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Energy Aware Congestion Adaptive Reactive Routing Protocol with Link Quality Monitoring

J.K. Singh[1*], M. Kalla[2]

[1*]CSE Dept, Sir Padampat Singhania University, Udaipur, India
[2] CSE Dept, Sir Padampat Singhania University, Udaipur, India

[*]Corresponding Author: jinesh.singh@spsu.ac.in, Tel.: +91-8502830274

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***Abstract* -** In MANETs, packet delivery from source to destination is a complex task as many factors affect the network performance. The major factors in routing are node mobility, node energy and congestion in the wireless bandwidth limited channel and battery operated nodes with dynamic topology. This paper proposes a cross-layer based feedback among different layers, namely physical, MAC and network to pass the link information from physical to network layer. The Cross-Layer design approach helps checking the link condition as well as energy and congestion status to select the optimal path between source and destination. The proposed energy aware congestion adaptive reactive routing protocol with link monitoring (EACARP-LM) also finds alternate path proactively before the link breaks due to mobility, becomes heavily congested or an intermediate node exhaust its battery power. The protocol uses energy monitor, congestion monitor and link monitor for monitoring the respective parameter during the node operations. Based on these monitors the node takes decision for transmitting the packets and selecting a new route for packet delivery. This cross-layer design approach is implemented in Network simulator (NS2 simulator) and its performance is compared with the traditional AODV routing protocol, which indicates the better QoS parameters and increased network life time.

Keywords - Cross-Layer, Energy aware, Congestion adaptive, Link monitoring, EACARP-LM

I. INTRODUCTION

A mobile ad hoc network is a collection of wireless nodes that can transfer data without the use of network infrastructure or administration. Such networks are composed of an autonomous group of mobile users who communicate through relatively bandwidth constrained wireless links. Here each node uses cooperative routing process to communicate with each other. These networks are generally referred to as MANETs (Mobile Ad-hoc Networks). The benefit of MANETs is that it is easier to establish and do not require any infrastructure resources. This makes it highly dynamic and deployable in many applications like human or nature induced disasters, battlefields, meeting rooms where either a wired network is unavailable or deploying a wired network is inconvenient. Some of the limitations of the MANETs are high mobility, low bandwidth and Energy of nodes.

The challenge with high mobility is that it causes links brakes. Due to mobility of nodes the network topology changes frequently over time [1], this makes routing decision complex. Consistent network information cannot be maintained easily. The path needs to be re-established again and again through new nodes and this incurs a heavy overhead and performance loss for the network.

Energy optimization is also challenging field in MANET Routing. Energy optimization in MANETs has many approaches including selecting the routing path based on the remaining energy of the nodes, use of sleep mode, selecting highest energy path etc.[2,3,4].

Congestion is one another related issue in MANET. When load on a node or link is increased beyond its capacity, packets starts to drop because of buffer overflow. Also packets suffer from high delay in congested route. The main objective of congestion control is to limit the delay and buffer overflow caused by network congestion and provide better performance of the network [5].

Many routing protocols have been designed of MANETs. They can be classified into three groups: proactive, reactive and hybrid. Proactive routing protocols, such as DSDV [6], try to maintain consistent and up-to-date routing information for network. But this increases the routing overhead considerably. In the on-demand routing protocols, such as AODV [7] and DSR [8] paths are discovered only when they are needed. This reduces the routing overhead but its performance gets degraded under stressful conditions. The hybrid routing protocols [1] combines the features of both proactive and on-demand protocols. Hybrid routing protocols defines zone and each node maintains routing information about its zone using the proactive approach and uses on-demand routing approach outside the zone.

The current routing protocols are not adaptive to congestion, energy and node mobility. While routing path is selected, no concern is given to node mobility, energy and congestion status of the nodes. This can cause higher delays and higher packet loss which leads to low throughput and low QoS parameters.

