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A Novel Energy Efficient Ad hoc On-demand Multipath Routing Protocol for Mobile Ad hoc Networks

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ABSTRACT

A mobile Ad-hoc Network is a Wireless Communication Network. The Multipath routing Protocols establish multiple routes between source to destination. The multipath routing protocols establish multiple routes between nodes. The construction of multiple routes should be done with minimum overhead and bandwidth consumption. The Proactive and Reactive protocols are selected for survey due to edges their over hybrid Ad-hoc routing protocol in various aspects load balancing. The purpose of this article is to analysis the characteristics of different multipath routing protocols.

Index terms : route failure, load balancing, multi hop, mobility, reactive protocols, proactive protocols, **MANET, AODV, AOMDV, OLSR.**

As the wireless nodes are having limited battery life, energy efficiency is the most important design consideration in mobile ad hoc networks. The network life time will be improved by appropriately using the power for connections. The main objective of this paper is to develop a novel energy efficient routing protocol for mobile ad hoc networks. We proposed an enhanced version of Ad hoc On-demand Multipath Distance Vector Routing (AOMDV) protocol called a **Novel Energy Efficient-AOMDV (NEE-AOMDV)** protocol. The

NEE-AOMDV uses two route metrics such as minimal nodal residual energy and hop count for route selection. It first finds minimal nodal residual energy and hop count of each route and then energy efficient shortest routes among the discovered routes based on the proposed **route priority algorithm**. We evaluate the performance of NEE-AOMDV using NS2.34 and compare it with both AOMDV and MMRE-AOMDV routing protocols. It reduces the energy consumption, average end to end delay, routing overhead and normalized routing overhead. It also improves packet delivery ratio and throughput. From the simulation results, it is found that the NEE-AOMDV routing protocol has performed better than AOMDV and MMRE-AOMDV routing protocols.

Keywords: Mobile ad hoc networks; Multipath Routing; Energy efficiency; average end to end delay; routing overhead; AOMDV; MMRE-AOMDV.

I. Introduction

A Mobile Ad hoc Network (MANET) is an interconnection of autonomous mobile nodes by wireless links forming dynamic topology and providing multi-hop communications without using much physical network infrastructure such as routers, servers, access points or cables or centralized administration. Each mobile node is acting as a router as well as a node. The properties of these networks make them to be very highly desirable in war zones, disaster recovery, aircraft and marine communications, industrial, home and other scenarios. The issues of MANET [1,2,3] are: ***(i) unpredictable link properties*** that expose packet collision and signal propagation, ***(ii) node mobility*** creates dynamic topology, ***(iii) limited battery life*** of mobile devices, ***(iv) hidden and exposed terminal problems*** occur when signals of two nodes are colliding with each other. ***(v) route maintenance*** is very difficult because of changing behavior of the communication medium, and ***(vi)lacking in security*** in boundaries of MANET leads to attacks such as passive eavesdropping, active interfering, and leakage of secret information, data tampering, message replay, message contamination, and denial-of-service (DoS).

Single path routing protocols find only a single route between a pair of source and destination. In which, a new route discovery is needed for every route break that leads high overhead and latency. Multipath routing protocols establish communication from source to destination by having backup routes. During end-to-end communication, if a primary route fails, the backup routes are used for efficient delivery of messages at their destination. These protocols [4] are generally classified into three groups such as ***(i) proactive***, ***(ii) reactive*** and ***(iii) hybrid*** based on route discovery and maintenance mechanisms. The proactive (table-driven) routing protocols determine the routes to all destinations at start up and maintain using periodic update process based on distance vector-based or link state-based routing strategies. Examples for multipath proactive routing protocols are the multipath destination-sequenced distance-vector (MDSDV) [5] and multipath optimized link state routing (MP-OLSR) [6]. The drawbacks of these algorithms are to update the routing tables frequently which consume a large amount of memory, bandwidth and power.

But, in the reactive (on-demand) routing protocol, there is no need to maintain the routing information in routing table by each node. The routes are determined and maintained only when they are required by the source for data transmission during route discovery process and the routing overhead is also reduced. Examples for multipath reactive routing protocols are the multipath dynamic source routing (MP-DSR) [7] and the ad hoc on-demand multipath distance vector (AOMDV) [8] protocol is a multipath extension of AODV[9]. AOMDV provides link-disjoint, loop free and fault tolerance paths which improves the network lifetime by minimizing packet loss, routing overhead and energy consumption. The main goal of a QoS multipath routing protocol is to identify loop free energy efficient paths from any source to destination with the available resources to meet the QoS requirements of the desired service.

The features of both proactive and reactive protocols are combined together to form a new generation of protocols called hybrid multipath routing protocols. This type of protocols are used to increase scalability by allowing nodes with close proximity to work together to form some sort of a backbone to reduce the route discovery overheads. This can be achieved by proactively maintaining routes to nearby nodes and determining routes to far away nodes using reactive route discovery strategy. Example for this category is Zone Routing Protocol (ZRP)[10].

Wireless ad hoc networks, due to their ad hoc nature and mobile environment, make frequent use of broadcast primitives such as bandwidth, energy, delay, etc. to adapt with network changes. Therefore, it is essential to develop efficient reactive routing protocol that optimize the energy consumption by incorporating information about nodes’ remaining battery levels into routing information in order to avoid the selection of route with low energy. The major contribution of this work is to introduce energy efficient and modified version of AOMDV routing protocol for wireless ad hoc networks, called **NEE-AOMDV** routing protocol.

