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A HIGHLY ADAPTIVE FAULT TOLERANT ROUTING PROTOCOL FOR ENERGY CONSTRAINED MOBILE AD HOC NETWORKS

[1] P. MANICKAM, [2] Dr. D. MANIMEGALAI

[1] Asst. Professor (Selection Grade), Department of Applied Sciences, Sethu Institute of Technology, India
[2]Professor and Head, Department of Information Technology, National Engineering College, India
E-mail: [1]softpm@gmail.com

ABSTRACT

In Mobile Ad hoc Network (MANET), mobile nodes dynamically set up a wireless network without the presence of fixed infrastructure. In MANET, each node acts as router to send and receive the information in a multi hop fashion. Since nodes are in random movement and operated on battery power, the network topology may change frequently. Moreover, nodes are operated by limited battery power and nodes exhaust their energy by overhearing the information even if node is in idle state. In order to extend the life time of network, routing protocols consider the residual power of nodes while selecting a route and distribute the load to all nodes in the network. So, designing an efficient routing protocol to route the information in MANET is a challenging task. In this paper, we have proposed a new protocol AODV-Energy Based Routing (AODV-EBR) protocol for energy constrained mobile ad hoc Networks. This protocol optimizes Ad hoc on demand distance vector routing protocol (AODV) by creating a new route for routing the data packets in the active communication of the network. The proposed protocol efficiently manages the energy weakness node and delivers the packets to destination with minimum number of packets dropped. The proposed scheme have simulated using Network Simulator (NS-2.34) tool and compared with AODV routing protocol. The results show that the new proposed protocol has better performance over AODV routing protocol by improving packet delivery ratio and control packets dropping during the communication.
Keywords: *AODV, Hello Packet, Node Energy, Sequence Number, Upstream Node*

1. INTRODUCTION

The advancement of next generation wireless technologies has directed to rapid development in communication system [1]. As a result, we are getting a new kind of network called Mobile Ad hoc Network. In MANET, source send packets to the destination in multi hop fashion. In this network, nodes have an intelligence to find out an optimal route to send or receive the information. Besides, MANET is an autonomous system in which nodes are acting as router to route the packets in the network without any central administrator [2] in the mobile scenario. The efficiency of any network depends on the Routing protocol. In MANET, Routing is an important Research Area due to dynamic movement of nodes and the nodes are battery powered. Wireless routing protocols are not directly suitable for MANET due to MANET characteristics. To achieve this, many routing protocols are developed for MANET to route the information in the network where nodes are in mobile state. These routing protocols are classified based on how they are maintaining the routing information. Broadly they are classified as Proactive, Reactive and Hybrid protocols [3] [4] [5] [6].

Proactive protocols are called as table driven protocols such as DSDV and OLSR in which, each node maintains the routing information of all nodes in routing table. This type of protocol is suitable for limited number of nodes. Unlike proactive protocols, reactive protocols are called as on demand protocols such as AODV, DSR [7] and establish the route to the destination whenever communication is needed. Hybrid protocols such as ZRP are the combination of proactive and reactive protocols. In spite of many routing protocols been developed, no one has addressed all these issues. This paper is organized as follows: Section 2 presents related work with a focus of detailed literature survey of research works which improve the performance of AODV Routing protocol. Section 3 presents Energy consumption model of

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the network Section 4 discusses our proposed Routing protocol with algorithm. Section 5 presents simulation results to show the performance of the new protocol using simulator and Section 6 concludes this paper.

2. RELATED WORK

Reactive protocols establish the route when source has data send to destination. Examples for Reactive protocols are AODV and DSR routing protocol. In this paper, our work is to improve performance of AODV routing protocol. In this section, we will see the function of AODV routing protocol and literature survey of various routing protocols which optimizes the performance of AODV. AODV (Ad hoc On demand Distance Vector) Routing Protocol was proposed [8] and it is designed for nodes which are in mobile fashion to set up an Ad hoc Network. As a reactive routing protocol, AODV protocol maintains the routing information of all destinations in the routing table.

Every route table entry at every node should include the latest information available about the sequence number for the IP address of the destination node for which the route table entry is maintained. This sequence number is called as the "destination sequence number". To enable the freshness of routes as well as loop-free of all routes, AODV uses this destination sequence number. AODV, which is a hop by hop routing protocol sends or receives data and maintains the active route using Route Request (RREQ), Route Reply (RREP), Route Error (RERR) and HELLO messages.

