Performance Analysis of AODV-UI Routing Protocol With Energy Consumption Improvement Under Mobility Models in Hybrid Ad hoc Network

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***Abstract*—In mobile ad hoc networks (MANETs), routing protocol plays the most important role. In the last decade, Ad hoc On-demand Distance Vector (AODV) routing protocol becomes the attention of focussed research on MANETs world wide. A lot of protocols had been proposed to improve and optimize AODV routing protocol to achieve the best in quest of reliable protocol. In this paper, we present some improvement suggestion to AODV routing protocol. Our proposed protocol, called AODV-UI, improved AODV in gateway interconnection, reverse route and in energy consumption. We also measure performance indicators for some metrics, such as energy, routing overhead, end-to-end delay, and packet delivery ratio. We performed our simulation scenarios with three mobility model with different maximum speed and sources in hybrid ad hoc network. The result shows that AODV-UI is more stable when it is used in random way point mobility model in any speed and number of sources.**

AODV; routing protocol; energy consumption; hybrid ad hoc network; MANETs

I. INTRODUCTION

For the last decade, many research had been performed in mobile ad hoc networks (MANETs), especially in routing protocol of Ad hoc On-demand Distance Vector (AODV) for the optimization or better performance. Many people expect that someday there will be a robust and reliable protocol due to the nature and characteristics of MANETs that always change, decentralized, self-configured, and had no infrastructure to manage.

In the early 2000s, researchers focused on the development of basic functions or services of the AODV protocol, such as shared channel, route discovery, and dynamic nodes. The purpose of their studies was to manage an ad hoc network topology that always change and answer the problem of disconnected route (route error) caused by the level of mobility ad hoc node that can not be predicted.

Since an ad hoc node may free to move to unpredicted direction, several papers discussed about the performance of routing protocols on various mobility models. There are a number of mobility models that have been widely used in research of MANETs .

In this paper, we proposed a new variant of AODV routing protocol, called AODV-UI, which performed some improvement such as gateway mode, reverse route, and energy consumption. The main contribution of this paper is we have proposed a new AODV variant and study about the performance evaluation of our proposed routing protocol, AODV-UI, under different mobility models, i.e Random Waypoint, Gauss-Markov, and Reference Point Groups Mobility model. We choose these models in order to find out the behavior of routing protocol over different mobility model with different velocity of mobile nodes.

This paper will be presented as follows. In Section 2 we will discuss the existing related research. Next on Section 3 we will discuss our proposed AODV protocol. Section 4 contains the simulation of protocol designed.

Section 5 discusses the result and analysis of proposed protocol. Finally, Section 6 describes the conclusions from this research.

II. RELATED WORK

A. Optimized AODV

In [1,2] provided a very comprehensive and in depth survey about the QoS of routing in Manets. Their papers offer a recent survey of major contributions to the Manets routing protocols published in the period of 1997-2006. It discussed about the QoS routing metrics, protocols, the factors that affect the performance of protocols, created the classification of protocols. Next, Thathacar et al. [3] presented variety of views on the learning automata as an alternative optimization algorithm.

Their conclusions focus on several things as follows:

- The design of protocol are classified based on MAC.
- The optimization of route discovery.
- Reliability protocol.
- Management session.
- Measurement of performance indicators.

They also identified several future research areas that can be done as follows:

- Optimization algorithm.
- Network topology and environment.
- Multi-constraint routing.

According to RFC3561 [4] AODV routing protocol still has many weaknesses. From several variants of AODV protocol proposed, it can be identified that the problems encountered in optimizing the AODV protocol are as follows:

- AODV use destination sequence number for each route entry. This causes considerable delay.
- AODV does not support security. This allows an attack from an unknown node in the Manets.
- How to improve the Hello Message.
- How to create an optimized mechanisms when handling a link failure (route error).
- How to improve route discovery mechanism.
- How to provide the source for gateway mode.
- Threats to security problems.

In this paper, we review the development of variants of AODV in the period of 2000-2010. In 2001, Ali Hamidian [5] introduced an improvement to AODV protocol and called their new protocol AODV+. It allows interconnection between Manets and the Internet. He performed his research using NS-2 simulations and ported AODV+ into it. His research investigated and compared three models of gateway discovery, i.e reactive, proactive and hybrid. AODV+ has been designed to achieve routing communication between a node in an ad hoc network and a node in a wired network or infrastructure. A gateway functions as a bridge between Manets and Internet. One of the interesting findings in his research is gateway mode for ad hoc node. The reactive gateway discovery is initiated by ad hoc node to create or update a routing table to a gateway. The mobile node will broadcast a route request (RREQ) message with “I” flag (RREQ_I). Only the gateways addressed by this message will process it. Other node have to rebroadcast the RREQ_I message. The proactive one is initiated by the gateway itself. An ad hoc node may be a gateway in this mode. It broadcasts a gateway advertisement (GWADV) message periodically to ad hoc network, so a mobile node that receive the GWADV will create or update its route entry. The hybrid gateway method is the combination of reactive and proactive gateway discovery.