The rest of the paper is organized as follows. Section II gives a brief description about the related works. Section III presents the proposed routing protocol. The simulation environment and experimental results are discussed in Section IV. Finally, conclusions and future work are given in Section V.

II. Related Work

A. Ad hoc On-demand Multipath Distance Vector routing (AOMDV)

AOMDV is an enhanced version of a prominent and well-studied on-demand single path routing protocol known as AODV. AOMDV eliminates the occurrence of frequent link failures and route breaks due to node mobility, node failures, congestion in traffic, packet collisions, and so on in highly dynamic ad hoc networks by adding some extra fields in routing tables and control packets in order to compute loop-free and link-disjoint multiple routes between the source and destination.

In multiple routes, the destination contains list of the next-hops along with the corresponding hop counts in routing table entries. If all the next hops have the same sequence number, the advertised hop count is defined as the maximum hop count for all the paths. Route advertisement effectively sends to destination by using this hop count value. If any duplicate route advertisement received by a node then it forwards the packet through alternate path to the destination. The loop freedom is ensured by selecting the alternate path for a destination on the basis of the hop count value if it is less than the advertised hop count for that destination. The destination node sorts out all the paths by maximum hop count value. The best path is selected and data forwarded through this path. In AOMDV, RREQ (route request) propagates from the source node to the destination to establish multiple reverse paths both at intermediate nodes as well as the destination. The corresponding multiple RREP (route reply) generates and traverses these reverse paths back to form multiple forward paths to the destination at the source and intermediate nodes. The major thing in AOMDV is to provide alternate path for intermediate nodes also and it is useful for reducing route discovery frequency. It is classified into node-disjoint or link-disjoint route. In node-disjoint routes, duplicate RREQs cannot be immediately rejected, because the reason is RREQ and RREP pair arriving through different neighbour of the source node in a node-disjoint path.

B. Power Efficient Routing

Power saving during route discovery and *power control during data transmission* are the two major classification of power saving techniques for wireless ad hoc networks. The total energy consumption is reduced in power saving technique in idle listening mode [11,12,13,14] by putting the mobile nodes into periodical sleep where as in power control technique [15,16], the total energy consumption is also reduced by adjusting the transmission ranges during data transmission. Several power efficient on-demand routing protocols have been developed. Liu et al. [17] proposed a novel Collision-Constrained Energy Algorithm (ECCA) by defining correlation factor to weigh collision probability while using node-disjoint multipath to transmit data simultaneously. It also calculates an upper limit for correlation factor according to service requirement, and find a minimum energy node-disjoint multipath routing to satisfy the upper limit.

Liang et al. [18] designed an energy and mobility aware geographical multipath routing for wireless sensor networks. This algorithm considers the remaining battery capacity, mobility, and distance to the destination node of candidate sensors in the local communication range for next hop relay node selection, and a fuzzy logic system applied for decision making. Simulation results showed that this scheme could extend the network lifetime. In [19], Bergamo et al. proposed a **DPC** (Distributed Power Control) energy efficient routing protocol for ad hoc networks by estimating the amount of power needed for reliable communications over any link. This power is then used to transmit a packet over the link and calculate the link weight using minimum-weight path search algorithm. In this way, transmit power can be tuned in order to build the desired connectivity diagram and its information is used to privilege lower energy paths while looking a route for packet transmission. Existing routing protocols, such as proactive and reactive protocols, can be modified in order to incorporate this power control feature which tries to minimize the interference in the network and the energy consumption of multihop operation.

Yumei Liu et al. [20] have proposed Maximal Minimal nodal Residual Energy

(MMRE) approach into the existing AOMDV protocol by finding minimal nodal residual energy of each route in the route discovery phase and sorting multiple routes by descending nodal residual energy and use the route with maximal nodal residual energy to forward data packets. This scheme could extend the network lifetime and packet delivery ratio.

III. Proposed Routing Protocol: NEE-AOMDV.

Novel Energy Efficient multipath routing protocol is extended by modifying the route update rules of AOMDV using **route priority algorithm** which uses two metrics such as residual energy and hop count in order to have more energy efficient shortest routes for data transmission. This scheme deals with conserving power by employing power control mechanism for data transmission. It reduces energy consumption, routing overhead and average end-to-end delay. It also improves packet delivery ratio and throughput. The following are the general procedures of NEE-AOMDV routing protocol:

(i) Finding minimal nodal residual energy and hop count of each route between any source and destination pair in the route discovery process.

(ii) Sorting the multiple routes by descending nodal residual energy and ascending hop count and then elect the route based on the **route priority algorithm** to forward data packets.

A. Network Model

A wireless ad hoc network is represented by a directed graph G (M, L) where M is a set of mobile terminals and L is a set of wireless links such that

(i) Each mobile terminal M is in turn represented as M = (E, T,...) where E is the energy, T is the transmission range and the ellipsis (…) is the other broadcast properties of that mobile terminal.

(ii) Each wireless link is also in turn represented as L= (B, D,…) where B is the bandwidth, D is the delay and the ellipsis (…) is the other broadcast properties of that wireless link.