A destination node increments its own sequence number in two circumstances, whenever a node originates a route discovery or a destination node originates a RREP in response to a RREQ. In those circumstances, it MUST update its own sequence number to the maximum of its current sequence number and the destination Sequence number in the RREQ packet. A node may change the sequence number in the routing table entry of a destination if it is the destination node itself and offers a new route to itself, or it receives an AODV message with the new information about the sequence number for a destination node, or the path towards the destination node expires or breaks. There are two major phases in operation of AODV such as Route Discovery and Route Maintenance.

In Route discovery phase, the source node has the data to send to destination node provided it does not have a route, it broadcasts a RREQ with incrementing broadcast-id and destination sequence number. Intermediate nodes receive this request and sends RREP if it has active route to destination; otherwise it simply forwards RREQ. As RREQ travels in the network, intermediate nodes receive this packet and add the node address to the routing table from which it has received for reverse route if it does not has a route. Either Intermediate node or destination may send RREP. If intermediate node has route to destination, it will generate RREP and send it to source node using reverse route with new sequence number in Unicast manner.

While receiving RREP, intermediate nodes are in the network established forward route to destination. If intermediate node has an active route to the destination, the destination sequence number in the node's existing route table entry for the destination is valid and greater than or equal to the Destination Sequence Number of the RREQ. The intermediate node also updates its route table entry for the node originating the RREQ by placing the next hop towards the destination for the reverse route entry. If the destination node sends RREP, it MUST increment its own sequence number by one if the sequence number in the RREQ packet is equal to that incremented value. The destination node places its sequence number into the Destination Sequence Number field of the RREP, and enters the value zero in the Hop Count field of the RREP. If destination generates RREP, the intermediate nodes in the route update their routing tables whenever they receive RREQ and RREP. The source node sends the data after it receives RREP.

In Route maintenance phase, all the nodes broadcast messages to inform the status of route. Every node broadcasts HELLO messages at particular intervals to its neighbors about its existence. If a node did not receive HELLO message from its specific neighbor, then there may be a link break. When a link break is detected, the detecting node sends Route Error (RERR) messages to all of its predecessor nodes about the broken link. Then, the source node reinitiates the route discovery process to the destination for continuing the data transfer.

Sung-Ju Lee et al. proposed a scheme called AODV-BR [9] which constructs a mesh structure for alternate routes to improve AODV performance. AODV-BR has to take extra care for maintaining the alternate routing tables. Wei Kuang Lai et.al proposed AODV-ABR & AODV-ABL [10] schemes which improve the performance of AODV protocol by maintaining alternate table in addition to routing table at each node. Besides this, some

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additional messages such as BRRQ, BRRP are generated to maintain the route.

Tejomayee Nath et.al [11] proposed a scheme which creates multipath such as primary path, node –disjoint path and fail-safe path in order to minimize the route break. In this scheme, the single path AODV has been extended for multipath routing. In node–disjoint path, the path does not have any particular node in common, except the source and destination, whereas failsafe path is a path between source and destination if it bypasses at least one intermediate node on the primary path. Z.wu [12] proposed a scheme which extends the hop-by-hop multipath to a cluster-by-cluster multipath by creating primary and backup cluster head. This scheme also establishes main and dual backup routes. It selects Primary Cluster Head (PCH) and Backup Cluster Head (BCH) in the same cluster based on Link Stability Degree (LSD). The PCH is responsible for forwarding routing information and transmitting data packets. Backup route will be active when primary route is down due to mobility.

Radwan S. Abujassar et. al [13] proposed a scheme which improves the table driven routing protocol's performance by maintaining multipath such as primary and backup route. The proposed algorithm computes a backup routing table based on the distance between nodes and number of hops to the destination.

Ying-Hong Wang and Chih-Feng Chao [14] proposed a protocol which improves the performance of the on demand protocol by setting up backup route using RD_request_Cache and Backup_Routes_ Cache. It establishes a complete route from the source node to the destination node on demand and sets up many backup routes dynamically for quick reconnection whenever a link fails. This protocol includes three phases—route discovery, backup node setup and route maintenance and requires two cache: RD_request_Cache and Backup_ Routes_ Cache. TheRD-request_ cache of a node is used to record how many times this node receives the RDrequest packets with the same identification number in the route discovery phase. The Backup_Routes_ Cache is used to store backup routes.

