	Mac/802.11	Transport Layer Protocol	UDP (User Datagram Protocol)
Simulation Area	800m x 800m	Traffic Model	CBR (Constant Bit Rate)
Initial Energy for Each Node	100 Joule	Packet Size	512 bytes
Transmission Power	2.0 W	Link Capacity	1.0 Mbps
Reception Power	1.0 W	Connection Rate	4 packets/sec
Idle Power	0.5 W	Number of Connections	1,2,3,4,5
Sleep Power	0.001 W	Node Speed	10m/s

```
$ns node-config -adhocRouting $val(rp) \
 -llType $val(ll) \
 -macType $val(mac) \
 -ifqType $val(ifq) \
 -ifqLen $val(ifqlen) \
 -antType $val(ant) \
 -propType $val(prop) \
 -phyType $val(netif) \
 -channel $chan_1\
-topoInstance $topo \
-agentTrace ON \
-routerTrace ON \
-macTrace ON \
-movementTrace ON \
-energyModel $opt(energymodel) \
        -idlePower 0.5 \
        -rxPower 1.0 \
        -txPower 2.0 \
        -sleepPower 0.001 \
        -transitionPower 0.2 \
        -transitionTime 0.005 \
        -initialEnergy $opt(initialenergy)
```

Fig. 3. Energy Model.

```
# dynamic rand destination procedure.
$ns at 0.5 "target"
proc target {} {
    global ns val n
    set time 1.0
    set now [$ns now]
    for {set i 0} {$i<$val(nn)} {incr i} {
        set xx [expr rand()*800]
        set yy [expr rand()*800]
        $ns at $now "$n($i) setdest $xx $yy 10.0"
    }
   $ns at [expr $now+$time] "target"
}
```

Fig. 4. Dynamic Mobility Function.

C. Mobility Model

In this research, the mobility model used is random waypoint, in which the mobile node move randomly and update their location, speed and acceleration change over time. It is simple and widely available model, thus, it is the most common mobility models to evaluate MANETs routing protocol [35]. In this research, node movement is done by dynamic destination setting procedure as shown in Fig. 4. The scenario files utilized for each simulation are distinguished by same pause time which is 0.5s. All nodes start the simulation by remaining stationary for the pause time period. At the end of pause time period, the node randomly select destination in the simulation area, moving in space at a uniform speed of 10m/s for the entire period of the simulation.

D. Communication Model

This research used the traffic pattern to be constant bit rate (CBR) source over the User Datagram Protocol (UDP) at transport layer. The origin and target pairs are spread randomly across the network. Packets size 512 bytes is used, while the number of CBR packets generated vary based on the connection rate, Hence, for all scenarios in these simulations, we choose to fix connection rate at 4 packets/sec. Five different communication patterns corresponding to 1, 2, 3, 4 and 5 connections for 10, 20, 30, 40, 50 nodes respectively were considered. The communication pattern of 5 connections is shown in Fig. 5.

```
#procedor CBR agent
   proc attach-CBR-traffic { node sink size interval } {
#Get an instance of the simulator
            set ns [Simulator instance]
#Create a CBR agent and attach it to the node
            set cbr [new Agent/CBR]
            $ns attach-agent $node $cbr
            $cbr set packetSize_ $size
            $cbr set interval_ $interval
            $cbr set rate_ 1.0Mb
#Attach CBR source to sink;
            $ns connect $cbr $sink
            return $cbr
   }
   set cbr0 [attach-CBR-traffic $n(0) $sink1 512 0.25]
   set cbr1 [attach-CBR-traffic $n(7) $sink2 512 0.25]
   set cbr2 [attach-CBR-traffic $n(20) $sink3 512 0.25]
   set cbr3 [attach-CBR-traffic $n(30) $sink4 512 0.25]
   set cbr4 [attach-CBR-traffic $n(40) $sink5 512 0.25]
   $ns at 1.0 "$cbr0 start"
   $ns at 1.0 "$cbr1 start"
   $ns at 1.0 "$cbr2 start"
   $ns at 1.0 "$cbr3 start"
   $ns at 1.0 "$cbr4 start"
   $ns at 100.0 "finish"
   puts "Start of simulation.."
   $ns run
```

Fig. 5. Communication Pattern.