The design of these ad hoc routing protocols is based on layered approach. In this approach the main focus is on a particular layer and its functionality, without any information from other layers [9, 10]. This has generally resulted in suboptimal performance of applications. The cross-layer approach has been designed to address this issue. The cross layer approach can help network layer to find optimal path from the information received from the MAC layer and Physical layer about the channel condition, as represented in figure 1. Higher energy efficiency and better congestion control can be achieved by using this cross layer information for routing decision making. The mobility of the neighbour node can be addressed by the received signal power (RSP) at physical layer. If the signal power is decreasing, means the distance between the nodes is increasing and vice-versa.

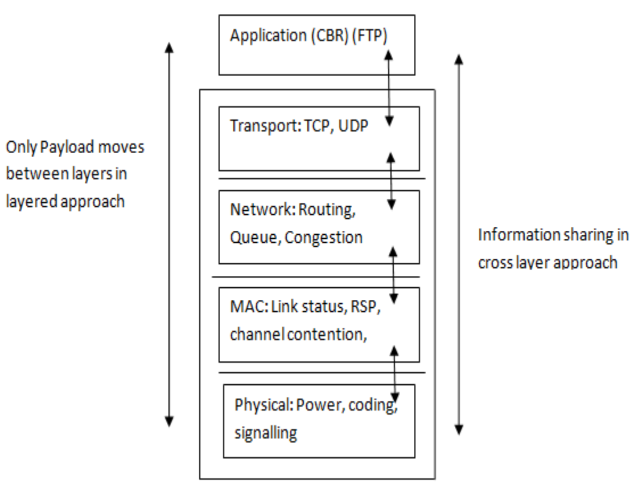

Figure 1 Cross layer Design Approach

In this paper, a cross-layer optimization is proposed that combines the link state, energy state and congestion state of the node. Using the received signal power (RSP) information from packets at physical layer, each node estimate the distance between neighbour nodes and predict the link break. Each node further monitors energy level (remaining node power) and congestion level (queue size), to decide whether to participate in the routing or not. This results in an optimal path selection.

The NS2 network Simulator provides three different models for received signal power estimation [11]. (i) Free space model (ii) TwoRay Ground Reflection Model (iii) Shadow Model

The free space propagation model (Friis model) assumes the ideal propagation condition that there is only one clear line of sight path between the transmitter and receiver. The received signal power is calculated as:

$$\mathrm{Pr} = \frac{Pt\ Gt\ Gr\ \lambda^2}{(4\pi d)^2\ L} \quad \ldots.(i)$$

Where Pt is the transmitted signal power, Gt and Gr are the antenna gains of the transmitter and the receiver respectively. L is the system loss, and λ is the wavelength. It is common to select Gt =Gr =1 and L ≥ 1 in ns simulations. The free space model basically represents the communication range as a circle around the transmitter. If a receiver is within the circle, it receives all packets. Otherwise, it loses all packets

The TwoRay ground reflection model considers both the direct path and a ground reflection path. It is shown that this model gives more accurate prediction at a long distance than the free space model. The power calculation is similar to equation (1) but with antenna height for transmitter (Ht) and receive (Hr).

$$\mathrm{Pr} = \frac{Pt\ Gt\ Gr\ Ht^2 Hr^2}{d^4 L} \quad \ldots.(ii)$$

Shadow mode is not used in general. It Includes path loss and variation of the received power at certain distance which estimate the power level more accurately compare to the other two models.

The paper is organized as follows. Section II shows the literature survey of the related work to energy aware congestion adaptive mechanism with physical link metrics in Ad hoc networks. Section III briefly describes the idea and mechanism of propose work which uses cross layer approaches and combines the energy metric, congestion metric and link metric in routing decisions to improve the network performance. Section IV introduces the simulation of the design network, shows the result of proposed work and compares it with existing AODV routing protocol. Section V draws the conclusion of the paper.

II. Related Work

Duc A. Tran and Harish Raghavendra [6] proposed CRP, a congestion-adaptive routing protocol for MANETs. A key in CRP design was the bypass concept. A bypass is a sub path connecting a node and the next non congested node. If a node is aware of a potential congestion ahead, it searches a bypass and uses it in case the congestion actually occurred. Also some part of the incoming traffic is redirected to bypass route to reduce congestion on next node. The congestion was avoided as a result.

