A Novel Cross Layered Energy based Ad Hoc On-Demand Routing Protocol for MANETs

K.Muthumayil[1], V.Rajamani[2], S.Manikandan[3]
[1]PSNA College of Engg. & Tech.,Dindigul, Tamilnadu, India, muthumayil@yahoo.com
[2]Indra Ganesan College of Engg., Trichy, Tamilnadu, India, rajavmani@gmail.com
[3]R.M.D Engg.College, Gummudipoondi, Chennai, Tamilnadu, India, manidindigul@rediffmail.com

Abstract— **The design of efficient routing protocols for Ad hoc neworks is a complex issue. These networks need efficient algorithms to determine ad hoc connectivity and routing. MANET aims not only to provide correct and efficient routes between pair of nodes but also to provide energy efficient route to maximize the life time of ad hoc mobile networks. In this paper, a dynamic energy conscious routing algorithm ECL-AODV where cross layer interaction is provided to utilize the energy related information from physical and MAC layers. This algorithm avoids the nodes which are having low residual energy. By maximizing the lifetime of mobile nodes routing algorithm selects a best path from the viewpoint of high residual energy path as part of route stability. The RTS/CTS transmission is a crucial step towards saving the energy of mobile nodes. In this scheme, the RTS/CTS transmission occurs after route discovery and route reply process. The path is reserved for further transmissions. The receiving power of sender, intermediate nodes and receiver are also another part of route stability. The protocol is implemented for achieving quality of service (QoS) in terms of average energy consumption, packet delivery ratio, end-to-end delay and throughput.**

Index Terms— **Routing protocols, Ad hoc networks, Cross layer design, Quality of Service**

I. INTRODUCTION

Mobile Ad Hoc Network (MANET) is collection of multi-hop wireless mobile nodes that communicate with each other without centralized control or established infrastructure. In MANET each node communicates with other nodes directly or indirectly through intermediate nodes. Thus, all nodes in a MANET basically function as mobile routers participating in some routing protocol required for deciding and maintaining the routes. Routing[1],[2],[3],[4],[5] is one of the key issues in MANETs due to their highly dynamic and distributed nature. The routing protocols of MANETs are divided into two categories as table-driven and on-demand. In table-driven routing protocols, each node attempts to maintain consistent, up-to-date routing information to every other node in the network. Many routing protocols including Destination-Sequenced Distance Vector (DSDV) [1] and Fisheye State Routing (FSR) protocol belong to this category. In on-demand routing, routes are created as and when required. Route discovery and route maintenance are two main procedures: The route discovery process involves sending route-request packets from a source to its neighbor nodes, which then forward the request to their neighbors, and so on. Once the route-request reaches the destination node, it responds by unicasting a route-reply packet back to the source node via the neighbor from which it first received the route-request. When the route-request reaches an intermediate node that has a sufficiently up-to-date route, it stops forwarding and sends a route-reply message back to the source. Once the route is established, the route maintenance process is invoked until the destination becomes inaccessible along the route. Note that each node learns the routing path as time passes not only as a source or an intermediate node but also as an overhearing neighbor node. In contrast to table-driven routing protocols, on-demand routing protocols don't maintain all up-to-date routes. Dynamic Source Routing (DSR) [3] and Ad-Hoc On-Demand Distance Vector (AODV) [2],[4],[5] are popular on-demand routing protocols.

In addition to simply establishing correct and efficient routes between pair of nodes, one important goal of a routing protocol is to maximize the lifetime of ad hoc mobile networks. The residual battery energy of mobile nodes is a simple indication of energy stability and can be used to extend network lifetime[6],[7],[8],[9],[10]. This information has to be taken from the physical and medium access control layers of data link layer since these layers are responsible layers to compute the power consumption and residual energy computation. Many MAC layer protocol[11],[12]has been discussed previously.