E. Performance Metrics Used in Simulation

In order to evaluate the performance of AODV and AOMDV, we considered the eight most commonly used quantitative indicators to judge the performance of the protocols: (1) Total Energy consumed by all nodes (TE); (2) Average Consumed Energy (ACE); (3) Average Residual Energy (ARE); (4) Packet Delivery Fraction (PDF); (5) Throughput Rate [kbps]; (6) End-to-End delay (E2ED); (7) Routing Load and (8) Normalized Routing Load.

1) Total Energy consumed by all nodes (TE): Energy consumption is computed as follows:

The time needed for transmitting a data packet is

$$Time = 8 \times (Psize/BW)$$

Therefore, we have:

$$Eti = Pti \times Time$$

$$Eri = Pri \times Time.$$

$$EIdi = PIdi \times Time$$

The transition power mode with transition time(*tt*) is as follows: Etpi = Ptpi × Time(*tt*)

Where Eti indicates the amount of energy consumed by a node *i* in the transmission power mode, Eri indicate the amount of energy consumed by a node *i* in the Reception Power mode, EId indicates the amount of energy consumed by a node *i* in the Idle mode, Esi indicates the amount of energy consumed by a node *i* in the sleeping mode, and Etpi indicates the amount of energy consumed by a node *i* in the TransitionPower mode with TransitionTime (*tt*) which is used for transition from sleep to idle. The total energy consumed by a node *i* is calculated as:

$$TotalE\ i = Eti\ +\ Eri +\ EIdi +\ EIdi +\ Esi +\ Et \qquad (1)$$

The Total Energy consumed (TE) by all nodes (N) is:

$$TE = \sum_{i=0}^{N} TotalE\ i \qquad (2)$$

2) Average Consumed Energy (ACE): It refers to the ratio of total energy consumed by each nodes (TE) to the number of nodes (N).

$$ACE\ = \frac{TE}{N} \qquad (3)$$

3) Average Residual Energy (ARE): It refers to the ratio of total initial energy of all nodes (IE) – total energy consumed by all nodes (TE) divided by number of nodes N.

$$ARE = \frac{\sum_{i=0}^{N} IE - \sum_{i=0}^{N} TE}{N} \qquad (4)$$

4) Packet Delivery Fraction (PDF): It indicates the ratio of correctly received packets to all sent packets in a period. It is an appraisal indicator of the reliability of transmission in Ad-Hoc network. The smaller value the packet delivery shows the worst performance.

$$PDF = \sum_{i=0}^{N} Pri)/(\sum_{i=0}^{N} Psi) \qquad (5)$$

N is the total number of nodes, Pri is the number of packets received by node *i*, Psi is the number of packets sent by node *i*.

5) Throughput Rate [kbps] (TR): It points to the total received packets' size successfully reached at target per unit time.

$$TR\ [kbps] = \frac{\sum recevd_{size}}{Stop_T - Start_T} \times \frac{8}{1000} \qquad (6)$$

6) End-to-End Delay (E2ED): The time taken by the data packets to be arrived at destination sent by the source is known as Average End-to-End Delay. The Average End-to-End delay value refers to the time used for all potential delays results in buffering procedure, interface queuing, the retransmission procedure executed at MAC and propagation times. The lower the delay time, the better the efficiency.

$$Average\ E2ED = \frac{1}{NP} \sum_{i=0}^{NP} \big(Rt(i) - St(i)\big) \qquad (7)$$

Where NP refers to total number of the packets received successfully, Rti points to the time when the packet *i* is received, Sti points to the time when the packet was sent.