N.Jaisankar [15] proposed a scheme which improves the on demand routing protocol's performance by maintaining multipath with changes in control packets. The proposed scheme provides multiple alternative paths using the combination of the node-disjoint path and failsafe paths. This scheme has more alternative paths than node joint or link-disjoint paths. Each MANET node keeps and maintains tables such as Routing table and neighbor node table.

Ravindra et al. [16] proposed a protocol which improves the performance of an on demand protocol by maintaining two tables at each node and check these tables periodically. Each node maintains two tables NPL (Neighbor Power List) and PDT (Power Difference Table). NPL contains the last received signal strength for packets originating from each neighbor. Ying-Hong Wang and Chih-Feng Chao [17] proposed a protocol which improves the performance of on demand protocol by having three caches: backup route using RD_request_Cache, Backup_ Routes_Cache and Fresh_Routes_ Cache. This protocol has three phases: route discovery, backup node setup and route maintenance. Mamoun Hussein [18] proposed a distributed on demand routing protocol that handles the broken-link recovery. Here, nodes are sending the data over the established main route. Moreover, this algorithm makes the nodes to overhear the packets for future route reconstruction in case if main route is broken.

Shakeel Ahmed and A. K. Ramani [19] proposed a protocol which maintains multipath by having both primary and backup route based on bandwidth and end-to-delay. Nodes are sending data over the primary route if it satisfies QoS parameters and transfers the data over the backup route which is stored in routing table. Sharmila Sankar & V. Sankaranarayanan [20] proposed a scheme to find out link strength based on received radio and sends a Help message to its neighbours when strength goes under threshold value in order to process necessary actions. Joo-Sang Youn [21] proposed two schemes, adaptive promiscuous mode and quick local repair schemes that repair the broken links in MANET. In adaptive promiscuous mode, each node continuously monitors the overheard packets to establish the route to all destinations. Quick local repair scheme initiates the local re-route discovery process by sending HELP message after a broken link.

3. ENERGY CONSUMPTION MODEL

Based on the energy consumption model used in this work, mobile nodes are equipped with an IEEE Network Interface Cards with 2Mbps. These values correspond to a 2,400 MHz WaveLAN implementation of IEEE 802.11.A wireless network interface can be any one of the following four states and consumes some amount of energy.

- Transmit : Node transmits a packet with transmission power Ptx.

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- Receive : Node receives a packet with reception power Prx and a Node consumes same amount of power when it discards a packet.
- Idle : Node neither sends nor receives a packet with idle power Pidle and node listens wireless medium with this power.
- Sleep : Node is in sleeping state with Psleep.

We could calculate the Energy consumed by node as multiplying power with time.

Energy = Power * Time (1)

Nodes dissipate their energy during transmission (Etx) or reception (Erx) of a packet and can be calculated using

Etx = Ptx * Duration (2)
Erx = Prx * Duration

where Duration is the transmission time.

4. AODV-ENERGY BASED ROUTING PROTOCOL (AODV-EBR)

This paper proposes a new energy efficient routing protocol called AODV-Energy Based Routing (AODV-EBR) protocol in order to avoid the broken link of routes due to energy and efficiently delivers packets to destination. AODV-additional route discovery attempts and also minimizes the route error messages. In MANET, a node may drain its energy by actively participating in finding out a route to the destination and also by sending or receiving data.

If a node acts as an intermediate node in many connections, it depletes its energy very soon. As a result, it will drain its energy completely and it will not be active. Absence of this node leads to partition of network in this occasion [22]. The situation will be viewed very seriously if such nodes are in the active route. Unknowingly, source node continuously transmits data unaware of this issue due to wireless technology. In AODV, the upstream node will try to solve the local repair and continue the data transmission. In worst case, upstream node will send RERR to the source node to find out the path. On receiving RERR, source node will send RREQ for new route.

Meanwhile, packets in the buffer will be dropped due to timeout for route and overflow of buffer. So, source node is forced to repeat the data transmission. It may be crucial in some real time data applications. But AODV-EBR efficiently handles this situation and delivers the data to the destination node. The algorithm is discussed in the following section.