II. ENERGY EFFICIENT ROUTING ALGORITHMS

Rekha Patil, A.Damodaram [13] developed a routing protocol based on MAC information. The discovery mechanism in this algorithm uses battery capacity of a node as a routing metric. This approach is based on intermediate nodes calculating cost based on battery capacity. The intermediate node judges its ability to forward the RREQ packets or drop it. That is it integrates the routing decision of network layer with battery capacity estimation of MAC layer. Ivan Stojmenovic, Xu Lin [14] developed a new power cost-metric based on the combination of both node's life time and distance based power metrics. This provides basis for power, cost and power-cost localized routing algorithms where nodes make routing decisions solely based on the location of their neighbors and destination. The power aware routing algorithm attempts to minimize the total power needed to route a packet between source and destination. The cost-aware routing algorithm is aimed at extending the battery's worst-case lifetime at each node. The combined power-cost routing algorithm attempts to minimize the total power needed and to avoid nodes with a short remaining battery life time.

Power-aware Source Routing (PSR) discussed by Morteza Maleki, Karthik Dantu, and Massoud Pedram [15] is to extend the useful service life of a MANET. This is highly desirable in wireless ad hoc network since death of certain nodes leads to a possibility of network partitions, rendering other live nodes unreachable. This algorithm assumes that all nodes start with a finite amount of battery capacity and that the energy dissipation per bit of data and control packet transmission or reception is known and presents a new source-initiated (on-demand) routing protocol for mobile ad hoc networks that increases the network lifetime. Multicast Multi-path Power Efficient Routing by S.Gunasekaran and K.Duraiswamy [16] addresses the problem of power awareness routing to increase lifetime of total network. Since nodes in mobile ad hoc network can move randomly, the topology may change arbitrarily and frequently at unpredictable times. Transmission and reception parameters may also impact the topology. Therefore it is very difficult to find and maintain an optimal power aware route.

Chansu Yu, Ben Lee and Hee Yong Youn [17] overviews on energy efficient routing approaches such as transmission power control approach, load distribution approach, sleep/power-down mode approach. For transmission power optimization, Flow Augmentation Routing (FAR) , Online Max-Min Routing (OMM), Power aware Localized Routing (PLR) protocols and minimum energy routing(MER) were discussed. For load Distribution Approach Localized Energy-Aware Routing (LEAR) and Conditional Max-Min Battery Capacity Routing (CMMBR) protocols were discussed. For sleep/power-down mode approach, SPAN protocol and the Geographic Adaptive Fidelity (GAF) protocol employ the master-slave architecture and put slave nodes in low power states to save energy. Unlike SPAN and GAF, Prototype Embedded Network (PEN) protocol saves more energy when the devices put into sleep state according to the need.

III PROPOSED SCHEME

In communication-related tasks, energy consumption depends on the communication mode of a node. A node may either in a mode of transmit, receive or idle. Transmission consumes more energy than the other two modes. Even though transmission consumes more energy, it can't be altered in mobile ad hoc networks since the transmission power is always constant. The receiver strength is predicted as required minimum receiving power for every node. The nodes which have required minimum receiving power and the nodes with high remaining battery power is considered for stability. In MANET, there is a high power consumption for sending RTS and CTS signals. By reducing the energy required to send and receive RTS and CTS signals, the energy of a node can be improved. The proposed scheme ECL-AODV routing protocol is developed by using AODV as the base.