In [12] used received signal strength as a parameter in cross layer design. The Received signal strength measured at the physical layer is communicated to MAC and network layer. The results indicate that using this feedback, issues like energy conservation, unidirectional link rejection and reliable route formation can be addressed efficiently.

In [13] proposed QoS based power aware routing protocol (Q-PAR), which prefer route with high energy and high bandwidth availability. The protocol Q-PAR is based on DSR route discovery mechanism. If a link fails the protocol searches for an alternative energy stable path locally. This increases the network lifetime.

In [14] proposed a cross-layer reactive routing protocol that focuses on node residual energy in order to decide the routes (EARR). Each node checks if it has enough energy to complete the task will take part in routing. RREQ packets carry additional information regarding traffic which is gathered from application layer. Source node picks the maximum energy path from all available routes. Hello messages and RREQ are modified to carry additional traffic and energy information.

In [15] proposed another congestion control protocol for controlling congestion in AODV named as Early Detection Congestion and Control Routing in MANET (EDAODV) which detects congestion at the node. It calculates queue_status value and thus finds the status of the congestion. Further, the non-congested predecessor and successor nodes of a congested node are used by it for initiating route finding process bi-directionally in order to find alternate non-congested path between them for sending data. It finds many alternate paths and then chooses the best path for sending data.

In [16] proposed a Congestion and Energy Aware Routing Protocol (CAERP). In order to achieve the congestion free communication with minimized energy utilization the data rate of the individual nodes are changed according to the queue state and signal strength identifier. If the value of the Received Signal Strength Indicator (RSSI) is low, it is assumed that the distance between the sources to sink is high. The RSSI and the queue size of the nodes in the ongoing path are used to adjust the data rate of the intended node transmission. It achieves the high link reliability for current transmission path and optimum energy utilization

In [17] present cross layer based energy aware routing and congestion control algorithm in MANET. The standard AOMDV protocol is modified with cross layer approach. The results indicate reduced packet retransmissions and losses and increase in network QoS parameters. Also the energy utilization is reduced and network life time increased.
In [18] proposed a bandwidth-efficient power aware routing protocol “QEPAR”. The routing protocol minimizes bandwidth consumption and reduces delay. The packet loss is also decreases and thus throughput is increased. The proposed protocol is also helpful in finding out an optimal path without any loop.

III. METHODOLOGY

The proposed EACAR-LM routing algorithm requires following steps:
A. RSP calculation: Hello packet is modified to contain RSP value for the node. The RSP value is calculated by MAC layer using TwoRay Ground Model according to equation (ii). A node get the Received signal Power information from MAC layer and under cross-layer design approach, uses it at network layer. The node broadcast this RSP value to neighbour node in hello packets, which is stored in NIT (Neighbour Information table) by each node. Every node also maintains ART (alternate Routing table) beside primary routing table which is used to find alternate path. Each node calculates Average Received signal power and divides the neighbours in two groups:

Blue nods	Received RSP < Avg_RSP	. . . . (iii)
Green nodes	Received RSP > Avg_RSP	. . . . (iv)

Each Node also calculates Average of LOW RSP (Avg_LOWRSP) which indicates the minimum RSP that should be received for good link stability. The RSP is always in-directionally proportional to the distance. Low RSP nodes are farther from the current node (high distance), while high RSP nodes are near to the current node (low distance). For all communications High RSP nodes are preferred over low RSP nodes.

B. Link Monitor: For active route: Check received RSP from MAC, if it is below Avg_LOWRSP, means node is moving further and link will break soon. The node initiate alternate path discovery between source and destination. The neighbour will search for alternate path and update routing tables to bypass the current route using Bidirectional path discovery if alternate path exists [16].