4.1 Operation of AODV-EBR

The proposed protocol has two phases such as Route discovery and Route maintenance. The operation of AODV-EBR is similar to AODV considering the energy of a node during establishment of route.

Figure 1 &2 shows the typical topology for illustrating the operation of AODV-EBR protocol. In Figure 1, one connection represents an active path from Source(S) to Destination (D) using nodes A, B, G and C as intermediate nodes. Let us assume, node G is weak node since its energy level is less than SEL value as shown in Figure 2. If we allow weak node continuously in the data transmission, node will get depleted soon. This leads to network partition, changing of topology and dropping of packets. According to AODV-EBR, Node G's energy level is also known to its neighbors while receiving HELLO packets. So, Node B broadcasts RREQ to destination to find out new route as stated in AODV-EBR Route maintenance algorithm. Node S sends data over an active newly discovered route (nodes A, B and F) to D bypassing weak node G.

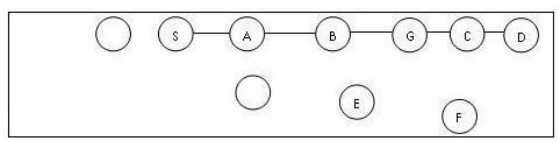

Figure 1: Active Path from S to D via Nodes A, B, G, C

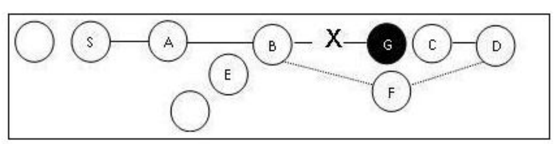

Figure 2: Active Path from S to D via Nodes A, B, F

4.2 Algorithm of AODV-EBR Route discovery:

In AODV-EBR Route discovery, source node broadcasts RREQ to destination node for sending data. Active intermediate nodes receive RREQ and help for finding route to destination.

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AODV-EBR RREQ GENERATION

if ((S has data send to D) || (S does not have valid route to D))
{
S creates fresh RREQ with sequence number and broadcasts in the network
S waits for RREP's arrival
if (S receives RREP and route to D)
Send data
}

AODV-EBR RREQ PROCESSING

if (node is intermediate node)
{
if ((fresh RREQ) && (E(node) > SEL))
{
Check routing table for D.
if (route to D)
Send RREP to S using reverse route
else
add S in the routing table for reverse route and forward RREQ
}
}
else if (node == D)
{
Send RREP with new sequence number to source using reverse route
Intermediate node receives RREP and update routing table for forward path as well as forwards to S using reverse route.
}
else if (E(node) < SEL) && !(new RREQ))
{
drop RREQ
}
Where,
- *S, D is source and destination node.*
- *SEL (SUSTAINABLE_ENERGY_LEVEL) value is 40% of node's initial energy.*
- *E(node) is the remaining energy of a node.*
- *Node is Active node if and only if E(node) > SEL otherwise it is a weak node.*

4.3 Algorithm of AODV-EBR Route Maintenance

In AODV-EBR, nodes in the network inform their existence by sending HELLO packet as shown in Figure 3 to their neighbors at regular intervals. AODV-EBR initiates its role in this situation. Nodes are reporting their energy level to their neighbors through HELLO packet. By receiving HELLO packet, nodes may know their neighbor's energy status.

Type	Hop_count	dst	dst_seqno	Lifetime	Node Energy

Figure 3: Hello Packet

Where,
Type - Packet type
Hop_count - Number of hops
dst - Destination number
dst_seqno - Destination sequence number
Lifetime - Lifetime of a packet
Node Energy - Remaining energy of a node

AODV-EBR ROUTE MAINTENANCE

Node broadcasts HELLO packet by specifying its remaining energy for one hop distance
if (packet == HELLO) {
update neighbor node's energy in neighbor table by receiving HELLO packet.
if (node is in the active path) {
if (E(neighbor node) < SEL) {
U sends RREQ to D as well as use the old route for sending data.
do AODV-EBR Route discovery process.
if (new route to D is found)
send data over new route continuously bypassing weak node.
}
}
}
- *U is the upstream node in the active path*

AODV-EBR enables the upstream node to take decision for continuing the data transmission in the existing active path. It finds out a new route to the destination bypassing weak nodes. If the neighbour node's energy level is less than SEL, then AODV-EBR activates the upstream node to initiate the new route discovery process.