Basic Assumptions

All the nodes in the given area have same transmit power and each node selects a threshold energy level (E_{th}) and each node must maintain the value in their routing table to select the nodes during route discovery. The residual battery energy value can be obtained to the network layer where it is stored in the routing /neighbor tables to make routing decisions based on the battery energy. When the residual energy is less than threshold energy value, that node is avoided in the route selection by the destination. On receiving the RREQ the intermediate nodes calculates the received signal strength which holds the following relationship for free space propagation model:

$$P_R = P_T\ (\lambda/4\pi d)^2\ G_T\ G_R \qquad (1)$$

Where P_T and P_R are transmitter power and receiver power respectively, λ is the carrier wavelength, d is the distance between the sender and the receiver and G_T G_R are the unity gain of the transmitting and receiving antenna respectively. Hence the node calculates the path loss using

$$Path\ loss = P_T - P_R \qquad (2)$$

The main impact of physical layer affecting a wireless ad hoc networks as perceived by the receiver, is the degradation of the received signal strength due to free space loss. By calculating the receiver strength, the data loss can be reduced and the connectivity can be predicted instead of calculating minimum transmission power. The receiver sensitivity, the minimum received power necessary for a signal to be correctly detected is, P_{Rmin} as from (1). The receiver strength is the only one parameter which decides the correct reception of signals.

The total amount of energy consumed per transmitted packet is written as

$$E_t = P_T * L/R_b \qquad (3)$$

Where

E_t = transmitted energy
P_T = transmitter power
L = packet length
R_b = data rate or bandwidth

The total amount of energy consumed per received packet is written as

$$E_r = P_{R_{min}} * L/R_b \qquad (4)$$

The transmission range between a pair of transmitter and receiver is calculated as

$$TR_{tx} = \sqrt{\frac{P_T\, G_T\, G_R}{P_{R\min}}}\ (C/4\pi f_c)^2 \qquad (5)$$

where, f_c – frequency
P_{Rmin} – minimum received power

The node then calculates the residual energy E_{res} using the following parameters:

E_I – Initial energy taken by the node
E_t – Energy consumed in transmitting packets
E_r – Energy consumed in receiving packets
E_i – Energy consumption in IDLE state.

$$E_{res} = E_T - (E_t + E_r + E_i) \qquad (6)$$

The node then piggybacks this residual energy along with the required minimum receiving power in the RREQ packet.

Our proposed Cross Layered AODV based on Energy (ECL-AODV) routing protocol consists of four phases:

A. Route discovery
B. Route reply
C. Energy conservation
D. Route repair

A. Route Discovery

In AODV, the proposed routing protocol modifies the route discovery procedure for balanced energy consumption. When the source node wants to send data packets to a destination node D and does not have a route to D, it initiates route discovery by broadcasting a route request RREQ (broadcast message) to its neighbors. RREQ packet length is about 40 bytes. Once a source node initiates the route discovery process it includes its required minimum receiving power and residual battery energy in the route request message just enough to reach to its neighbor nodes. In AODV, when a node receives a route-request message, it checks its residual energy (E_{res}) with threshold value (E_{th}).When E_{res} is higher than E_{th}, it appends its identifier and residual energy in the message and forwards it toward the destination. Thus, an intermediate node always relay messages if the corresponding route is selected. However, in proposed algorithm, a node determines whether to forward the route-request message or not depending on its residual battery energy (E_{res}). When E_{res} is higher than a threshold value (E_{th}), the node forwards the route-request message including its battery level; otherwise, it drops the message and refuses to participate in relaying packets. Obviously, the calculation residual energy by every node consumes more energy in ad hoc networks. It increases with number of nodes. The overhead in considering residual energy should be $O(n^2)$. The node also calculates the required minimum receiving power by above mentioned equations and piggybacks this receiving power to the RREQ packet. Therefore, destination node will receive a route-request message only when all intermediate nodes along a route have good battery levels, and nodes with low battery levels can conserve their battery power. The RREQ packet is about 40 bytes in length and it has following fields:

TABLE I
PACKET FORMAT OF RREQ MESSAGE (IN BYTES)

SA	DA	RREQ ID	Sender ID	E_{res}	P_{Rmin}	RREQ Message	T_{SIFS}
6	6	1	1	2	2	0-20	2