Erik Nordstrom and Bjorn Wiberg from Uppsala University [6,7] have a lot of contribution in simulation result and real world implementation of AODV. Their protocol is called AODV-UU. There are similarities between AODV+ and AODV-UU, in which they provides a gateway mode for a node in the ad hoc networks to communicate with nodes in the network infrastructure or the Internet. In 2006, Chonggum Kim and Elmurod et al. [8,9] created a protocol called Reverse-AODV (R-AODV). Furthermore, R-AODV has been developed into Path Hop based R-AODV (PHR-AODV). The main objective of development R-AODV is to provide solutions to some conditions which rapidly change in the topology of Manet that cause route reply packet does not reach the source node, especially when a node moves. PHR-AODV is an extended version of R-AODV to cover weaknesses in the security side. The main goal of PHR-AODV is able to protect data from unauthorized nodes attack. Figure 1, and 2 show the Route Request (RREQ) and Route Reverse Request (R-RREQ) message format of R-AODV.

<table>
<tr><td>Type</td><td>Reserved</td><td>Hop Count</td></tr>
<tr><td colspan="3">Broadcast ID</td></tr>
<tr><td colspan="3">Destination IP Address</td></tr>
<tr><td colspan="3">Destination Sequence Number</td></tr>
<tr><td colspan="3">Source IP Address</td></tr>
<tr><td colspan="3">Source Sequence Number</td></tr>
<tr><td colspan="3">Request Time</td></tr>
</table>

Figure 1. RREQ (Route Request) Message Format

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<tr><td colspan="3">Reply Time</td></tr>
</table>

Figure 2. R-RREQ (Route Reverse Request) Message Format

In 2009, Mehdi Zarei [10] created an extension to R-AODV by combining it with learning automata in order to obtain a reliable protocol, especially in the route discovery phase. The protocol is called RAODVA. The idea is that a source node will choose the best route with the highest stability among the available routes. Their proposed protocol is capable of operating efficiently under burst traffic conditions. In RAODVA when a route has been established between source and destination node, data transmission stage can be initiated. In high mobility, link failure is a common problem. The routing algorithm of RAODVA design is suitable for these environment. On the initiation of data transmission, learning automata will start learn and generate stability of all available routes periodically. A source node will be aware of the fitness of routes which has been found with learning automata. If an intermediate node move and then link error occur or fitness of one route in other available set of routes be higher than of active route, source node can select a stable route instead of failed route. In R-AODV and standard AODV, a source node will select new route based on the shortest path. When nodes move faster, this condition cause a bad performance of the protocol. RAODVA added link stability parameter to select the best route between the available routes set, when active route breaks.

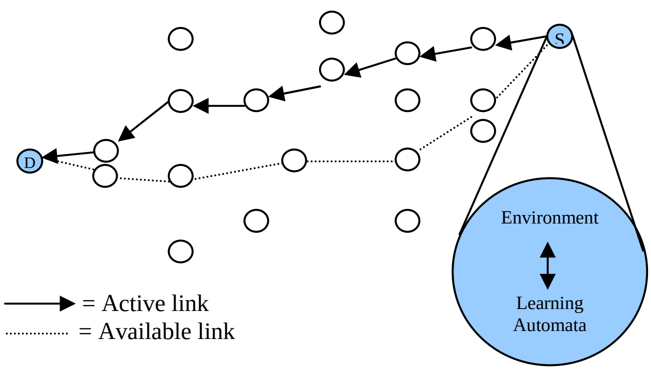

Figure. 3 Routing Algorithm of RAODVA

Previously, A. Rani and M. Dave [11], in 2007, modified AODV for load balancing purpose. In their proposed protocol each node measures the number of packets queued up in its interface. When a source node begin a route discovery procedure by flooding RREQ messages to network, then each node receiving a RREQ will rebroadcast it and add its own interface queue length. Destination node will select the best path and replies with RREP. Route selection procedure is as follows : When a source node starts a route discovery procedure by flooding RREQ messages, each node that receives the RREQ looks in its routing table to see if it has a fresh route to the destination. If it does not have the route it adds the number of packets in its interface queue and rebroadcasts it further to neighbor node. This process is repeated till either the destination is reached or no destination is found. If an intermediate node has a fresh route to the destination or for the same sequence number the intermediate node has a shorter route or the Aggregate Interface Queue Length (AIQL) is smaller, the intermediate node replies with the route. The metric AIQL is used as the sum of interface queue lengths of all the intermediate nodes from the source node to the current node. The function of AIQL metric is to find out the heavily loaded route. If the aggregate queue length for the path is not lower than other, then it obviously means that either all nodes on the path are loaded or there is at least one node laying on the route that is overloaded.

A.A. Pirzada and M. Portmann [12] in 2007, presented the extension to AODV routing protocol with the goal to exploit the heterogeneity of hybrid wireless mesh networks. Their proposed protocol achieves more than 100% improvement than the standard AODV in terms of the performance indicators such as packet loss, throughput and delay. Their proposed protocol is called High Performance AODV (AODV-HP) which adds two simple modifications to AODV. In their first modification, they use the (Hop Count) – (Mesh Router Count) as the routing metric instead of the standard hop count, to facilitate preferential routing of packets via mesh routers. By selecting routes which minimize this metric, they guarantee that the established routes primarily consist of mesh routers.