(iii) Let N be the wireless network denoted by $N = (N_1, N_2, N_3, \ldots, N_n)$ where $N_1, N_2, N_3, \ldots, N_n$ are wireless nodes.

(iv) Multiple paths of the network is represented by P.$P=P_1, P_2, \ldots, P_n$, where n is a number of paths and the residual energy of the multiple paths between a source S and destination D are represented by $RE(S,D) = (RE_1, RE_2, \ldots, RE_n)$, where $RE_1, RE_2, \ldots, RE_n$ are the residual energy of $P_1, P_2, \ldots, P_n$ respectively.

(v) The hop count of the set of paths between a source S and destination D is represented by $H(S,D) = (H_1, H_2, \ldots, H_n)$ where $H_1, H_2, \ldots, H_n$) are the hop counts of $P_1, P_2, \ldots, P_n$ respectively.

The problem is to find more energy efficient shortest paths between any source and destination pair. Notations and Descriptions used in this paper are shown in Table 1.

Table 1 Notations and Descriptions

Notation	Description
E_{TH}	Threshold value for High Energy
E_{TM}	Threshold Value for Medium Energy
H_{TS}	Threshold Value for Short Hop Count
H_{TM}	Threshold Value for Medium Hop Count
H_{TL}	Threshold Value for Long Hop Count
min_re_energy	Minimal nodal residual energy of the path
I	Intermediate Node
S	Source Node
D	Destination Node
RE	Residual Energy of a node

B. Finding minimal nodal residual energy

Several changes made in the route discovery phase of AOMDV to find the minimal nodal residual energy of each route between any source and destination pair. Each RREQ and RREP now carries an additional field called ***min_re_energy*** in order to have the route's minimal residual energy. Structure of Routing Table Entries of AOMDV, MMRE-AOMDV and NEE-AOMDV routing protocols are illustrated in Fig. 1

destination
sequence number
advertised hop count
route list {(nexthop$_1$,hopcount$_1$), (nexthop$_2$,hopcount$_2$),…}
expiration time out

(a) AOMDV

destination
sequence number
advertised hop count
route list {(nexthop$_1$,hopcount$_1$,**min_re_energy$_1$**), (nexthop$_2$,hopcount$_2$,**min_re_energy$_2$**),…}
expiration time out

(b) NEE-AOMDV

Fig.1 Structure of Routing Table Entries of AOMDV and NEE-AOMDV routing protocols

In the source node the value of *min_re_energy* should be assigned as a maximum value such as node's initial energy. At the intermediate nodes, the route update rule of NEE-AOMDV is shown in **Algorithm 1** invoked whenever a node receives the route advertisement.

In other words, when an intermediate node receives RREQ if the sequence number of just received packet is greater than this node, it updates its residual energy with the *min_re_energy* of RREQ of this node if it is less than *min_re_energy* of RREQ of this node in order to keep the value of *min_re_energy* lowest among all the nodes in this route. When an intermediate node receives RREQ if the sequence number of just received packet is equal to this node, it updates its residual energy with the *min_re_energy* of RREQ of this node based on **Algorithm 2** in order to keep the value of *min_re_energy* lowest among all the nodes in this route as well as the value of hop count highest among all the nodes in this route.

Algorithm 1 Route Update Rule of NEE-AOMDV Routing Protocol

```
if ($seqnum_i^d < seqnum_j^d$) then
    $seqnum_i^d := seqnum_j^d$;
    if ($i \neq d$) then
        if ($re\_energy_i < min\_re\_energy_j^d$) then
            $min\_re\_energy_j^d := re\_energy_i$;
        end if
        $advertised\_hopcount_i^d := \infty$;
    else
        $advertised\_hopcount_i^d := 0$;
    end if
    $route\_list_i^d = NULL$;
    insert ($j$, $advertised\_hopcount_j^d + 1$, $min\_re\_energy_j^d$) into $route\_list^i_d$;
else if ($seqnum_i^d = seqnum_j^d$) and (($advertised\_hopcount_i^d$, i) > ($advertised\_hopcount_j^d$, j)) then
    if ($min\_re\_energy_j^d >= E_{TH}$) then
        if (($advertised\_hopcount_i^d$, i) <= $H_{TS}$) then
            $min\_re\_energy_j^d := re\_energy_i$;
        else if (($advertised\_hopcount_i^d$, i) <= $H_{TM}$) then
            $min\_re\_energy_j^d := re\_energy_i$;
        else
            $min\_re\_energy_j^d := re\_energy_i$;
        end if
    else if ($min\_re\_energy_j^d >= E_{TM}$) and (($advertised\_hopcount_i^d$, i) <= $H_{TS}$) then
        $min\_re\_energy_j^d := re\_energy_i$;
    end if
    insert ($j$, $advertised\_hopcount_j^d + 1$, $min\_re\_energy_j^d$) into $route\_list^i_d$;
end if
```

Whenever a node i receives a route advertisement to a destination d from a neighbor j, it invokes NEE-AOMDV route update rules in order to setup forward routes as shown in **Algorithm 1**. The variables $seqnum_i^d$, $advertised\_hopcount_i^d$, route $\_list^i_d$, and $min\_re\_energy_j^d$ are *sequence number, advertised hop count, route list* and *minimal nodal residual energy* for *destination d* at *node i* or *node j* respectively. The route with maximal nodal residual energy and minimal hop count for any source to destination is adopted for forwarding data packets. The set up of reverse routes at the destination node of NEE-AOMDV routing protocol is similar to AOMDV routing protocol. Source finds an energy efficient shortest route to a destination is illustrated in Fig. 2.