Where,
SA – Source IP address
DA – Destination IP address
RREQ Id – Route request identifier used to avoid the duplicate route requests
Sender ID – Identifier of sender (initially source ID is the sender ID)
E_{res} - Residual energy of the node
P_{Rmin} – minimum receiving power of the node which forwards the message
RREQ Message – Route request message for a particular destination.
T_{SIFS} – waiting time before getting the route reply from destination

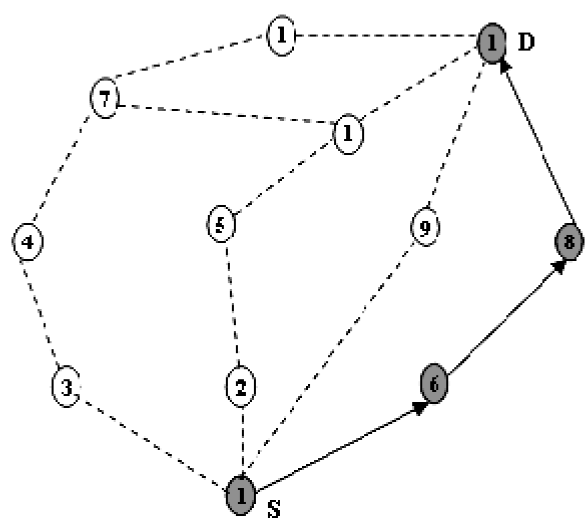

Fig 1. Route discovery process

In AODV protocol, when the route-request reaches an intermediate node that has a sufficiently active route, it stops forwarding and sends a route-reply message back to the source. In figure 1, the source node 1 sends route request broadcast message the path 1-6-8-12 has been selected as a stable path since it has nodes which have high residual energy and minimum transmission energy. Here the shortest path is 1-9-12 but it has less stability because of residual power and transmission power.

The primary objective of this cross layered energy based AODV (ECL-AODV) routing protocol is to maintain a connected topology using the minimal receiving power and residual energy of the node based on their battery power so as to minimize the receiving power and maximize the lifetime of the node. Energy efficient routing protocols based on receiving power control find the best route that optimizes the total receiving power between a source-destination pair.

B. Route Reply

In AODV protocol, once the source node wants a data packet to be sent it initiates the route discovery process and waits for route reply and when it gets route then it transmits the data. However in this proposed protocol, the route selection is concerned with the remaining battery power (residual energy) and required minimum receiving power.

Among the various route request messages from the intermediate nodes, the destination node selects the best path having high residual energy and minimum and optimized receiving power as included in the route request messages. This path is more energy efficient as it involves optimized receiving power and nodes with maximum lifetime stability. The route reply message which has 40 bytes of length is sent back to the source node through the selected path and this path is used for data communication. If the route reply (RREP) packet in table 2 has not come back to the source before the expiration of T_{SIFS}, the source will retransmit the same RREQ packet as broadcast packet. When the same intermediate nodes receive this same RREQ packet, first it checks its table to search for the particular RREP. It it has RREP, it is sent back to the source and the intermediate nodes simply drop because of same RREQ identifier.

TABLE II
PACKET FORMAT OF RREP MESSAGE (IN BYTES)

SA	DA	RREP ID	E_{res}	P_{Rmin}	RREP Message	T_{SIFS}	IN_{list}
6	6	2	2	2	0-10	2	0-10

Where,

RREP ID - Route reply identifier used to avoid duplicate reply

RREP Message - Route reply message from receiver after selection of route

TSIFS - short waiting time to receive the next data packet.

IN_{list}- Intermediate nodes list those are selected by destination based on the high residual energy and required minimum receiving power.