7) Routing Load: The total routing packets transmitted including the packets which are forwarded at network layer are known as Routing Load.

$$Routing\ Laod = CPSn + CPFn \qquad (8)$$

where, CPSn points to the number of routing control packets generated to be sent, CPFn points to the number of routing control packets to be forwarded, CPSn and COFn at network layer.

8) Normalized Routing Load (NRL): Normalized routing load is the average number of routing control packets transmitted at network layer per data packets received by destination at the application layer. It refers to the congestion status of the network. The higher routing load increases the probability of network congestion.

$$NRL = \frac{Routing\ Laod}{DPn} \qquad (9)$$

Where DPn refers the total number of the data packets received.

IV. Results And Discussion

This section includes the details discussion about the results generated during simulation. In this research for analyzing the trace file for each scenario the AWK scripting language [36], [37] is used. Fig. 6 illustrates the energy tracking function of nodes which uses the trace files generated through simulation as input and store the output in the matrix. While Fig. 7 illustrates compute function of energy that is consumed by nodes, which uses the output of tracking function as input and compute consumed energy for each node as output.

Tables II, III, IV, V and VI show the results obtained regarding energy consumption by each node in the various scenarios separately for both protocols AODV and AOMDV.

```
BEGIN {
        initialenergy = 100
        energy_left[size] = initialenergy
        maxenergy=0
        totalenergy=0
        total=0
        n=50
        n1=0
        nodeid=0
        i=0;
        }
{
        event = $1
        time = $2
       if (event=="N"){
                node_id = $5
                energy=$7
               for(i=0;i<n;i++) {
                       if(i == node_id) {
                               finalenergy[i]=energy;
                        }
                }
        }
        if(event == "N") {
              for(i=0;i<n;i++) {
                   if(i == node_id) {
                         energy_left[i] = energy_left[i] - (energy_left[i] - energy);
                    }
              }
         }
 }
```

Fig. 6. Energy Tracking Function.

```
BEGIN {
# Compute consumed energy for each node
        for (i in finalenergy) {
                consumenergy[i]=initialenergy-finalenergy[i]
                totalenergy +=consumenergy[i]
                if(maxenergy<consumenergy[i]){
                        maxenergy=consumenergy[i]
                        nodeid=i
                }
        }
 #compute average energy
        averagenergy=totalenergy/n
 #output
        for (i=0; i<n; i++) {
                print("node",i, consumenergy[i])
        }
        print("average",averagenergy)
        print("total energy",totalenergy)
        for(i=0;i<n;i++) {
                total=total+energy_left[i];
                if(energy_left[i]!=0)
                        n1++;
        }
        n1--;
        printf("Average residual energy  :%.6f\n", total/n);
  }
```

Fig. 7. Compute Consumed Energy Function.

TABLE II. ENERGY CONSUMPTION BY EACH NODE IN 10 NODES SCENARIO

Node No.	AODV	AOMDV	Node No.	AODV	AOMDV
0	55.2753	55.8414	5	55.5218	56.0896
1	53.4916	54.0586	6	53.2687	53.8353
2	53.2687	53.8403	7	53.2143	53.7748
3	55.5221	56.0913	8	53.2687	53.8362
4	53.2687	53.7633	9	53.2687	53.8386

TABLE III. ENERGY CONSUMPTION BY EACH NODE IN 20 NODES SCENARIO

Node No.	AODV	AOMDV	Node No.	AODV	AOMDV
0	59.7815	59.6455	10	57.8163	57.7453
1	58.0402	57.9685	11	57.8163	57.7374
2	58.0594	57.9863	12	57.8163	57.7341
3	57.8163	57.7386	13	57.6738	57.6145
4	60.0735	57.7366	14	60.0701	57.7366
5	57.8163	57.7341	15	57.8163	59.9957
6	60.0697	57.7332	16	60.0704	57.7378
7	59.8023	59.7733	17	57.8163	57.7357
8	57.8163	59.9987	18	60.0613	59.9865
9	57.8163	60.0051	19	57.8163	57.7378