Their second modification maximizes the channel diversity of paths, which comprise of multi-radio nodes. In this case, multiple links can exist between neighboring nodes. The choice of link (interface) to be use between two nodes will not affect the routing metric. that is why they need some other method to select the best link. In their protocol, nodes forwarding a RREQ packet also recommend a channel, which is subsequently used to communicate with the next hop node. In order to minimize co-channel interference, nodes recommend the least loaded channels for next hop communication. If a hop shares multiple channels with the sender of the RREQ packet, it will receive multiple copies of it. If possible, the node will create a reverse route via the recommended channel. They use the remaining 7 reserved bits in the AODV header to convey the recommended channel information to the next hop node. The route establishment and optimization process is shown in algorithms below. The algorithm for source node is as follows:

1) Start.
2) Need route to destination.
3) Run route optimizer.
4) Recommend channel in the RREQ.
5) Send RREQ to all interfaces.
6) End.

The algorithm for route optimizing is as follows:

1) Scan routing table.
2) Check whenever any channels free.
3) If Yes, then randomize channels.
4) Else find least loaded channels.
5) Return channel.

The algorithm for destination or intermediate node is as follows:

1) Start.
2) Received RREQ.
3) If I am a destination then Start RREQ Timer
4) Buffer RREQ.
5) Check whenever RREQ Timer expired.
6) If Yes, then Select Max RREQ.
   a. Create Reverse route on rec channel.
   b. Send RREP on rec channel interface.
7) If No, then back to Start.
8) If I am not a destination, and

9) If Interface = Rec channel, then.
10) Create Reverse route on channel.
11) Run route optimizer.
12) Recommend channel in the RREQ.
13) Mesh router count ++.
14) Send RREQ on all interfaces.
15) If Interface != Rec channel, then Route optimized.
16) Recommend channel in the RREQ.
17) End.

When a source node needs to find a route by sending RREQ message, it first executes the Route Optimization Function (ROF). The ROF first scans the existing routing tables and finds the interfaces which are not being used in any of the active data connections. In case of none of the interfaces is free, it examines the Network Interface Queue (IFQ) of each interface. The IFQ is a drop-tail FIFO buffer, establish between the Link and MAC layers. IFQ holds packets to be transmitted on to the Physical Layer. The IFQ length gives the current number of the packets, which are awaiting transmission.

A.A. Pirzada et al. [13] then extended AODV with multi-linked, and the protocol is called AODV-ML. AODV-ML provides an improvement of more than 100% in terms of packet delivery rate, latency and routing overhead over the standard multi-radio AODV routing protocol. In contrast to Multi Radio AODV (AODV-MR) [25], AODV-ML provides multi-homed nodes to discover multiple concurrent bi-directional links between each nodes during the route establishment process of a reactive routing protocol. The discovery process is carried out in two stages of AODV-ML, as follows:

Stage 1 :

1) During route establishment, source and intermediate nodes broadcast route request packets on all interfaces.
2) For each interface a route request was received on the receiving node which created a reverse link to the sending node.

Stage 2:

3) Destination and intermediate nodes unicast a route reply packet on one or more reverse links created in Stage 1.
4) Receiving node creates one or more forward links to the sending node based upon the information derived from the route reply packets.

The first stage occurs during route discovery when a source node floods the network with a Route Request message in order to discover a route to the destination node. The source node broadcasts a Route Request message on all of its interfaces. Similarly, all intermediary nodes, which receive the same Route Request message, rebroadcast the Route Request message on all of their network interfaces. Depending upon the communication range, channel assignment, collisions or other factors, the destination or intermediate nodes may receive the Route Request message on one or more wireless interfaces. Nodes that receive the Route Request message create a temporary “reverse link” to the adjacent node where the Route Request message was received from. A reverse link may consist of an entry in a neighbor routing or link table, consisting of the identifier (e.g. IP address) of the adjacent node and the corresponding local network interface via which it can be reached. Separate reverse links are established for each interface on which a Route Request message was received. This is contradict to the current reactive routing protocols, which only establish a single reverse link, required for the establishment of a single reverse route. Asymmetric or unidirectional links are not uncommon in wireless networks. Therefore, reverse links, which are created upon receipt of a Route Request message, represent only unidirectional connectivity from the sender of the Route Request to the recipient. At this stage, the connectivity in the reverse direction has not been verified yet.

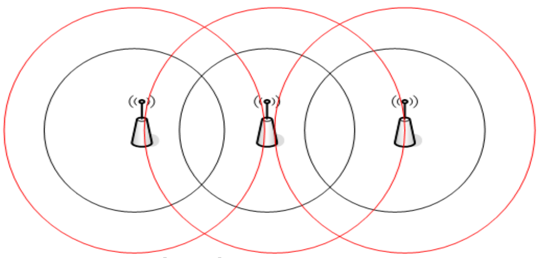

Figure 4. Multi-Links creates using AODV-ML

Figure 4 illustrates the basic concept of multi-links. It shows the ranges of the individual radio interfaces as concentric circles. The source node is single-homed and hence only able to create a single bidirectional link with its adjacent node. The other nodes are multi-homed and discover multiple concurrent links to their immediate neighbors during the route establishment process of AODV-ML. These additional links can subsequently be used for variety of applications without incurring any expensive route establishment or route repair mechanisms.

Hamideh Babaei and Morteza Romoozi [15] in 2010 proposed Multi Objective AODV based on realistic model. In their simulation research, they find new algorithm which find the optimum path for mobile ad hoc node. Their algorithm considered realistic movements and environments like facing obstacle or pathway.