C. Energy Monitor: Each node monitors its remaining battery power. Two threshold values are defined: en_th1 (en_th1 is 20% of initial power) and en_th2 (en_th2 is 10% of initial power) for energy monitoring.

- For received RREQ If Rem_power < en_th1 drop RREQ, not to allow new connection from it.

- For data packet If Rem_power < en_ th2 then the node initiate alternate path discovery between source and destination. The neighbour will search for alternate path and update routing tables to bypass the current route using Bidirectional path discovery if alternate path exists.

D. Congestion monitor: Each node monitors its current queue size to estimate the congestion status. Two threshold values are defined: co_th1 (co_th1 is 80% of total buffer capacity) and co_th2 (co_th2 is 90% of total buffer capacity) for congestion monitoring.

- For received RREQ If the queue size > co_th1 then DROP RREQ, not to allow new connection from it.
- For received Data packet If queue_size > co_th2, the node initiate alternate path discovery between source and destination. The neighbour will search for alternate path and update routing tables to bypass the current route using Bidirectional path discovery if alternate path exists.

E. Route Discovery: Every node monitors RSP, Remaining _Energy and Congestion_status. The Total cost function is calculated based on the Function:

Decision = F1(RSP , Remaining_Energy, Congestion_status) ..(v)

Which checks RSP>Avg_LowRSP, REMp>en_th1 and CONGs<co_th1. If the function returns false the RREQ is dropped. Else it is processed as with normal AODV flow.

F. Route Rediscovery: The route rediscovery takes place in three cases:
(a) For active route with node mobility: Check received RSP from MAC, if it is below Avg_LOW RSP, it means node is moving further and link will break soon. The node initiates alternate path discovery in this case before the link breaks. If alternate path exist, node will update routing table to bypass the moving node, else continue with the existing path until link breaks.

(b)Low energy Node: If Rem_power < 10% of the initial power then node finds alternate path by sending special ALT_PATH_REQ packet to its neighbours, indicating its low energy status. The neighbours will search for alternate path and update routing table if it exists, else continue using the same path until node exhaust its battery.

(c) High Congestion status: If queue_size >90% of total buffer capacity, then node finds alternate path by sending special ALT_PATH_REQ packet to its neighbours, indicating its high congestion status. The neighbours will search for alternate path and update routing table if it exists, else continue using the same path.

The combined function is

Decision = F2(RSP, Remaining _Energy, Congestion_status) . .(vi)

Which checks RSP>Avg_LowRSP, REMp>en_th2 and CONGs<co_th2. If the function returns false the alternate path discovery is initiated and packet is forwarded, else only packet is forwarded without alternate path discovery.

Thus the protocol evaluates two functions F1 and F2 and based on the returning value takes necessary action. The RRER and RREP are handled in same way as in normal AODV routing protocol. Figure 2 and figure 3 are the flow chart of the proposed routing algorithm.