TABLE IV. ENERGY CONSUMPTION BY EACH NODE IN 30 NODES SCENARIO

Node No.	AODV	AOMDV	Node No.	AODV	AOMDV
0	62.0289	62.3113	15	62.3425	60.4472
1	62.4216	60.6681	16	60.0786	62.7112
2	60.3226	60.6946	17	60.0786	60.4405
3	60.0786	62.71	18	62.3304	60.4111
4	60.2165	60.4458	19	60.0786	60.442
5	60.0786	60.4421	20	62.1021	62.4772
6	60.078	60.3897	21	60.3209	60.7035
7	62.0824	62.3957	22	60.0786	60.4405
8	60.0786	60.4496	23	60.0786	60.4428
9	62.2012	60.4561	24	60.0786	60.4429
10	60.0786	60.4412	25	60.0786	60.4491
11	62.3355	60.4604	26	62.3341	62.7078
12	60.0786	60.4413	27	60.0786	60.4471
13	59.975	62.686	28	59.9649	60.2529
14	60.0786	62.7056	29	60.0265	60.3115

TABLE V. ENERGY CONSUMPTION BY EACH NODE IN 40 NODES SCENARIO

Node No.	AODV	AOMDV	Node No.	AODV	AOMDV
0	68.8375	68.2596	20	68.9956	68.4826
1	71.4571	66.6842	21	67.2109	66.6952
2	69.331	66.7028	22	66.9651	66.4381
3	69.0919	66.452	23	66.9685	66.4482
4	69.3759	66.4544	24	71.4909	66.4494
5	67.1073	66.4397	25	66.9685	66.4499
6	66.9337	68.6657	26	69.242	66.4486
7	68.8342	68.4365	27	66.9679	66.4493
8	66.9685	68.7176	28	69.085	66.1894
9	66.9685	68.7181	29	66.862	66.3122
10	66.9685	68.7128	30	68.8081	68.3569
11	66.9685	70.9735	31	67.0836	66.5254
12	69.2285	66.4527	32	66.9685	66.4462
13	66.7829	68.6642	33	66.9658	66.4346
14	66.9685	66.4478	34	66.9685	66.4486
15	66.9685	66.4478	35	66.9685	66.4487
16	69.2305	68.717	36	66.9563	66.4145
17	66.9679	66.4428	37	66.6084	66.2002
18	66.9229	66.328	38	66.9018	66.3646
19	67.1089	66.4519	39	66.9685	68.7203

TABLE VI. ENERGY CONSUMPTION BY EACH NODE IN 50 NODES SCENARIO

Node No.	AODV	AOMDV	Node No.	AODV	AOMDV
0	66.7606	73.3017	25	64.8803	73.8995
1	65.1066	71.875	26	64.8799	71.6341
2	67.2366	71.8762	27	67.1378	73.8461
3	64.973	71.6389	28	64.6579	71.2808
4	67.1531	71.6319	29	64.7657	71.3901
5	64.967	71.5672	30	66.7479	73.4913
6	64.8442	71.5385	31	65.0551	71.5351
7	66.8665	73.613	32	64.883	71.6359
8	64.8819	71.6327	33	64.8614	71.6213
9	67.1568	71.6373	34	64.8771	71.6133
10	67.1546	72.5123	35	64.8786	71.6206
11	64.882	71.6337	36	64.7843	73.8235
12	64.9353	71.6114	37	64.534	73.4686
13	64.7378	71.486	38	64.8162	71.5277
14	64.8811	76.7877	39	64.9392	73.899
15	67.149	71.6372	40	66.9181	73.6779
16	66.9909	73.9153	41	64.9904	71.3731
17	64.8782	71.5975	42	64.7865	71.5662
18	64.8756	73.8302	43	64.6201	70.7853
19	64.8773	71.6173	44	64.6883	71.4151
20	66.9138	76.5577	45	64.5232	70.5279
21	67.4006	72.4824	46	64.5299	71.1699
22	64.9339	73.8115	47	64.308	69.802
23	64.8771	71.6168	48	64.3463	70.7955
24	64.878	71.62	49	63.9482	68.8861

Table VII and VIII show the evaluation results obtained for the AODV in different scenarios used in this research. Table IX and X shows the evaluation results obtained for the AOMDV in different scenarios.