Upstream node broadcasts RREQ to find out a new route to the destination instead of existing route due to neighbour node's energy weakness. While RREQ travels in network, AODV-EBR restricts the weak nodes from participating in the new route discovery process since its energy is less than SEL value.

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After receiving RREQ, destination or intermediate node will send RREP to upstream node. Meantime, Source sends data in the existing route to destination without any interruption. Once AODV-EBR discovers the new route, it enables the nodes to use the new route for sending data packets to the destination before the network is partitioned due to presence of weak nodes.

5. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

5.1 Simulation Model

The requirements of Routing Protocol [7][23] includes minimum route acquisition delay, quick routing reconfiguration, loop-free routing, distributed routing approach and minimum control overhead. This section presents simulation results of AODV-EBR and AODV using NS2 simulator [24]. Network Simulator (version 2.34), widely known as NS2, is simply an event driven simulation tool that has proved useful in studying the dynamic nature of communication networks.

We simulated our proposed scheme with a network consisting of 30 mobile hosts randomly positioned within a 750 meter X 400 meter area. Radio propagation range for each node was 250 meters. We run our simulation for 120 seconds by creating 20 different mobile scenarios and the results are averaged. The parameters for simulation are illustrated in Table 1. Each node will send HELLO packet every one second. We investigated the performance of AODV-EBR with AODV in two ways and plotted the graphs. First is by varying node movement speed as 0,1, 5, 10 and 15 m/s while fixing pause time as 20s and second is by varying pause time by 0,15,30,45 and 60s with the fixed speed of 5 m/s.

Table 1: Simulation Parameters

Parameters	Value
Antenna	Omni Antenna
Mobility Model	Random waypoint
Network Interface	Wireless PHY
MAC protocol	IEEE 802.11
Packet size	512 bytes
Number of nodes	30
Transmission range	250 m
Traffic source	CBR
CBR data rate	2 pkts/s
Connections	5
Data payload	512 Bytes

5.2 Packet Delivery Ratio (PDR)

Packet delivery ratio is defined as the total amount of data received at destination to total amount of data transmitted at source during the simulation. Packet delivery ratio defines the performance of any routing protocol. An efficient routing protocol should provide high PDR.

Figure 4 & 5 shows comparison of PDR between AODV & AODV-EBR by varying speed and pause time. The Packet Delivery Ratio of AODV-EBR is higher than AODV in both scenarios. In Figure 4, we can see the efficiency of AOD-EBR and AODV for various node movement speeds. We observed that, Packet Delivery Ratio of AODV decreases when node movement speed is increased. AODV's Packet delivery ratio is low compared to AODV-EBR when speed is at 15s.

AODV drops the data packets whenever the nodes in active path become inactive due to their energy weakness. Upstream node takes some time to do local repair and also sends RERR to source.

In worst case, source starts to send RREQ to find out new route. Meantime, the packets in the buffer will be dropped due to timeout. But in AODV-EBR, upstream node endlessly monitors the neighbour's energy through HELLO packets. When anyone's energy goes below SEL value, then upstream node immediately finds out new route without any delay and begins to send data over the new route without dropping of packets.

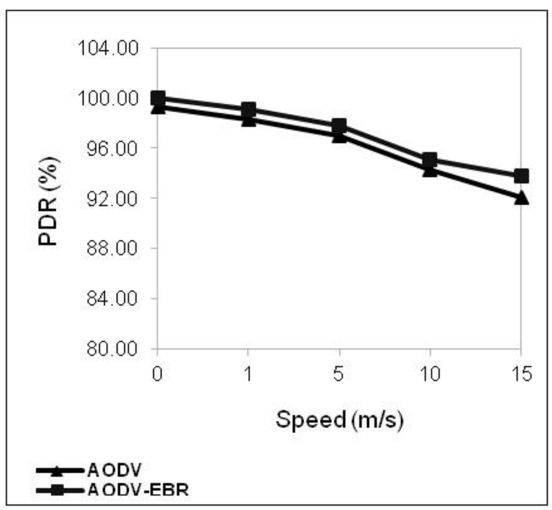

Figure 4: PDR For Different Speed

In Figure 5 also, we notice that AODV-EBR provides better performance than AODV when pause time is increased. AODV has low PDR initially and has slowly increased when pause time is increased. But, AODV-EBR constantly delivers more packets than AODV even in presence of weak

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nodes with the help of HELLO packets. Thus, AODV-EBR is capable of delivering more packets to the destination than AODV.