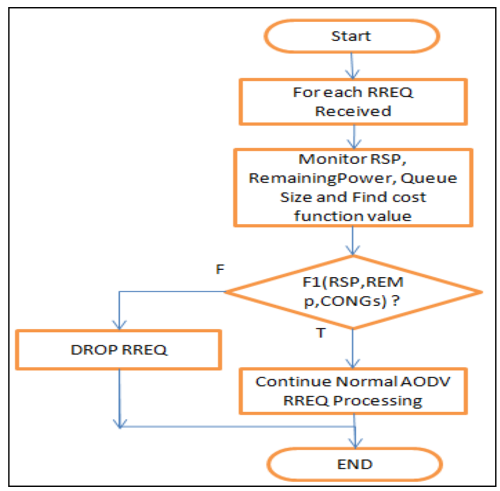

Figure 2 Flowchart for Route Discovery process

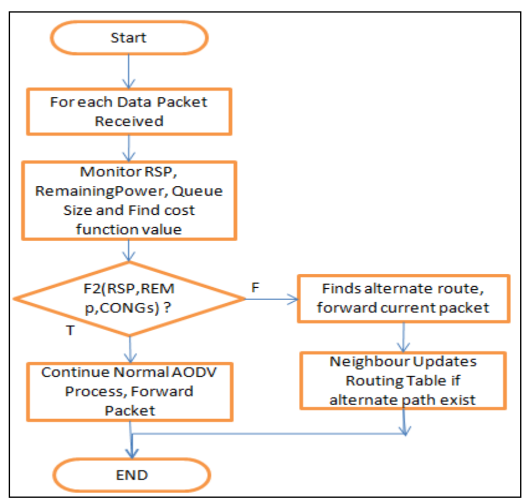

Figure 3 Flowchart for Route Rediscovery process

IV. Results and Discussion

The EACARP-LM protocol is implemented in NS2 and compared with traditional AODV. Energy model is used in

NS2 to initialize transmission range (250m), initial power (50J) etc. Table1 shows the parameters setting for the simulation setup. The channel bandwidth is set to 2Mbps. The traffic type is CBR with packet size 512 bytes. The Random-Waypoint node mobility model is used with maximum speed 10m/s. Table 1 shows the simulation parameters.

Table 1 Simulation Parameters

Type	Values
Channel	Channel/Wireless Channel
Radio Propagation Model	Propagation/Tworayground
Network Interface	Physical/Wirlessphy
MAC	MAC/802_11
Interface Queue	Queue/DropTail/PriQueue
Antenna	Antenna/Omniantenna
Link Layer	LL
Interface Queue Length	50
Simulation Time	100s

Three different scenarios are used for experiments:

A. Different number of Nodes (10 to 50).
B. Different number of Connection (from 10 to 40).
C. Different node mobility (0 to 30).

A. Different number of Nodes: (From 20 to 50):

Here number of nodes is variable from 20 to 50, which are randomly scattered in a region of 1000m X 1000m. The load on the network is kept constant, 15 connections. The cbrgen.tcl and setdest utility is used for traffic and mobility model generation. The performance of the proposed algorithm is evaluated and compared with the traditional AODV.

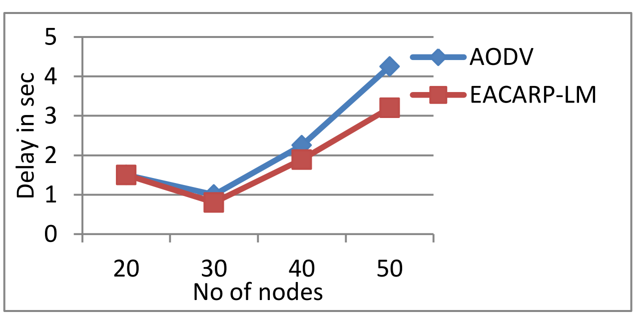

Figure 4 No of nodes and End to End Delay

Figure 4 indicates that in initial condition when number of nodes is less the load on the network in high (15 connections), both AODV and EACARP-LM both experience high delay. The delay is reduced when number of nodes increases to 30. Then again the delay increases as the number of nodes increases to 50. From the result it is clear that as the number of nodes increases the delay in EACARP-LM is lower than AODV.

Figure 5 indicates low PDR in initial high load condition for both AODV and EACAR-LM. When the number of nodes increases the PDR also increases. The PDR for EACARP-LM is higher compare to AODV. The higher PDR is achieved because less number of packets are dropped in EACARP-LM due to the energy monitor and congestion handling.

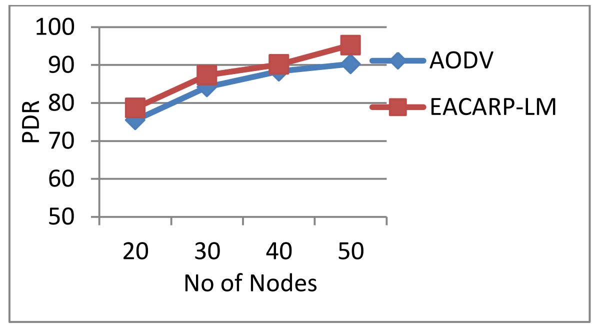

Figure 5 No of nodes and PDR

Figure 6 indicates the routing overhead is same initially for both the protocols. The routing overhead increases as the number of nodes increase. EACARP-LM performs better then AODV when the number of nodes increased from 30 to 50. As the number of nodes are increasing the number of available alternate paths are also increased which are used by the proposed protocol.