C. Energy Conservation

The basic medium access control (MAC) of IEEE 802.11 is DCF which employs carrier sense multiple access with collision avoidance (CSMA/CA). Each Node will sense the channel before transmission and reserve the channel through RTS-CTS control packets to avoid collision between data packets due to hidden terminal problem. But in our proposed algorithm we modify the basic MAC layer function of sending the RTS-CTS control packets. Here in our cross layer implementation, after the route discovery phase of sending RREQ and route reply getting RREP phases, the source node will send RTS packet to reserve the selected path. The basic idea of reserving the path is to avoid the intermediate nodes participating in other routing. Since the routing decisions were based on residual battery power, any intermediate node participating in other nodes routing may reduce the battery power, so there is a chance that the selected path may become unstable. A need for energy reservation arises. This scheme transmits RTS/CTS packets after the route is discovered. The route is discovered by the receiver using required minimum receiving power and high residual battery energy.

D. Route Repair

After the destination selects the best route based on the residual battery energy and transmission energy, the source uses to transmit data packets through selected path. When a link break occurs in active route during the transmission, route repair procedure is invoked. In this protocol, Local Repair (LR) message is sent to the source node by the upstream node of the broken link. Then the upstream node attempts to find the alternate path based on the residual energy and transmission power mentioned above.

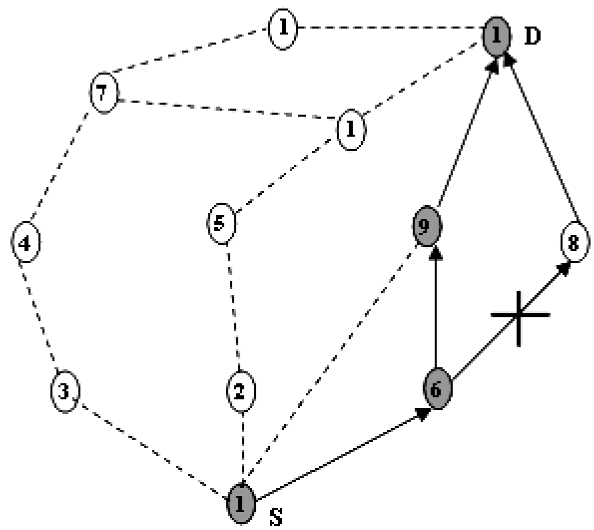

Fig 2 : Route Repair process

In figure 2, suppose the link between node 6 and node 8 is broken, the upstream node of the broken path 6 sends Local Repair (LR) back to the source. Also it attempts to find an alternate path. In this example node 6 finds the alternate path 1-6-9-12 since it has next high stability nodes based on the residual energy and minimum receiving power than all other paths.

IV PERFORMANCE EVALUATION

Simulation Environment

Simulation study has been carried out to show the performance of our proposed protocol. Simulation used here is NS2 (Network Simulator).Simulation results have been compared with various existing protocols like AODV and DSDV in terms of quality of service(QoS) parameters such as packet delivery ratio, delay and throughput.

TABLE III

SIMULATION PARAMETERS

Parameter	Value
Test Area	1500m X 1500m
Channel type	Wireless channel
Radio propagation	Two Ray Ground
Antenna type	Omni directional
Interface queue type	Drop tail with priority queue
Max.ifq length	50
Transmission range	250m
Number of nodes	20
Node separation	Half of radio range, vertically and horizontally
Transmission Bandwidth	1Mbps
MAC	IEEE 802.11 with RTS/CTS
Mobility Model	Random waypoint
Mobility Speed	0 – 10m/s
Mobility Pause Time	30s
Traffic Type	CBR, UDP
Packet size	512 bytes
Initial energy	100 Joules