The proposed protocol considers not only hop count but also other objectives, such as mobility model, mobile node specification and routing algorithm. By considering these multi objectives, the protocol can find the best paths. In their proposed protocol, the selection of object that participate in finding path is optional. If a node lacks of facilities such as GPS, objectives which need GPS can not be considered. Therefore their proposed protocol support GPS less than mobile nodes.

Gianni Di Caro et al. proposed AntHocNet [16] using Qualnet. This protocol, AntHocNet, designed as an algorithm which works efficiently in Manets while maintaining the properties which make Ant Colony Optimization (ACO) routing algorithms so appealing. While most of the previous proposed protocol or algorithms were adopting a proactive scheme by periodically generating ant-like agents for all possible destinations, AntHocNet adopts a hybrid approach which generated according to both proactive and reactive schemes. It is done in a reactive path setup phase, where ant agents called reactive forward Ants are introduced by the source in order to find multiple paths to the destination, and backward ants return to set up the paths. After path setup, data packets are routed stochastically as datagrams over the different paths using pheromone tables. While a data session is going on, the paths are probed, maintained and improved the proactive protocol using different agents, called proactive forward ants. The AnthocNet algorithm reacts to link failures with either local path repair or by warning preceding nodes on the paths.

Hui Yao Zhang, M.E Bialkowski, Garry A Einicke, John Homer [17] in 2009, proposed an extended AODV (EAODV) for VoIP application in Manets. The proposed routing method is based on a simple modification to the existing AODV's route discovery mechanism, allowing selection of an optimal path. By modifying the RREQ message and the method in selecting the route, the proposed protocol is more stable and can increase the packet delivery ratio. To implement the proposed method, first, two time recorders are used to estimate channel activity. One is use to monitor neighbor nodes in the MAC layer, while the other monitors the route layer. When the MAC layer receives a data packet which is not for the specific node, it discards the packet and the neighbor's time recorder records the current time. Otherwise, the packet is forwarded to the routing layer where its own time recorder registers the current time. Following this, an 8-bit channel activity counter is added to the RREQ header. It should be noted that the counter uses the existing 8 reserved bits in the AODV RREQ header which means it does not incur any additional byte overhead. The algorithm of route request process for VoiP in EAODV is as follows :

1) Start.
2) Receive RREQ.
3) If I am the source or intermediate node have heard the RREQ, then Drop.
4) Else create reverse route in the route table.
5) If I am not the destination, and
6) If I have fresh enough route , then send RREP.
7) Else forward RREQ adding channel activity counter.
8) If I am destination and receive the first RREQ, and
9) If channel activity counter = 0, then send RREP.
10) Else start RREQ-timer and RREQ-counter=0.
11) If timer expired or counter threshold met.
12) Drop RREQ.
13) Else buffer RREQ.
14) RREQ-counter++.
15) If timer expired or counter threshold met,
16) then select Min (channel flag) RREQ.
17) Send RREP.

B. AODV with Energy Model

Developing routing protocol for mobile ad hoc networks (MANETs) could be from any point of views. However, the majority of proposed routing proposals have not focused on the energy constraints of wireless nodes, although many proposals have been proposed recently with energy-aware routing protocols, but only a few proposals have especially focused on the design of route determination protocols that provide efficient energy utilization when performing route discovery [12, 13,14].

Since mobile nodes use wireless connection in MANETs then energy and load are two factors which very important problems for routing protocols in MANETs [18]. They proposed mathematical model of MANETs by considering sustainable energy, consumed energy and bandwidth estimation model. Their goals was to improve AODV routing protocol by takes the minimum hops as the selected route with no problem in energy and bandwidth. Their proposed to improve AODV routing protocol based on energy and bandwidth is described as follows :

- The node will select the best route to forward data which has maximum weight value (Amax). But the node will choose the the best route that has least hops If Amax is corresponding with several routes.
- Add four fields in the RREQ message, energy weight (E_p), load weight (B_p), remaining energy threshold (E_w) and overload threshold (B_w).

To estimating the bandwidth, they tried to avoid selecting the overloading nodes. To get a balanced distribution, it will choose node with less load. So, when RREQ message broadcasted or forwarded, each node detects its path information about the condition in real time. However, their research in mathematical model only, not in simulation or testbed.

In [19] presented a comprehensive energy optimization both locally and globally for AODV routing protocol. Their research investigated about combination of runtime battery capacity and propagation power loss information. The energy information embedded at Hello message and route discovery message. In order to maintain local connection, Hello message is broadcasted only one hop. Energy information is embedded to it, so neighbor nodes can update the energy information of each neighbor node. They also modified RREQ/RREP message for end-to-end or global optimization. They implemented their algorithm into AODV in simulation using OPNET.

Tolba et al. [20] used a variable transmission range in order to save energy and to keep the connectivity. Their algorithm was implemented at data link layer. The main objective of their proposed protocol was to propose a generic solution that can be used by other protocols such as AODV. The following are their proposed main parts of protocol:

- Transmission range. It is an important factor in the wireless communication. Since nodes in ad hoc networks are mobile in or out the transmission range which correlated to energy consumption. For that reasons the transmission is a feature counted into their proposed protocol.
- Node Position: In their protocol, each node update its position in period of time. It is assumed that a node that receive a broadcast message can estimate their distance.