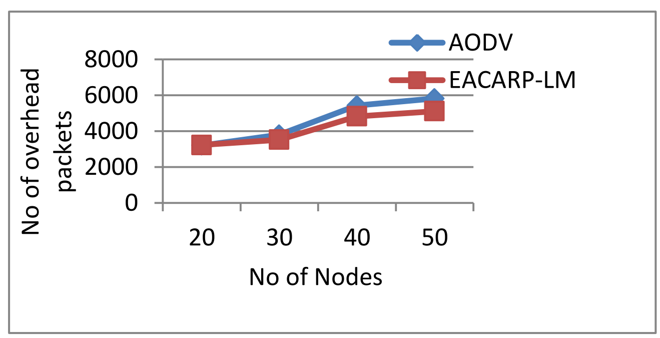

Figure 6 No of Nodes and Routing Overhead

B. Different number of Connections: (From 10 to 40)

Here 50 nodes are used which are randomly scattered in a region of 1000m X 1000m. The load on the network is increased in terms of number of connections from 10 to 40. The cbrgen.tcl and setdest utility is used for traffic and mobility model generation. The performance of the proposed protocol is evaluated and compared with the traditional AODV.

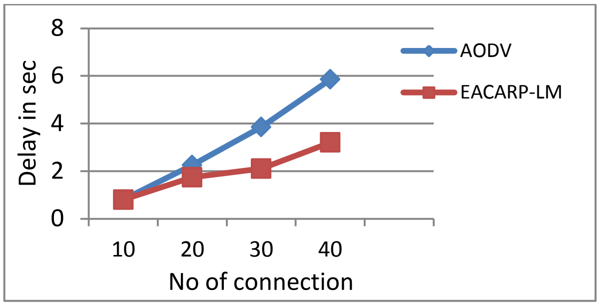

Figure 7 No of connections and Delay

Figure 7 indicates same delay in the initial condition of the network, which increases as the load on the network increases in terms of number of connections. As the number of connection increases the delay in EACARP-LM is lower than AODV, thus EACARP-LM performs better in high load situations. The EACARP-LM is performing better in higher load conditions because of its congestion control mechanism which reduces the overall delay for packet transfer.

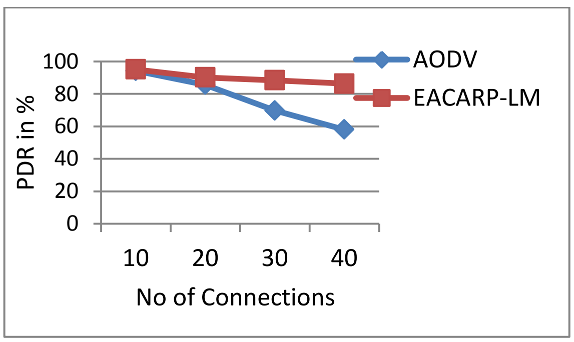

Figure 8 No of connections and PDR

Figure 8 indicates high PDR in initial condition for both AODV and EACARP-LM. As the number of connections increase the PDR decrease. But the PDR for EACARP-LM is higher compare to AODV. This is due to the congestion handling and link monitoring which reduces the number of overhead packets required for the packet transmission.