TABLE VII. ENERGY CONSUMPTION EVALUATION OF AODV

N	PS	PR	PD	TE	ACE	ARE
10	396	396	0	539.368	53.9368	46.0632
20	792	792	0	1171.87	58.5933	41.4067
30	1188	1187	1	1822.18	60.7394	39.2606
40	1584	1582	2	2710.98	67.7744	32.2256
50	1980	1976	4	3268.67	65.3734	34.6266

N: NO. OF NODES, PS: PACKET SENT, PR: PACKET RECEIVED, PD: PACKET DROPPED, TE: TOTAL ENERGY CONSUMED BY ALL NODES (JOULES), ACE: AVERAGE ENERGY CONSUMED BY EACH NODE, ARE: AVERAGE RESIDUAL ENERGY FOR EACH NODE.

TABLE VIII. PERFORMANCE EVALUATION OF AODV

N	PDF %	TR [bps]	TR kbps	E2ED (s)	RL	NRL
10	100	202752	16.42	0.017984	12	0.030
20	100	405504	32.84	0.0322659	45	0.057
30	99.9158	607744	49.21	0.0412604	159	0.134
40	99.8737	809984	65.55	0.140721	527	0.333
50	99.798	1011712	81.90	0.403008	664	0.336

N: NO. OF NODES, PDF: PACKET DELIVERY FRACTION, TR: THROUGHPUT RATE,E2ED: AVERAGE END-TO-END DELAY, RL: ROUTING LOAD, NRL: NORMALIZED ROUTING LOAD

TABLE IX. ENERGY CONSUMPTION EVALUATION OF AOMDV

N	PS	PR	PD	TE	ACE	ARE
10	396	396	0	544.969	54.4969	45.503058
20	792	792	0	1168.08	58.4041	41.595934
30	1188	1188	0	1830.82	61.0275	38.972501
40	1584	1583	1	2685.89	67.1473	32.852694
50	1980	1977	3	3609.32	72.1863	27.813691

N: NO. OF NODES, PS: PACKET SENT, PR: PACKET RECEIVED, PD: PACKET DROPPED, TE: TOTAL ENERGY CONSUMED BY ALL NODES (JOULES), ACE: AVERAGE ENERGY CONSUMED BY EACH NODE, ARE: AVERAGE RESIDUAL ENERGY FOR EACH NODE.

TABLE X. PERFORMANCE EVALUATION OF AOMDV

N	PDF%	TR [bps]	TR kbps	E2ED (s)	RL	NRL
10	100	202752	16.42	0.01812	1005	2.538
20	100	405504	32.84	0.02989	2027	2.559
30	100	608256	49.25	0.03975	3110	2.618
40	99.9369	810496	65.61	0.05884	4155	2.625
50	99.8485	101222	81.92	0.07327	5219	2.64

N: No. of Nodes, PDF: Packet Delivery Fraction, TR: Throughput Rate, E2ED: Average End-To-End Delay, RL: Routing Load, NRL: Normalized Routing Load