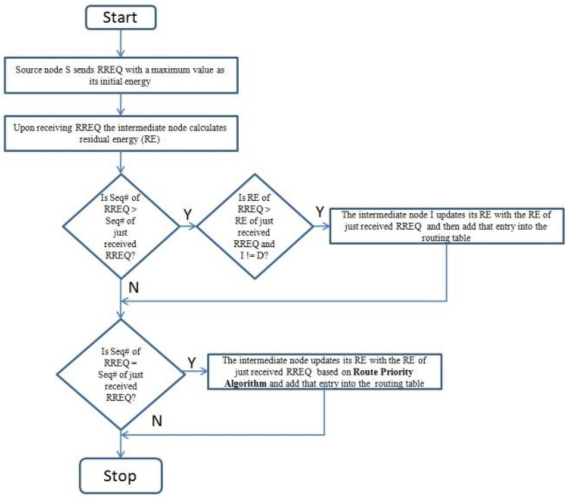

Fig. 2 Energy efficient route discovery by Source

C. Route selection process

Each node maintains route list as shown in Fig.1. After computing the minimal nodal energ, the multiple routes between any source and destination pair are sorted by descending nodal residual energy. We introduce another field into the route list called *min_re_energy*. The value of *min_re_energy* is updated according to the rules as shown in **Algorithm 1**.

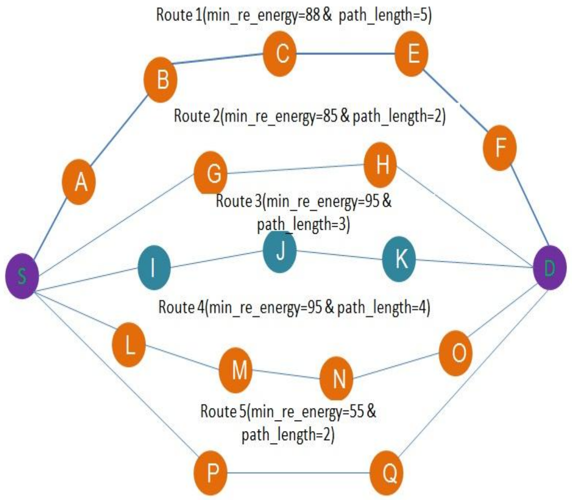

Fig. 3 Route Selection Process of NEE-AOMDV

Algorithm 2 Route Priority

```
Step 1:  Let min_re_energy be the minimal nodal residual energy of a route between a source and destination
Step 2:  Let hop_count be the hop count of a route between a source and destination
Step 3:  if (min_re_energy >= $E_{TH}$ and hop_count <= $H_{TS}$) then
             Select that route for data transmission
         else if (min_re_energy >= $E_{TH}$ and hop_count <= $H_{TM}$) then
             Select that route for data transmission
         else if (min_re_energy <= $E_{TM}$ and hop_count <= $H_{TS}$) then
             Select that route for data transmission
         else if (min_re_energy >= $E_{TH}$ and hop_count <= $H_{TL}$) then
             Select that route for data transmission
         else
             Select that route for data transmission
         end if
```

IV. Simulation Environment and Experimental Results

A. Simulation model

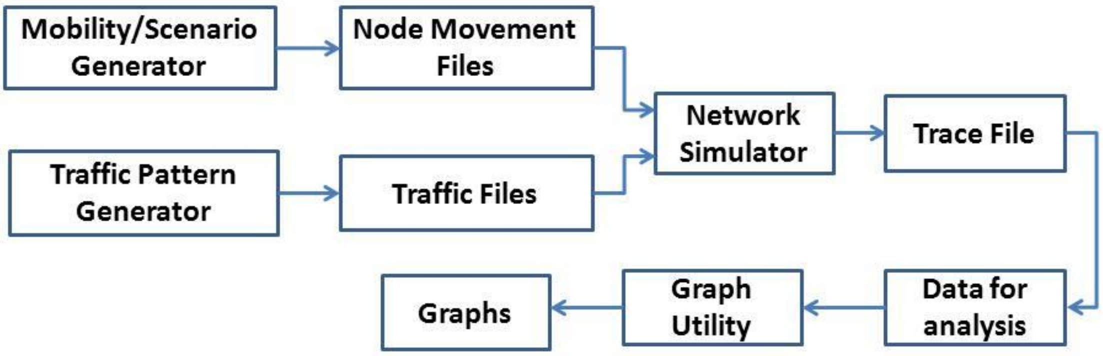

Fig. 4 Overview of the simulation model.