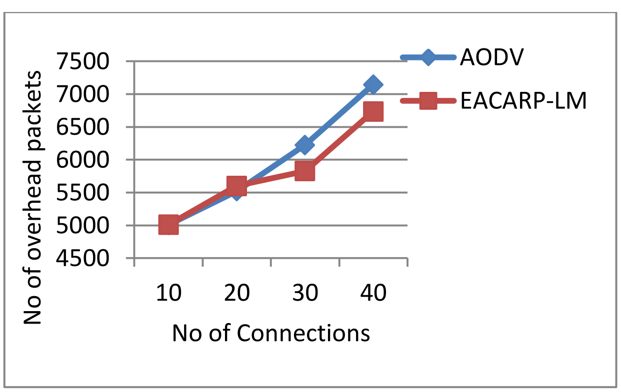

Figure 9 No of connections and Routing Overhead

Figure 9 indicates the routing overhead increases as the number of connections increase due to the increased load on the network. EACARP-LM has lower routing overhead compare to AODV at higher loads. The results indicates that the proposed protocol perform better with its cross layer approach for handling energy and congestion monitor.

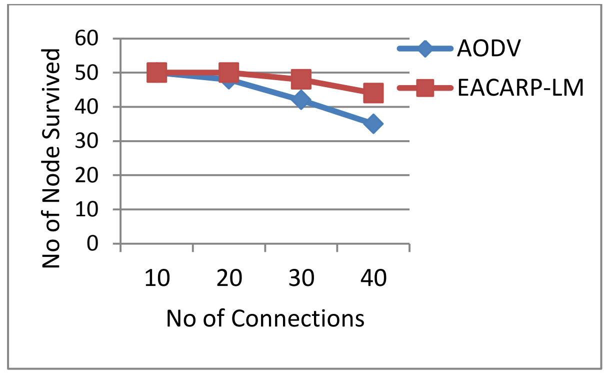

Figure 10 No of connections and Survived Nodes

Figure 10 indicates the number of nodes survived as the number of connections increase. EACARP-LM has higher number of node survived because of its higher energy efficiency compare to AODV at higher load. The energy monitor makes the uniform energy consumption from all the nodes and saves energy from low battery nodes, which contributed significantly in increasing network life time.

C. Different Node Mobility :(From 0 to 30 m/s)

Here 50 nodes are used which are randomly scattered in a region of 1000m X 1000m. The load on the network is kept constant, 15 connections. The mobility of the nodes is increased from 0 to 30 m/s in step size of 10 m/s. The cbrgen.tcl and setdest utility is used for traffic and mobility model generation. The performance of the proposed algorithm is evaluated and compared with the traditional AODV.

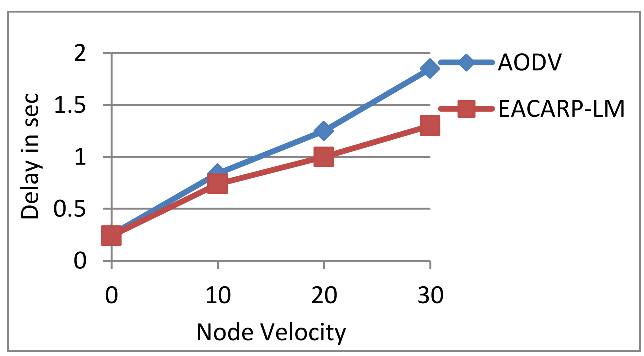

Figure 11 Node velocity and Delay

Figure 11 indicates same delay in the initial condition of the network, which increases as the mobility of the nodes increases. As the node mobility increases the delay in

EACARP-LM is lower than AODV because of its link monitoring and alternate path discovery. The link monitor together with congestion control results in less delay even at higher node mobility as indicated by the results.

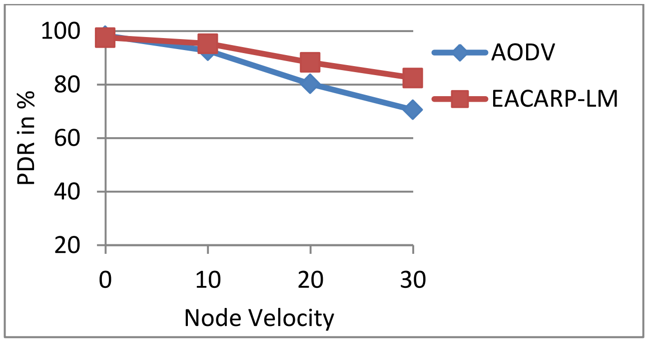

Figure 12 Node velocity and PDR

Figure 12 show that initially the PDR is same for both AODV and EACARP-LM. This is because at low node mobility the links are already relatively stable and link monitor do not contribute in PDR. The PDR decreases as the mobility of the nodes increases because of unstable links between the nodes. But the PDR is better in EACARP-LM compare to AODV.