In [21] they continued their research by proposing a clustering algorithm.

C. Mobility Model

The main role of mobility models is to decribe the movement of mobile node in real world. While it is efficient to be use in almost simulations, such as Random Waypoint. This often imply that the scenarios for which the protocols are simulated have huge numbers of nodes, so that the relevant protocol features are given statistically realistic distributions of events. The Random Waypoint model is the most commonly used mobility model. In the network simulator (ns-2.34) distribution, the implementation of this mobility model is as follows: at every instant, a node randomly chooses a destination and moves towards it with a velocity chosen uniformly randomly from [0,V_max], where V_max is the maximum allowable velocity for every mobile node. After reaching the destination, the node stops for a duration defined by the 'pause time' parameter. After this duration, it again chooses a random destination and repeats the whole process again until the simulation ends.

For scenarios with few nodes, the difference between different usage scenarios become more significant. Thus, movement models that depict more precisely some specific types of movement are needed. This model does not suffer from the density waves in the center of the simulation space that Random Waypoint model does. In this model, mobile nodes choose a random direction to move similar to the Random Walk Mobility Model. A mobile node then moves to the border of the simulation area in that direction. Once the simulation boundary is reached, the mobile node pauses for a specifed time, chooses another angular direction (between 0 and 180 degrees) and continues the process.

The original implementation of the Gauss-Markov model follows the publication [28]. In the implementation, the mean velocity vector is not specified directly. Of course, a norm of 0 yields only the vector (0,0). The implementation also allows the user to specify a maximum speed. A velocity vectors with a larger norm will be multiplied with an appropriate scalar to reduce the speed to the maximum speed. The model has been adapted to deal with scenario borders in the following way: If a station moves onto the border, its velocity vector as well as its expected velocity vector are "mirrored".

The modified Gauss-Markov mobility model [25,26] uses its velocity and the previous position of node in determine the next position. Every time a node moves, it will calculate the distance it has covered. The node will update its position when it has covered a minimum acceptable distance. It sends a message in shorter distance order to determine its current position based on the velocity and previous position.

The Reference Point Group Mobility (RPGM) model represent the random movement of a group of mobile nodes their random individual movement within a group [28]. RPGM model in determine the next position is by calculating group motion vector in order to define velocity and destination position of mobile nodes. This group mobility can be used in military battlefield communication or emergency environtment. Here, each group has a logical center (group leader) that determines the group's motion behavior. Initially, each member of the group is uniformly distributed in the neighborhood of the group leader. Subsequently, at each instant, every node has a speed and direction that is derived by randomly deviating from that of the group leader. Important characteristics of this model is each node deviates its velocity (both speed and direction) randomly from that of the leader.

III. Description of Proposed Protocol

Before In this section, we present an overview of our proposed new variant protocol, we called it AODV-UI. Actually in this research, we improve our proposed protocol by combining gateway mode, adopted from AODV+[5] and reverse route, adopted from R-AODV[8]. Our aim is to design an algorithm that has a capability to determine which nodes as an intermediate node. Our proposed protocol, AODV-UI, has main objectives for select a node with energy as a parameter. Every mobile node has an initiated amount of energy. In order to increase the lifespan of the node, it is desireable to take into account the remaining energy. Therefore, it is significant to select a node with a high remaining energy. In the following, we describe the algorithm for the proposed protocol. We consider a network topology represented by a graph G = (V, E) where V is a set of mobile nodes, and E is a set of edges where e = (u, v) where e is a model of wireless link that connect two nodes. U and v are a pair of nodes which in a direct communication if and only if they are within their coverage area. The energy consumption model which use in this research is adopted from [22,23].

The energy is calculated periodically defined by :

$$Ei\ (\Delta t) = Poweri \times \Delta t \qquad (1)$$

So, the total remaining energy can be axpressed as :

$$Ei\ (t + \Delta t) = Ei(t) - Ei\ (\Delta t) \qquad (2)$$

The algorithm route discovery process in AODV-UI is as follows :

1. Update position of node
2. Update energy of node
3. If remaining energy is high
4. If number of hops is 1, then create route reverse
5. Else performed forwarding packet to neighbor

The Gateway selection algorithm is as follows:

1. If there is no default route then create and update route
2. else update route while number of hops to the old gateway is bigger than the new one.