Table 1 Simulation Parameters

Parameter	**Value**
Simulator	NS-2.34
MAC Type	802.11
Simulation Time	100 seconds
Channel Type	Wireless Channel
Routing Protocols	AOMDV, MMRE-AOMDV & NEE-AOMDV
Antenna Model	Omni
Simulation Area	2200 m x 600 m

Traffic Type	CBR(udp)
Data Payload	512 bytes/packet
Network Loads	4 packets/sec
Number of Connections	40
Radio Propagation Model	TwoRayGround
Idle Power	0.005
Transmission Power	12.7
Receiving Power	12.7
Sleep Power	0.0001
Transition Power	0.002
Transition Time	0.005
Initial Energy	100 Joules
Interface Queue Length	50
Interface Queue Type	DropTail/PriQueue
Number of nodes	100
Pause Time	0
Speed	5,10,15,20,25
Mobility Model	Random Waypoint (RWM)
Simulation Time	100 Sec.

The performance of **NEE-AOMDV, MMRE-AOMDV** and **AOMDV** routing protocols are evaluated using NS 2.34 [21,22,23,24,25,26]. Fig. 4 and Table 2 illustrate the simulation model and the simulation parameters respectively.

B. Experimental results and Discussion

Performance metrics are quantitative measures used to evaluate any MANET routing protocol. We evaluate the following six different performance metrics:

(i) *Average End-to-End delay* – the average time of the data packet to be successfully transmitted across a MANET from source to destination. It includes all possible delays such as buffering during the route discovery latency, queuing at the interface queue, retransmission delay at the MAC, the propagation and the transfer time.

(ii) *Routing overhead* – the total number of control packets or routing packets generated by routing protocol during simulation.

(iii) *Normalized Routing overhead* – the number of routing packets transmitted per data packet towards destination during simulation.

(iv) *Total Energy consumed* – the summation of the energy consumed by all nodes in the simulation environment. i.e., *energy consumed by a node = initial energy of that node – residual energy of that node*. *Throughput* – the number of bytes received successfully.

(v) *Packet Delivery Ratio* – the ratio of data packets delivered to the destination to those generated by the sources.

Table 3 Average End-to-End Delay (in ms) of AOMDV, MMRE-AOMDV and NEE-AOMDV

Max. Speed (in m/s)	AOMDV	MMRE-AOMDV	NEE-AOMDV
5	1.828	2.119	1.790
10	1.758	1.913	1.793
15	1.647	1.733	1.648
20	2.117	2.440	1.908
25	2.180	2.039	1.916

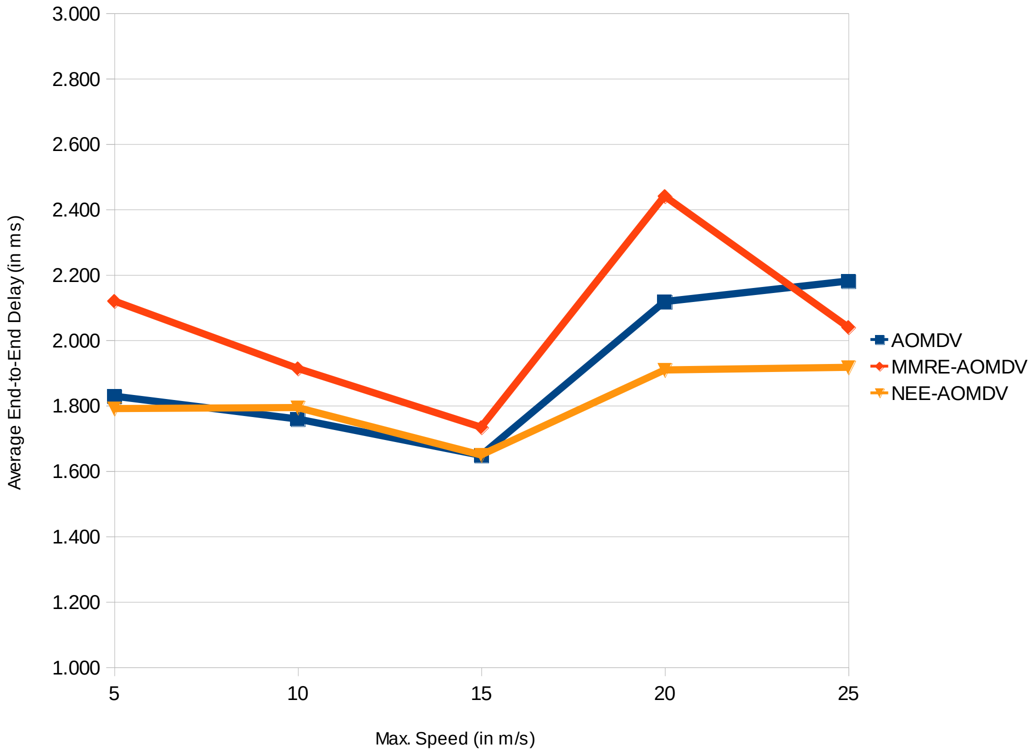

Fig. 5 Average End-to-End Delay (in ms) of AOMDV, MMRE-AOMDV and NEE-AOMDV

Table 3 and Fig. 5 represent the Average End-to-End Delay (in ms) of AOMDV, MMRE-AOMDV and NEE-AOMDV routing protocols. The NEE-AOMDV routing protocol is reducing end to end delay whenever speed of the node increases.