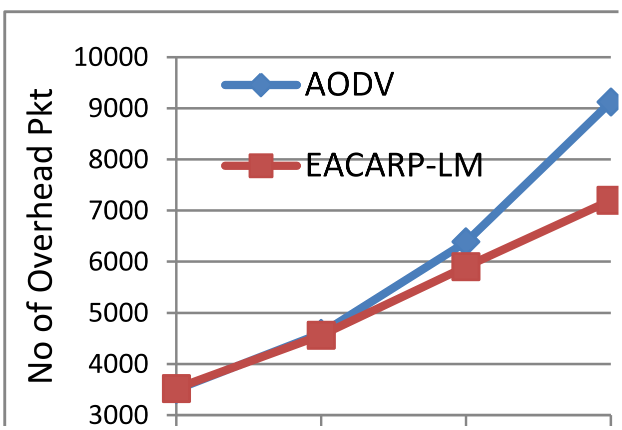

Figure 13 Node velocity and Routing Overhead

Figure 13 shows routing overhead increases as the node mobility increases. This is because of the unstable link conditions at higher mobility. The mobility causes more frequent link breaks between the nodes. This increases the routing overhead as more number of overhead packets are required for finding new links between source and destination nodes. The proposed EACARP-LM shows better results compare to AODV in controlling the routing overhead. This is due to the proactive link monitoring and alternate path discovery which resulted in less link breaks and less number of routing overhead packets.

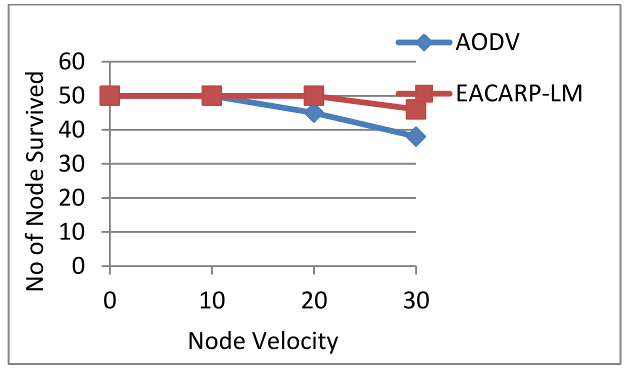

Figure 14 Node Velocity and Survived Nodes

Figure 14 shows that the number of nodes survived is higher in EACARP-LM compare to AODV when the network is more unstable due to high mobility. Here the main contribution is by link monitor and energy monitor. Energy monitor enforce uniform energy consumption between the nodes while the link monitor saves overhead and reduce energy consumption required for overhead packets.

V. Conclusion and Future Scope

The paper proposed a new cross layer based energy and congestion adaptive routing algorithm with link monitoring to find an optimal path in MANETs. The protocol is based on three monitor namely energy monitor, congestion monitor and link monitor. The combined energy, congestion and link metric leads to achieve higher packet delivery ratio, lower delay and energy consumption, as indicated in results. The results indicates that the proposed protocol has improved QoS parameters and at the same time increase the network life time by fairly consuming energy from all node and avoid low energy nodes. The congestion monitor is useful for handling the high load conditions in the network topology and maintaining a good throughput eve at higher loads. The link monitoring is very useful for dynamic network topology with moving nodes. The unstable links due to node mobility can also increase routing overhead and reduce PDR. The link monitor in useful in such cases and improve the performance of the proposed protocol. The node mobility, congestion status and remaining energy are cross layer information which helps network layer in making better routing decisions to improve overall performance in wireless scenario.

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