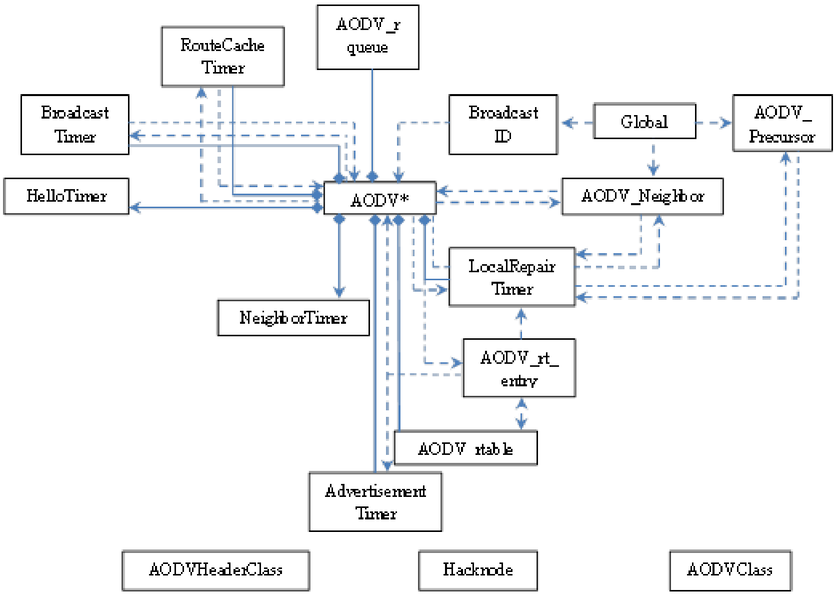

Figure 5. Class Diagram AODV-UI

The class diagram of our proposed routing protocol can be seen at Figure 5. Reverse function added in protocol AODV. Class which run the reverse function is hacknode class. Gateway function is not a class, but it is just a modul added to AODV* class.

IV. Simulation and Parameter

A. Simulation Scenario

We implement our proposed protocol in NS-2.34. We assume that the transmission range, the maximum possible distance between two communication mobile nodes is 250 m.

The simulation scenario consists of 10 mobile nodes, 2 gateways, 2 routers and 2 host in infrastructure or wired network. The data type is Constant Bit Rate (CBR). The topology dimension of this simulation is a rectangular area of 1000 x 800 meter. The entire simulation lasted for 500 seconds.

B. Parameter

The parameters we use in the simulation are given in Table 1. In this simulation, we used 2 gateway nodes, 10 nodes as mobile ad hoc node with some variation in source node and maximum speed and mobility models.

TABLE I. SIMULATION PARAMETER

Parameter	Value
Range transmission	250 m
Simulation time	500 s
Topology	1000 x 800 m
Nodes Ad hoc	10
Sources	2, 4, 6 nodes
Mobility	Random Way Point, Gauss-Markov, RPGM
Gateways	2
Traffic type	CBR
Packet rate	5 packet/s
Packet size	512 bytes
Initial Energy	100 Joules
Pause time	10 s
Maximum speed	10, 20, 30, 40 (m/s)

Some parameters evaluated and analyzed based on simulation are as follows:

- packet delivery ratio is as the ratio between the number of packets sent by Constant Bit Rate (CBR) at application layer and the number of received packets by the CBR sink at destination.

- end-to-end delay is defined as the time between the point in time the source want to send a packet and the time the packet reach its destination.
- routing overhead is the sum of all transmissions of routing packets during the simulation. For packets transmitted over multiple hops, each transmission over one hop is counted as one transmission.
- Remaining energy is the available energy after the simulation completed.
- Energy consumption is the energy used for various node density and speed.

For those purpose, we use formulas to calculate these performance indicators.
Packet delivery ratio is defined as

$$\frac{\sum NumberOfReceivedDataPackets}{\sum NumberOfSentDataPackets} \qquad (3)$$

End-to-end delay is defined as follows:

$$\frac{\sum (TimePacketArrive@Dest - TimePacketSent@Source)}{TotalNumberOfConnectionPairs} \qquad (4)$$

Routing overhead is defined as follows:

$$\frac{TotalBytesOfControlMessagesTransmittedByAODV}{TotalBytesTransmitted} \qquad (5)$$

Remaining Energy is defined as:

$$InitialEnergy - EnergyUsed \qquad (6)$$

Average Energy Consumption is defines as follows:

$$\frac{\sum PercentageEnergyConsumedByAllNodes}{NumberOfNodes} \qquad (7)$$

V. RESULT AND ANALYSIS

In this research we performed the performance evaluation of AODV-UI. Each simulation is conduct for different sources, maximum speed, and mobility models.

Figure 6 shows the result of the evaluation of remaining energy versus maximum speed of mobile nodes. We can observed that, when consider 2 nodes as sources from 10 mobile nodes with maximum speed of 10 m/s is the lowest energy remaining after 500 seconds of simulation. However, when nodes move with 20 m/s. 30 m/s, and 40 m/s of maximum speed, we obtain the similar results in terms of remaining energy of nodes.

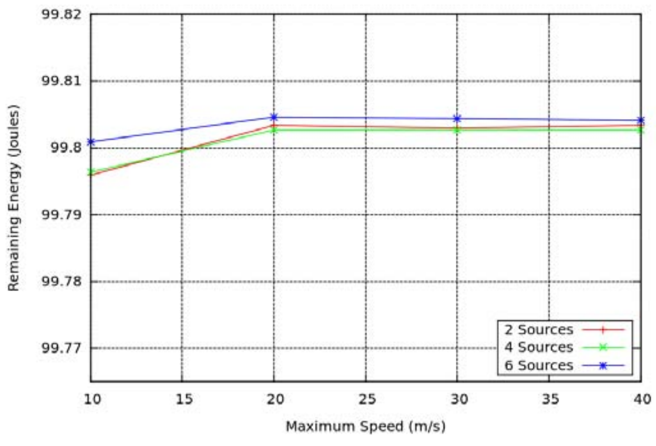

Figure 6. Remaining Energy

Figure 7 shows the energy consumption of nodes according to ratio between the maximum speed (m/s). The initial energy used in our simulation is 100 Joules.