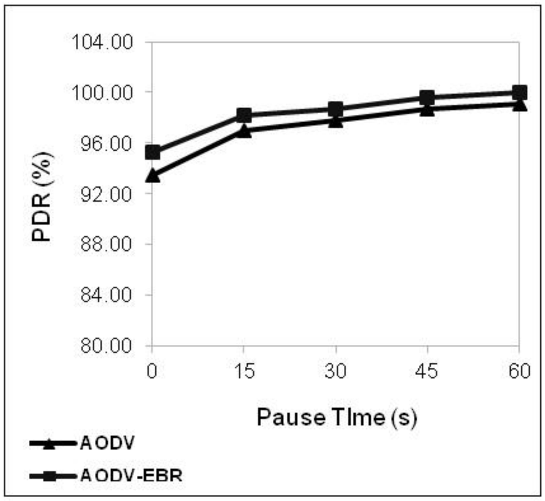

Figure 5: PDR For Different Pause Time

5.3 Average End-to-End delay

The packet End-to-End delay is the time that a packet takes to traverse from source to destination in the network. It includes all the delays in the network such as buffer queues, transmission time etc. This is also justifying the performance of any routing protocol and how a protocol will adapt to constraints.

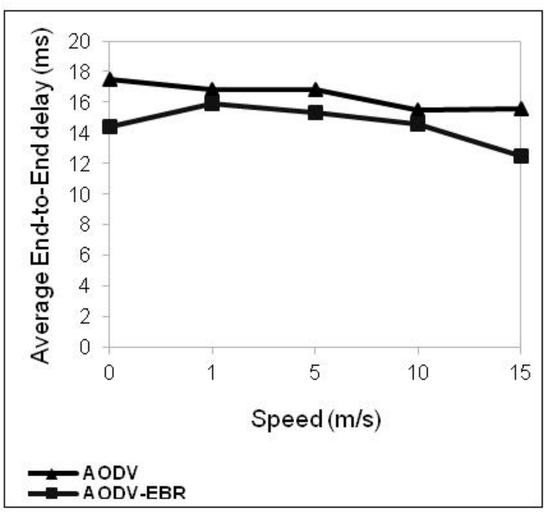

Figure 6: Avg. End-To-End Delay For Diff. Speed

Figure 6&7 shows the results of AODVEBR and AODV for average End-to-End delay metric by varying speed and pause time. It is observed that, AODV-EBR takes minimum delay to transfer a packet from source to destination when comparing

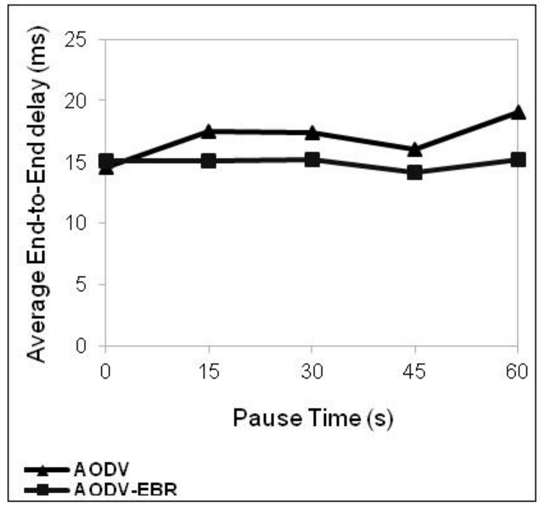

Figure 7: Avg. End-To-End Delay For Pause Time

with AODV routing protocol. AODV makes delay to do local repair failing which it initiates route discovery mechanism. AODV-EBR considerably reduces the time to find out new route to the destination. AODV-EBR initiates route discovery mechanism when node's energy goes below SEL value. While data is transmitting over the primary route, it starts sending the data after finding the new route.

5.4. Average Route Acquisition delay

Route acquisition delay is the time taken by a source node to find out a route to destination in the network. We simulated to observe the performance with respect to average route acquisition delay of AODV-EBR and AODV Routing Protocol.