Table 4 Routing Overhead (in pkts) of AOMDV, MMRE-AOMDV and NEE-AOMDV

Max. Speed (in m/s)	AOMDV	MMRE-AOMDV	NEE-AOMDV
5	72	71	73
10	73	73	73
15	71	70	68
20	64	63	61
25	70	68	69

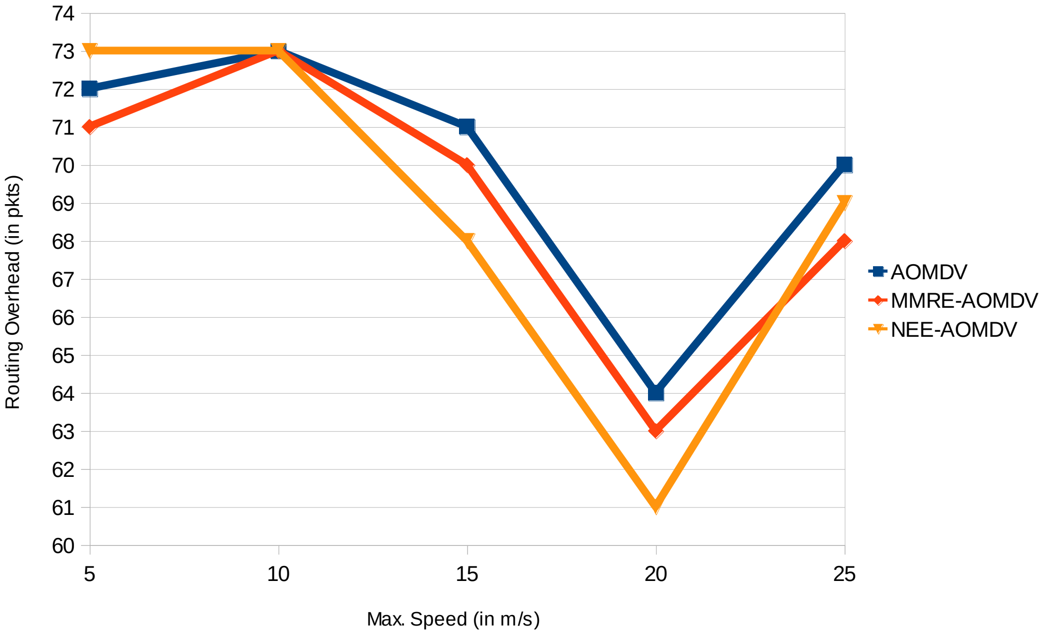

Fig. 6 Routing Overhead (in pkts) of AOMDV, MMRE-AOMDV and NEE-AOMDV

Table 4 and Fig. 6 represent the routing overhead of AOMDV, MMRE-AOMDV, and NEE-AOMDV routing protocols. The NEE-AOMDV routing protocol reduces the routing overhead by selecting maximal nodal energy and minimal hop count route than AOMDV and MMRE-AOMDV routing protocols.

Table 5 Normalized Routing Overhead (%) of AOMDV, MMRE-AOMDV and NEE-AOMDV

Max. Speed (in m/s)	AOMDV	MMRE-AOMDV	NEE-AOMDV
5	11.276	11.867	11.048
10	12.402	13.016	12.133
15	11.733	11.730	10.897
20	17.910	16.999	15.129
25	17.943	21.081	18.937

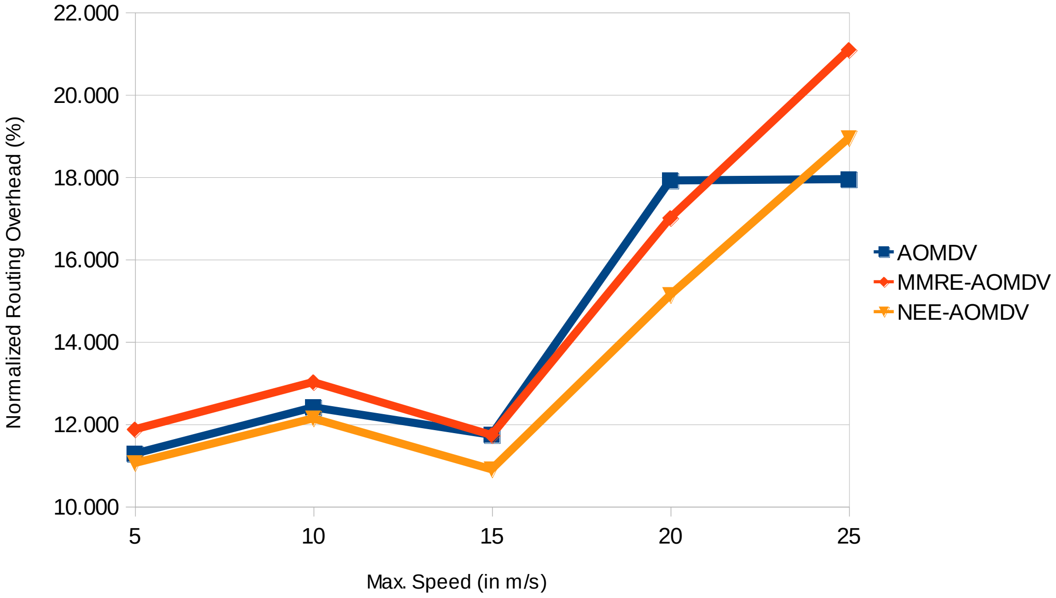

Fig. 7 Normalized Routing Overhead (in pkts) of AOMDV, MMRE-AOMDV and NEE-AOMDV

From Table 5 and Fig. 7, the normalized routing overhead of NEE-AOMDV routing protocol is reduced than the normalized routing overhead of both AOMDV and MMRE-AOMDV routing protocols.