As depicted at Figure 8, it can be determine that the routing overhead is related with the number of source node and velocity. We can observed that the higher routing over head occured when the number of mobile nodes sources with speed 40 m/s is 6 .

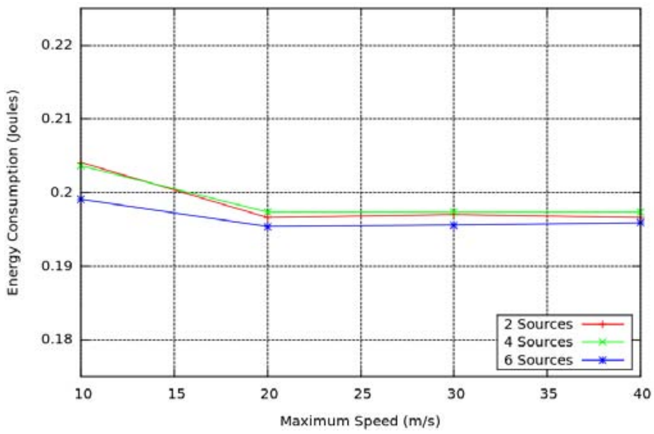

Figure 7. Energy Consumption

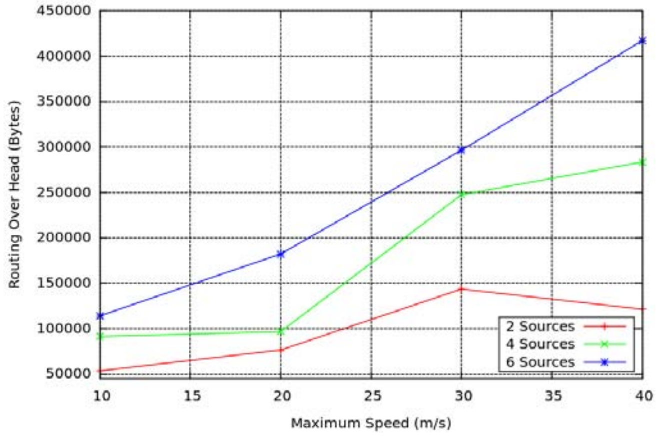

Figure 8. Routing Overhead

Figure 9 shows how the packet delivery ratio is affected with speed of mobile node and number of sources. We can see that the best packet delivery ratio is when only 2 mobile nodes act as sources and the other become the intermediate nodes. It means that there is a correlation between speed aspect and packet delivery ratio.

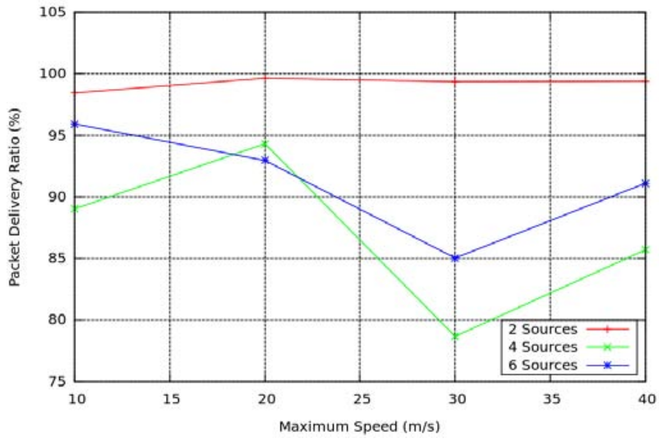

Figure 9. Packet Delivery Ratio

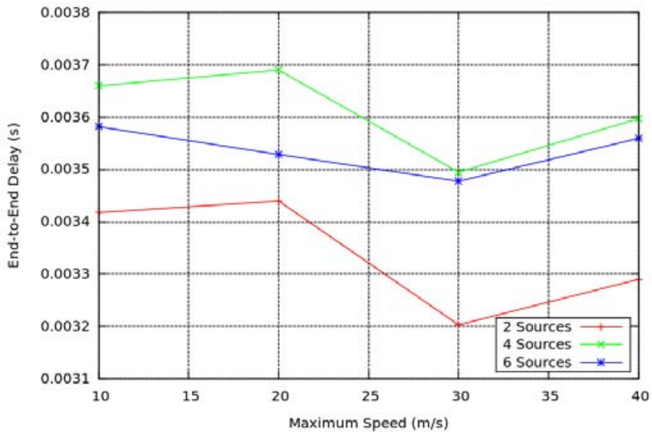

Figure 10. End-to-End Delay

The end-to-end delay of our proposed protocol can be seen at Figure 10. We can also determined that end-to-end delay is related with the numbers of sources and mobility speed.