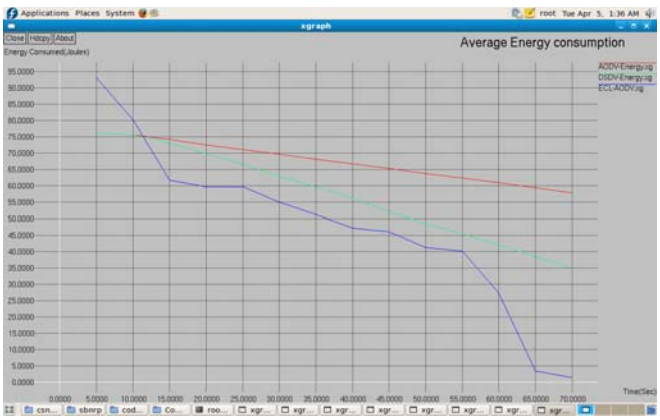

Fig 3 : Average Energy Consumption with Time

Average energy consumption with time is depicted in fig 3. It is seen from the figure that AODV consumes more energy for control packets transmission and data transmission more than DSDV. DSDV consumes more energy than ECL-AODV since DSDV sends route updates about all the nodes to their neighbors control packets and data transmission. DSDV consumes more energy for route updates either that are either partially or full updates. In contrast, ECL- AODV is able to use the limited battery power more effectively since it considers the node's minimum receiving power level also uses the high residual energy nodes for calculating the path between sender and receiver. It uses low level energy consumption for RTS/CTS mechanism. Thus energy consumption for ECL-AODV protocol is low than other two protocols.

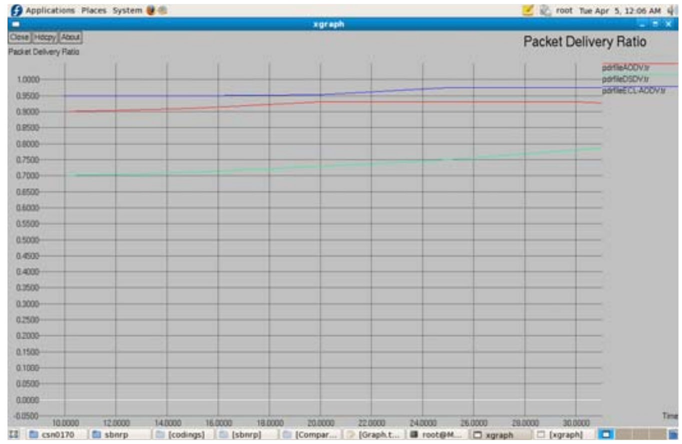

Fig 4 : Packet Delivery Ratio with Time

Packet delivery ratio with time is depicted in fig 4. Packet delivery ratio is the ratio between number of packets received and number of packets transmitted. This parameter finds the fraction of successful packet reception. In figure , the ratio of packet delivery in ECL-AODV becomes greater than in AODV and DSDV in dynamic environment. In the case of ECL-AODV, the ratio of packet delivery is high by maintaining a stable route by considering residual energy and receiving power taken from PHY and MAC layers. It reduces the rate of packet loss due to link break by choosing an alternate path according to residual energy and receiving power.

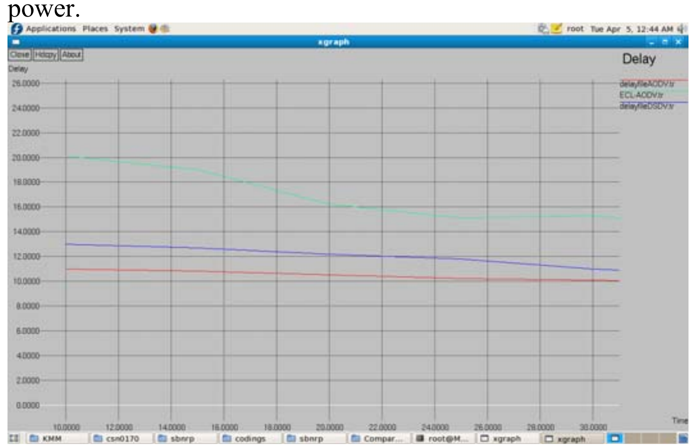

Figure 5 : End-to-End Delay with Time

End-to-End delay with time is depicted in fig 5. It is the delay experienced for successfully delivered packets in reaching their destinations. It includes the delays occur in route discovery and retransmission delay occur at MAC layer. In this scheme, the proposed protocol has higher delay than AODV and DSDV because AODV doesn't take energy constraint. ECL-AODV spends time to calculate a stable route using residual energy and minimum receiving energy. DSDV has lower delay than ECL-AODV and higher delay than AODV. DSDV works based on the full route updates, there is high delay in dynamically forming the route and transmission than AODV also it doesn't take energy as a constraint. So it has lower delay than proposed protocol.