Table 6 Total Energy Consumed (in Joules) of AOMDV, MMRE-AOMDV and NEE-AOMDV

Max. Speed (in m/s)	AOMDV	MMRE-AOMDV	NEE-AOMDV
5	420.540	365.020	378.280
10	473.080	435.200	374.840
15	364.590	345.300	335.300
20	400.120	376.960	367.680
25	734.780	726.120	700.340

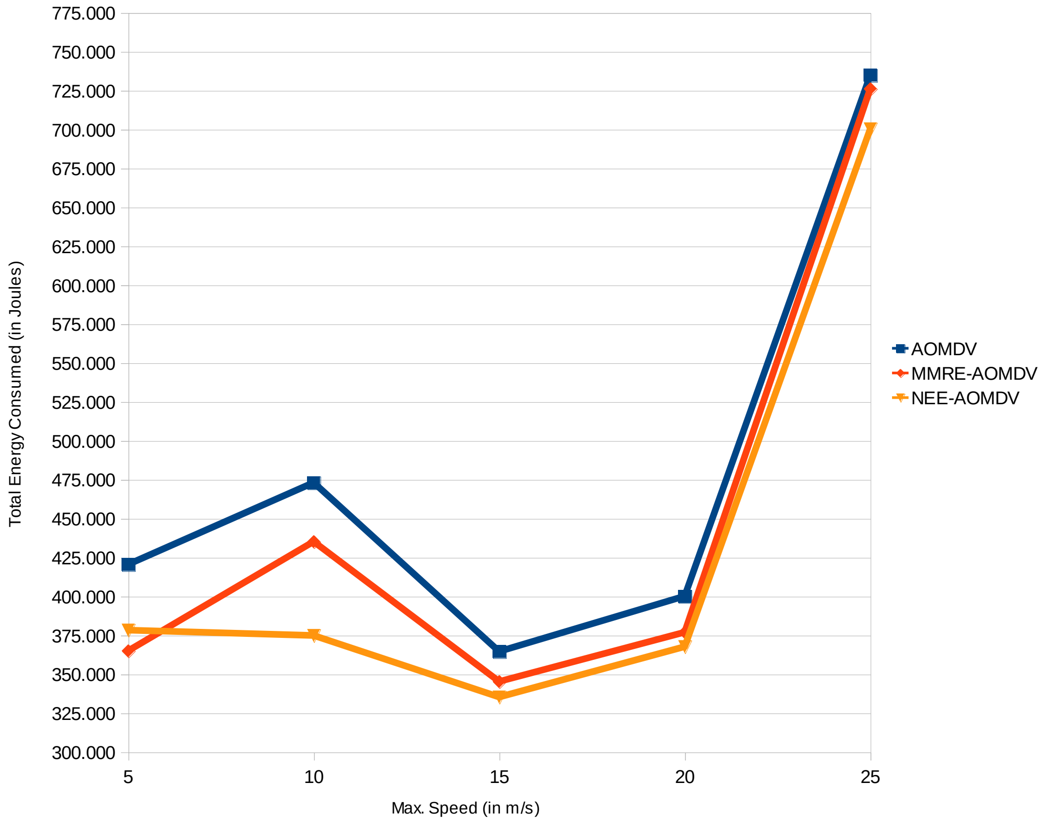

Fig. 8 Total Energy Consumed (in Joules) of AOMDV, MMRE-AOMDV and NEE-AOMDV

It is also found that the total energy consumption of NEE-AOMDV routing protocol is very less (more efficient) when we compare it with AOMDV and MMRE-AOMDV routing protocols as shown in Table 6 and Fig. 8.

Table 7 Throughput (in kbps) of AOMDV, MMRE-AOMDV and NEE-AOMDV

Max. Speed (in m/s)	AOMDV	MMRE-AOMDV	NEE-AOMDV
5	47.581	44.341	47.127
10	44.914	41.494	43.744
15	55.300	53.902	58.253
20	39.398	40.062	44.068
25	42.413	35.741	39.549