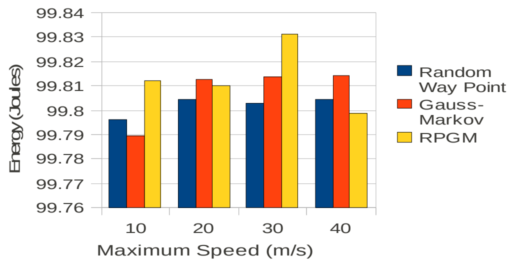

Figure 11. Average Remaining Energy with 2 Source Nodes

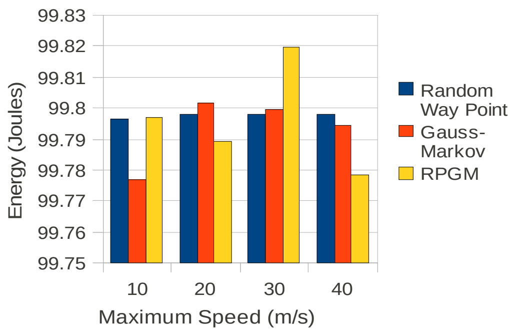

Figure 12. Average Remaining Energy with 4 Suorce nodes

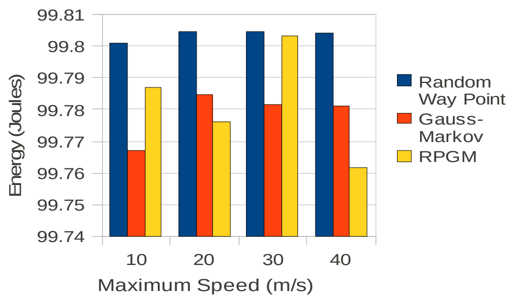

Figure 13. Average Remaining Energy with 6 Source Nodes

Figure 11, 12, and 13 show the average energy remaining when nodes act as sources with cbr packet type under different mobility models. We can observed that from our scenarios with different mobility models and different velocity, RPGM consumed more energy when the speed of node increase over 30 m/s. Gauss-Markov model plays its rule. It results a fluctuative energy consumption of nodes. However Random way point model looks more stable in any circumstance of speed and number of sources.

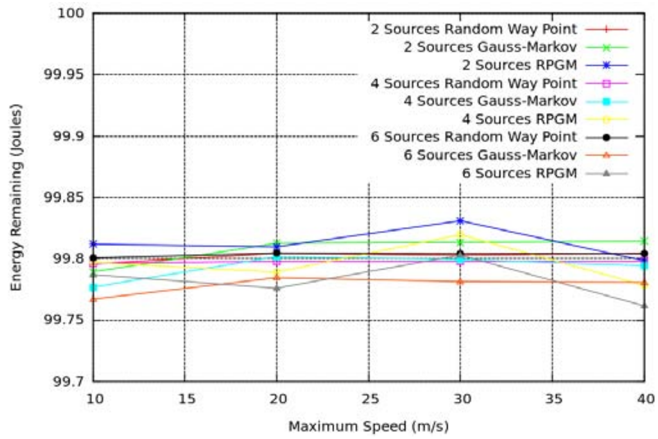

Figure 14. Average Energy Remaining under Mobility Models

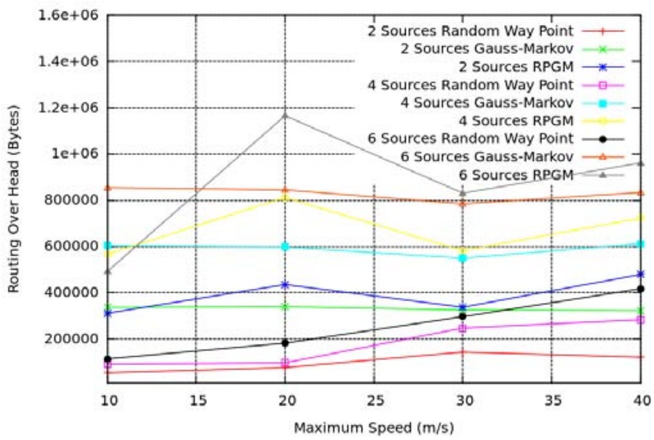

Figure 15. Routing Overhead under Different Mobility Models

Figure 14 shows the average remaining energy under three mobility models. It can be seen that almost all mobile nodes have the same level of remaining energy after 500 seconds of simulation even in the different speed. The range of remaing energy of all mobile nodes are between 99.75% until 99.85%.

The routing over head of our porposed protocol, AODV-UI, can be show in Figure 15. This is the important finding in this research. It can be concluded that AODV-UI produces more AODV messages when implemented in Gauss-Markov and RPGM mobility models. On the other side, random way point mobility model will create a lower routing overhead rather than Gauss-Markov and RPGM.

VI. Conclusion

In this work, we propose a new variant of routing protocol AODV with combination of AODV+ and R-AODV. Our proposed protocol is called AODV-UI. The main feature of AODV-UI is it can be used in hybrid ad hoc networks and it has some improvement suggestion in routing overhead and energy consumption. We performe a simulation with NS-2 and compare the performance indicator in hybrid ad hoc network scenario with different source node, different maximum speed, and also under three mobility models, Random Way Point, Gauss-Markov, and Reference Point Group Mobility. The experiment result shows that our proposed protocol is more stable in random way point with any different number of sources and velocity. In term of routing overhead, AODV-UI results the lowest of is 53,468 bytes when it is used in random way point with 2 source of nodes with maximum speed 10 m/s. The highest routing overhead is 1,165,072 bytes when it is under RPGM mobility model with 6 sources and 40 m/s of velocity. In the future research we will observe and find the optimum number for maximum speed of mobile nodes and we will also implement the bandwidth estimation for AODV-UI routing protocol.

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