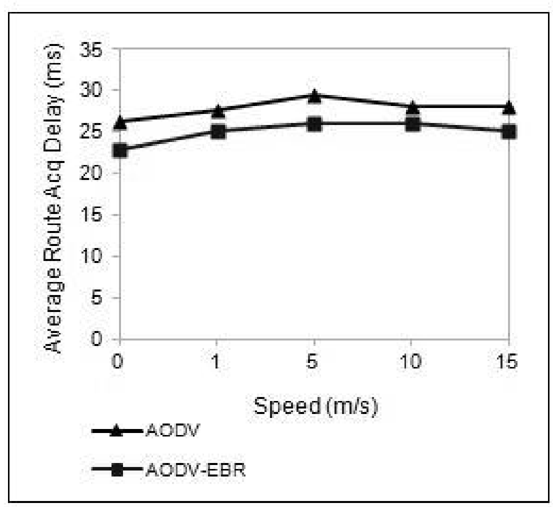

Figure 8 : Avg. Route Acq. Delay For Diff. Speed

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Figure 8 & 9 present the performance of AODV-EBR and AODV for different speed and pause time. It is observed that, AODV-EBR results in minimum delay to find out route from source to destination compared to AODV Routing Protocol. AODV has more delay due to the initiation of the route discovery process after failure of local repair. The delay of AODVEBR is low even when the node's speed is increased. Similar performance was observed while varying the pause time.

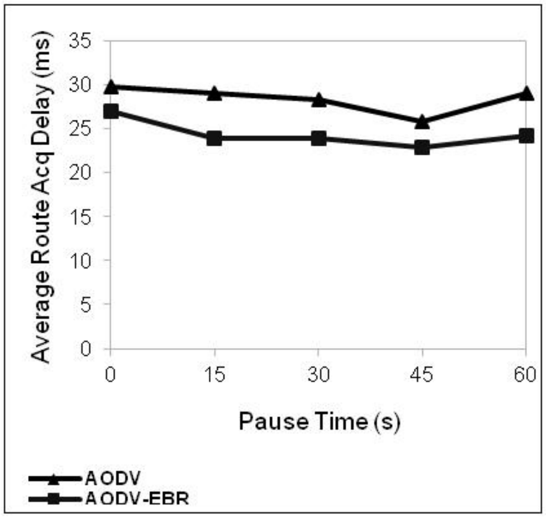

Figure 9:Avg Route Acq. Delay For Diff. Pause Time

5.5 Routing Load

This metric describes about how a Routing Protocol efficiently uses control packets to deliver data packets. This is the Ratio of number of control packets needed for delivery of data Packets. As in Figure 10 & 11, AODV-EBR consumes minimum routing overhead compared to AODV irrespective of node's speed. In high speed environment, routing load of AODV drastically increased than AODV_EBR. AODV will use control packets for local repair and to solve link error due to energy drained node performance. Then it sends RERR packet to source through neighbours to inform the link error. This will induce considerable routing overhead. After receiving this RERR packet, source will initiate route discovery mechanism by broadcasting RREQ packet.

Source will wait for RREP, failing which again starts route discovery mechanism. It also influences the AODV's performance in packet delivery ratio. But AODV-EBR will send data once the new route is found. Here, there is no need for local repair mechanism.