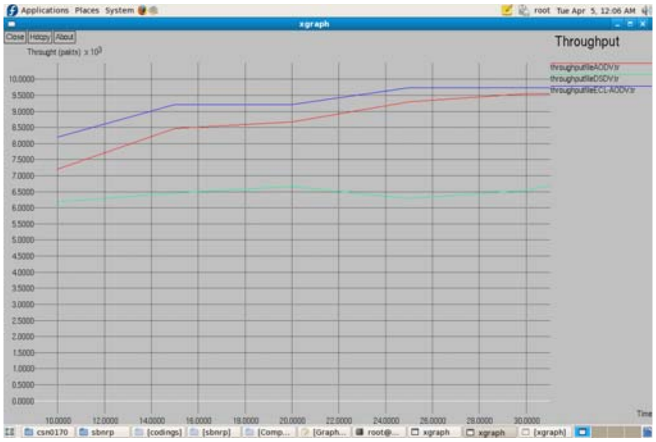

Figure 6 : Throughput with Time

Throughput with time is depicted in fig 6. It is defined as successful transmission of packets per second in the network. It is the total successful transmissions within the time period from simulation starts and ends. In this scheme, the proposed protocol achieves better throughput than other two protocols AODV and DSDV. AODV makes no such stable route like ECL-AODV. AODV experiences heavy packet loss due to inconvenience in stable route. So the source node retransmits data packets whenever there is no reply from other end. AODV suffers from high node mobility. Like AODV, DSDV also suffered by node mobility. If there is high mobility, DSDV achieves only 65% successful delivery of packets and AODv achieves 90% of successful packet delivery. But our proposed protocol ECL-AODV achieves 95% of successful packet delivery eventhough there is high mobility.

V CONCLUSION

In MANET, there were no such power conscious algorithm which rectifies all the problems of ad hoc network. In our proposed algorithm, we show that the remaining energy of the node is used to calculate the stable path. The residual energy is calculated from initial energy and spent energy at each stage. The power of RTS/CTS mechanisms are reduced to a desired level in accordance with minimum receiving power of the intermediate nodes. The receiving energy is kept to a minimum level using the receiver's sensitivity. In this protocol, RTS/CTS transmission occurs after the route discovery and route reply to reserve the selected path so that the energy of the ad hoc node can be saved. RTS/CTS transmission consumes low energy since this transmission occurs only in the selected path. The MAC layer and physical layer functions are crucial to make a dynamic routing protocol and perform QoS parameters comparison. Here average energy consumption, packet delivery ratio, end-to-end delay and throughput are plotted against time. In future, these parameters are to be addressed against high mobility using many mobility models. Our proposed ECL-AODV performs better than AODV and DSDV in all these parameters when the energy of mobile nodes depends on the transmission of RTS/CTS after route discovery and route reply also depends on minimum receiving energy based on the receiver sensitivity.

REFERENCES

[1] C. E. Perkins and P. Bhagwat, ."Highly dynamic destination sequenced distance-vector routing (DSDV) for mobile computers",*SIGCOMM '94: Proc. Conference on communications architectures,protocols and applications. New York, USA: ACM Press,* 1994, pp.234.244.

[2] C. Perkins, ".Ad-hoc on-demand distance vector routing", *MILCOM '97, Panel on Ad Hoc Networks*, 1997.

[3] D. Johnson and D. Maltz, ."Dynamic source routing in ad hoc wireless networks",. *Mobile Computing (ed. T. Imielinski and H. Korth), Kluwer Academic Publishers, Dordrecht, The Netherlands*, 1996.