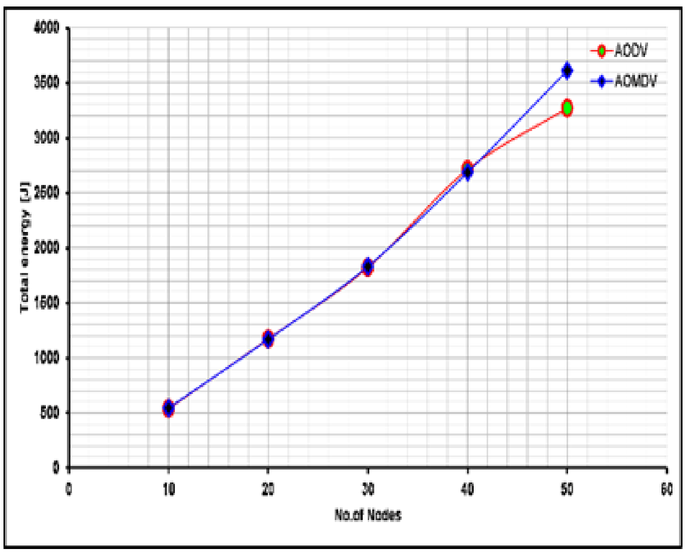

Fig. 8. Total Energy Consumed By All Nodes (Joules) Vs Number of Nodes.

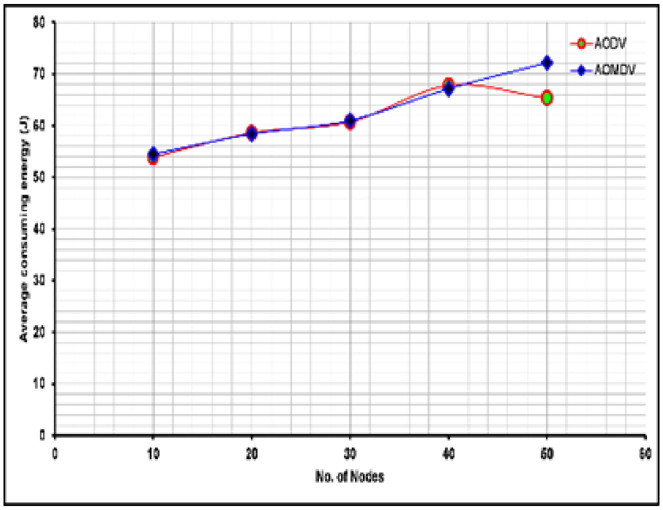

Fig. 9. Average Energy Consumed by each Nodes Vs Number of Node.

Fig. 8 shows the total energy consumed by all nodes of each scenario. The outcomes demonstrated that the AODV consumed less energy as compared to AOMDV, the possible reason behind this is that AODV is single-path protocol and found single path to destination due to which it consumed less energy. The term average energy consumed reflects the percentage of energy consumed by each node. Fig. 9 shows this result, which shows more energy consumed by the AOMDV when the number of nodes increased.

Fig. 10 shows the percentage of residual energy or battery life for each node in different scenarios, by using the equation number (4); it is clear from Fig. 10 that the AODV has more residual energy as compared to AOMDV. PDF indicates the percentage of packets that arrived at the destination successfully. Fig. 11 shows the PDF of AODV and AOMDV in the first two scenarios (at 10, 20 nodes with 1 and 2 connections) are almost same. However, with the increase in the number of nodes and CBR connections (at 30, 40, 50 nodes with 3, 4, 5 connections) AOMDV showed better results as compared to AODV.

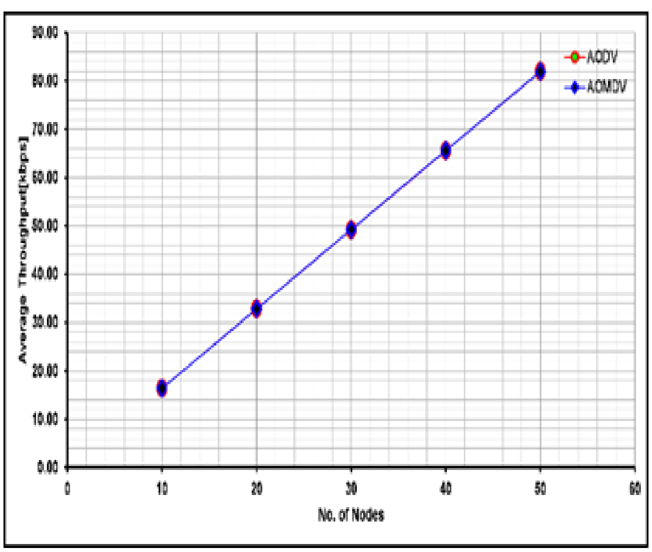

Fig. 10. Average Residual Energy Vs Number of Nodes.