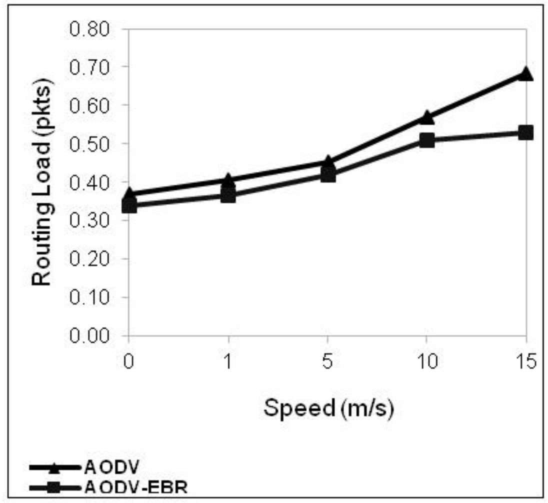

Figure10: Routing Load For Different Speed

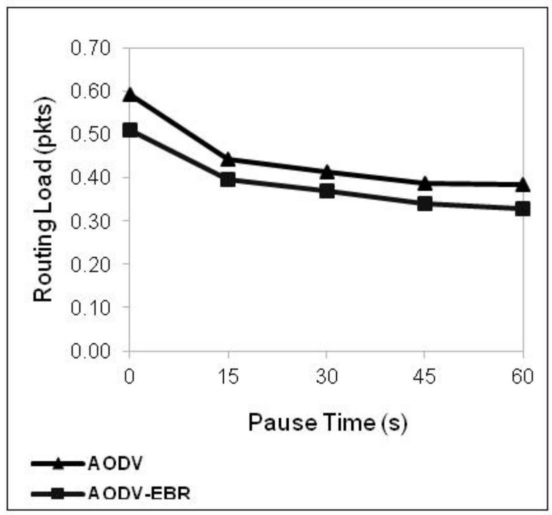

Figure 11.Routing Load For Diff. Pause Time

As in Figure 11, the Routing Load of AODV-EBR is less than AODV and it is clear that AODV-EBR outperforms AODV.

5.6 Throughput

Throughput is the number of bits transmitted per second in the network during simulation. Figure12 & 13 show the performance of AODV-EBR and AODV for different node movement speed and pause time. In both cases, AODV-EBR yields high throughput than AODV, since AODV simply drops data packets when there are weak nodes in the active route. AODVEBR continuously monitors the node's energy status.

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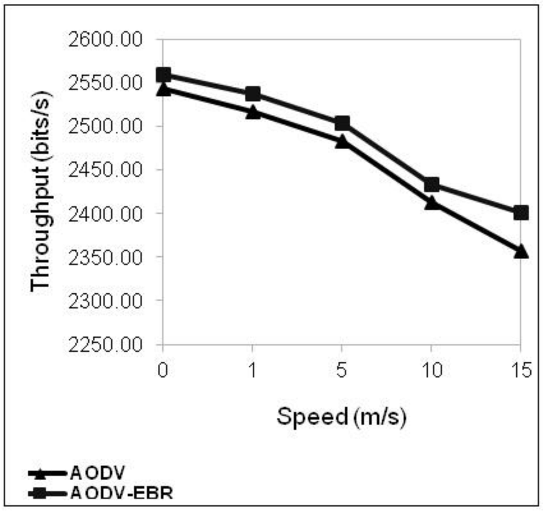

Figure 12: Throughput For Different Speed

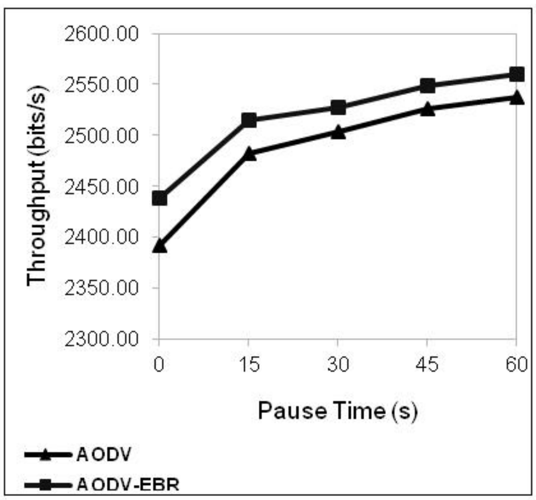

Figure 13: Throughput For Diff. Pause Time

AODV-EBR will initiate route discovery process for new route before network is partitioned due to weak node in the active path and permits the nodes to use the new route for data transmission continuously.

6. CONCLUSION

In this paper, we have proposed a new routing protocol named AODV-EBR to transmit data continuously without dropping of packets. The new scheme does not use additional packet for RREQ and RREP to discover a new routes. Also, AODV-EBR does not use any additional routing tables for maintaining the alternate or backup routes. In this way, AODV-EBR reduces the control overhead at each node and efficiently utilizes the existing control packets and routing table. We have investigated the efficiency of AODV-EBR protocol using NS2 simulator and observed the performance over metrics such as Packet Delivery Ratio, Average End-to-End delay, Routing load and Acquisition delay. The strength of AODV-EBR continuously transmits data even when the nodes in the active path get down by finding the new path. Overall, AODVEBR outperforms AODV since it delivers more packets with minimum routing overhead when nodes are in high mobility.

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