[4] C. E. Perkins and E. M. Belding-Royer, ."Ad-hoc on-demand distance vector routing", *2nd Workshop on Mobile Computing Systems and Applications (WMCSA '99)*, 1999, New Orleans, USA, 1999, pp.90.100.

[5] C. E. Perkins, E. M. Royer, S. R. Das, and M. K. Marina. "Performance Comparison of Two On-demand Routing Protocols for Ad Hoc Networks". *IEEE Personal Communications*, 8(1):16–28, 2001.

[6] Kamrok Lee, Jae Young Choi, Wook Hyun Kwon, Hong Seong Park "An Energy-efficient Contention-based MAC Protocol for Wireless Ad Hoc Networks", *IEEE/ACM Transactions " on Networking, Volume: 12 ,Issue:3* ,pp 493 - 506 ,ISSN: 1063-6692, June 2004.

[7] Sylwia Romaszko and Chris Blondia "Cross Layer PHY-MAC Protocol forWireless Static and Mobile Ad Hoc Networks", *EURASIP Journal on Advances in Signal Processing Volume 2009, Article ID 278041*, 13 pages, doi:10.1155/2009/278041.

[8]Thriveni J, Anita Kanavalli, K R Venugopal, L M Patnaik "Probabilistic Mean Energy Flooding to Increase the Survivability of MANET" , *Proceedings of the International MultiConference of Engineers and Computer Scientists 2008 Vol II , IMECS 2008*, 19-21 March, 2008, Hong Kong

[9]Natarajan Meghanathan, "Exploring the Stability-Energy Consumption-Delay-Network Lifetime Tradeoff of Mobile Ad Hoc Network Routing Protocols", *Journal Of Networks, Vol. 3, No. 2*, February 2008.

[10]Geunhwi Lim Kwangwook Shin Seunghak Lee _ H. Yoon Joong Soo Ma "Link Stability and Route Lifetime in Ad-hoc Wireless Networks", *Proceedings of the International Conference on Parallel Processing Workshops (ICPPW'02).*

[11] Sunil Kumar , Vineet S. Raghavan , Jing Deng "Medium Access Control protocols for ad hoc wireless networks: a survey" , *Elsevier doi:10.1016/j.adhoc.2004.10.001 2004.*

[12] Hsiao-Hwa Chen, Zhengying Fan, and Jie Li "Autonomous Power Control MAC Protocol for Mobile Ad Hoc Networks" , *EURASIP Journal onWireless Communications and Networking Volume 2006, Article ID 36040*, Pages 1–10 , DOI 10.1155/WCN/2006/36040

[13] Rekha Patil , DrA.Damodaram "Cost Based Power Aware Cross Layer Routing Protocol For Manet", *IJCSNS International Journal of Computer Science and Network Security*, VOL.8 No.12, December 2008.

[14]Ivan Stojmenovic, Xu Lin " Power-Aware Localized Routing in Wireless Networks", *IEEE Transactions on Parallel and Distributed Systems, Vol.12*, No.10, October 2001.

[15]Morteza Maleki, Karthik Dantu, and Massoud Pedram "Power-aware Source Routing Protocol for Mobile Ad Hoc Networks" *ISLPED'02, August 12-14, 2002, Monterey, California, USA*.Copyright 2002 ACM 1-58113-475-4/02/0008.

[16]S.Gunasekaran and Dr.K.Duraiswamy " Multicast Multi-path Power Efficient Routing in Mobile AdHoc networks", *IJCSNS International Journal of Computer Science and Network Security, VOL.10 No.4,* April 2010.

[17]Chansu Yu, Ben Lee and Hee Yong Youn "Energy efficient routing protocols for mobile ad hoc networks" , *Wirel. Commun. Mob. Comput. 2003*; 3:959–973 (DOI: 10.1002/wcm.119)