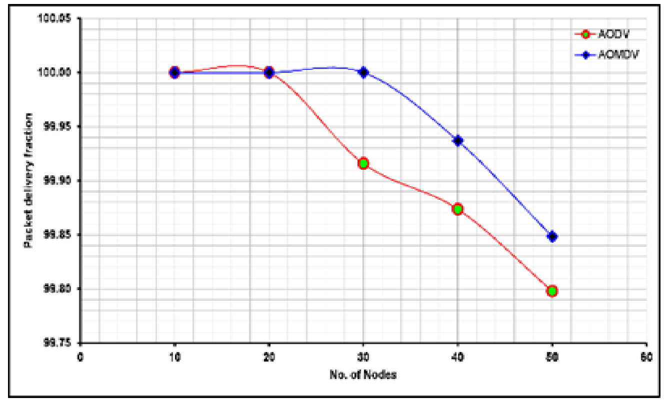

Fig. 11. Packet Delivery Fraction Vs Number of Nodes.

Fig. 12 shows the network throughput rate of AODV and AOMDV versus the number of nodes. Based on the results, AOMDV produced better throughput rate. In other words, when the number of nodes increased the AOMDV throughput increased and when the number of nodes decreased the AOMDV throughput decreased. AODV is a single-path routing protocol whose average end-to-end delay is higher as compared to multi-path protocols. Fig. 13 clearly shows the higher delay of AODV as the number of nodes and the number of connections increases, and in case of AOMDV it reduced. This is the nature of the AOMDV protocol, which works to find alternate paths when the basic path is lost without having to rediscover the path, and therefore does not require extra time.

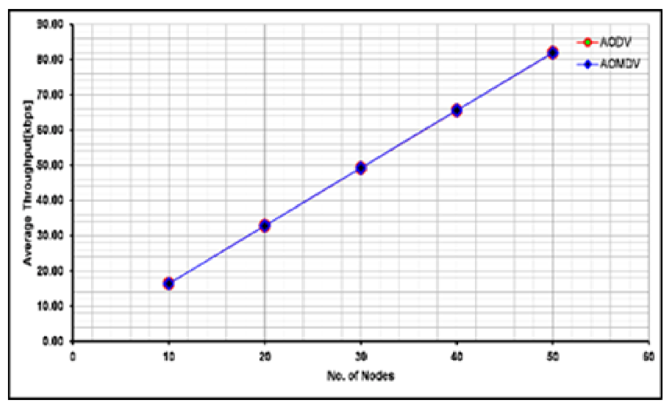

Fig. 12. Throughput Rate [kbps] Vs Number of Nodes.

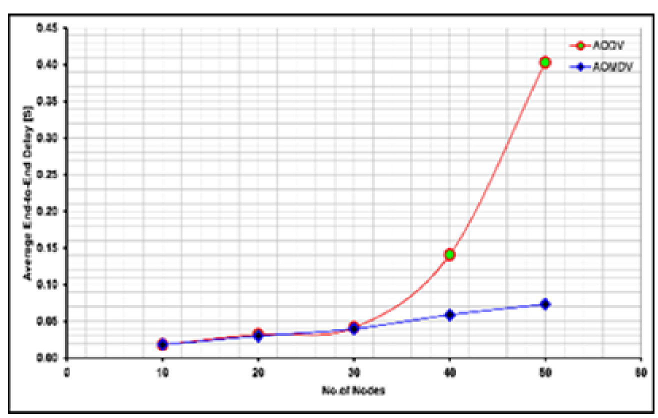

Fig. 13. Average End-to-End Delay Vs Number of Nodes.