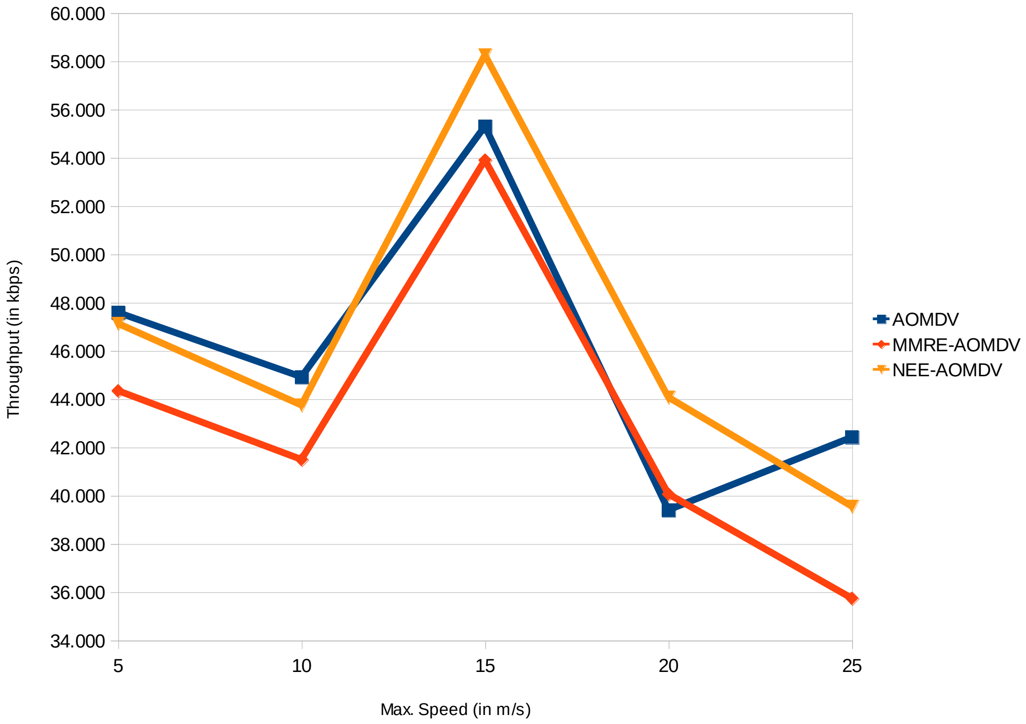

Fig. 9 Throughput (in kbps) of AOMDV, MMRE-AOMDV and NEE-AOMDV

The NEE-AOMDV routing protocol gives better throughput than AOMDV and MMRE-AOMDV protocols as shown in Table 7 and Fig. 9.

Table 8 Packet Delivery Ratio (%) of AOMDV, MMRE-AOMDV and NEE-AOMDV

Max. Speed (in m/s)	AOMDV	MMRE-AOMDV	NEE-AOMDV
5	45.597	45.535	47.107
10	41.487	38.854	41.516
15	37.866	38.136	39.172
20	29.123	31.030	33.847
25	32.362	26.974	30.379

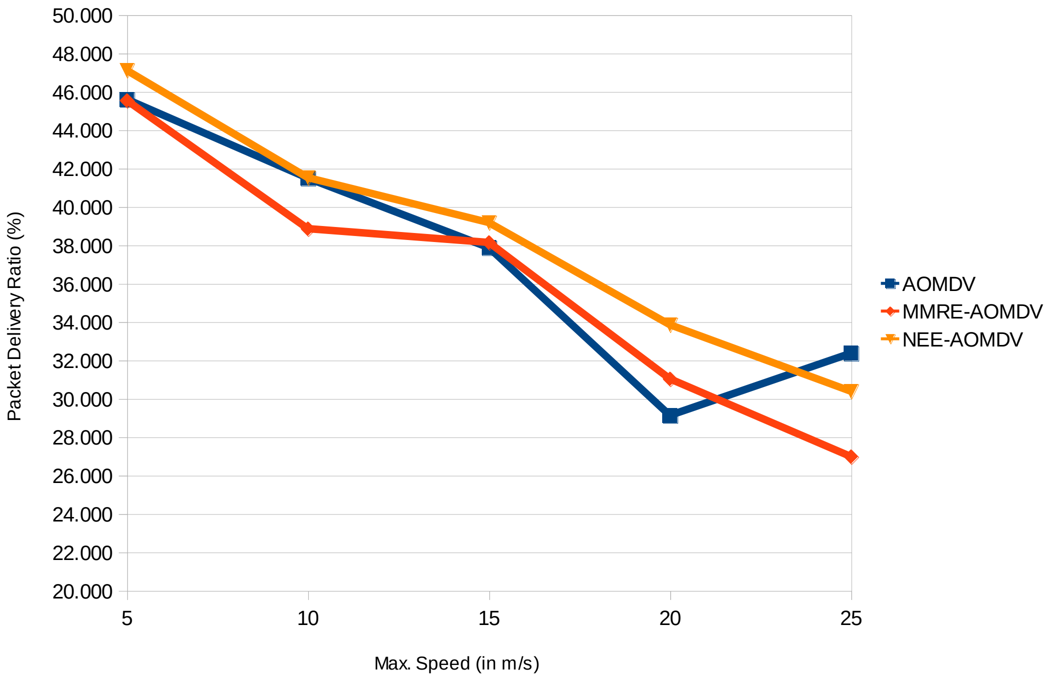

Fig. 10 Packet Delivery Ratio (%) of AOMDV, MMRE-AOMDV and NEE-AOMDV

The NEE-AOMDV routing protocol gives better packet delivery ratio than AOMDV and MMRE-AOMDV protocols as shown in Table 8 and Fig. 10.

V. Conclusions and Future work

We proposed a NEE-AOMDV routing protocol in order to reduce the energy consumption, average end to end delay, routing overhead and normalized routing overhead. It also improves the throughput and packet delivery ratio under random way point mobility model.

Simulation results show that the NEE-AOMDV routing protocol performed better than AOMDV and MMRE-AOMDV routing protocol. In future we will put a greater effort to improve its overall performance considering new metrics associated with network nodes such as networks lifetime and reduction in average number of nodes dying in different mobility models by studying and enhancing recent power efficient strategies. We will also make changes in NEE-AOMDV to cooperate with MAC layer’s multi-interface and multi-channel assignment schemes for wireless sensor or vehicular networks.

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