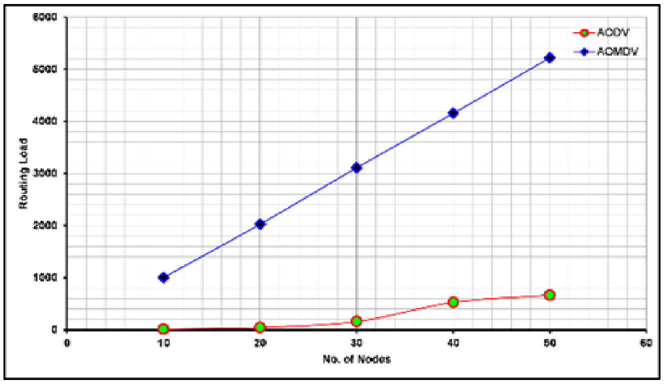

Fig. 14. Routing Load Vs Number of Nodes.

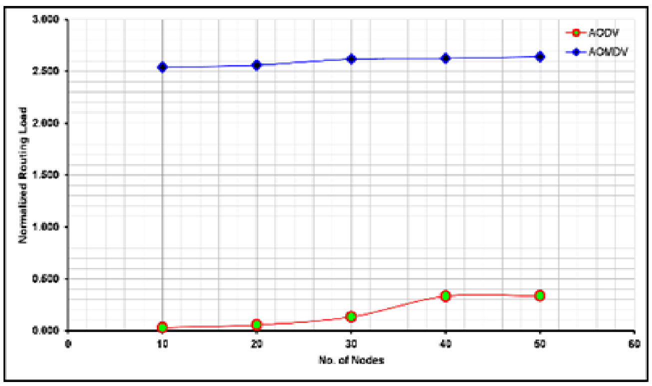

Fig. 15. Normalized Routing Load Vs Number of Nodes.

Routing load of AODV and AOMDV protocol is shown in Fig. 14. The simulation outcomes demonstrated that the AODV protocol produced less routing overhead because it is a single-path protocol. NRL indicates the number of routing packets transmitted including the forwarded packets per data packets delivered at application layer to the destination. Fig. 15 shows the simulation results of the NRL of AODV and AOMDV at different number of nodes, and in various CBR connections. It has been observed that AOMDV has higher NRL. The reason is that routing overhead is higher in AOMDV because the nature of the protocol is multi-path, where the routing packets seeking to find many alternate routes are retained and are used in case of loss of connection of the main path in order to reduce end-to-end delay and increases packet delivery rate.

V. Conclusion

In this research performance evaluation of two routing protocols AODV and AOMDV in MANETs has been done. There is a lack of detailed evaluation of energy consumption of mobile ad-hoc network protocols. Furthermore, there is a great need to investigate the energy consumption of known-protocols in MANETs for future research studies. The vast majority of studies concentrated on performance parameters based on traditional performance metrics. This research provides a paradigm for future studies for the development of dynamic routing protocols, which are more efficient and effective in terms of energy consumption and producing less overhead.

Extensive simulation has been done in NS2 simulator, which includes ten scenarios, five for each protocol; vary in density of nodes and traffic. It has been concluded in this research that the performance of AOMDV is more optimal as compared to AODV in terms of packet delivery fraction, throughput and end-to-end delay. However, in terms of energy consumption and normalized routing load, AODV is more optimal as compared to AOMDV. It is also concluded that AOMDV is more suitable when the network is stable; however, its performance is reduced when the network topology changes frequently. Furthermore, there is a trade-off in AOMDV routing protocol between energy consumption on the one hand and PDF efficiency and throughout on the other hand.

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