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Energy Aware Cooperative Routing In Mobile Ad-Hoc Networks

H. Srikanth Kamath
Assistant Professor - Sl. Grade/Department of E & C
Manipal Institute of Technology, Manipal, India

Krishna Chaitanya Marri
Undergraduate Student/Department of E & C
Manipal Institute of Technology, Manipal, India

***Abstract*—A mobile wireless channel suffers from fading, meaning that the signal attenuation can vary significantly over the course of a given transmission. Spatial diversity is a technique used to combat fading, diversity is achieved by transmitting signals from different locations, thus allowing independently faded versions of the signal at the receiver. In wireless communication spatial diversity requires more than one antenna at the transmitter. However many wireless devices are limited by size and hardware complexity to one antenna. Recently cooperative communication has been proposed that enables single antenna mobiles in a multiuser environment to share their antennas and generate a virtual multiple-antenna transmitter that allows them to achieve spatial diversity. Cooperative communication generates this diversity by making use of the broadcast nature of the wireless environment. In this paper we have proposed a modified version of the AODV protocol for achieving cooperation in MANETs. We have further modified this protocol keeping energy efficiency in mind by making use of the concept of variable transmit power. We have also modified the data link layer protocol Automatic Repeat Request (ARQ) to work for cooperative networks.**

Index terms -MANETs, Cooperative communication, spatial diversity, AODV,Energy efficiency, variable transmit power,routing.

I. INTRODUCTION

Cooperative communication generates this diversity in a new and interesting way. The mobile wireless channel suffers fading, meaning the signal attenuation can vary significantly over the course of a given transmission. Transmitting independent copies of the signal generates diversity and can effectively combat the deleterious effects of fading. In particular spatial diversity is generated by transmitting signals from different locations, thus allowing independently faded versions of the signal at the receiver. Figure 1 shows a source communicating with the destination. Each mobile has one antenna and cannot individually generate spatial diversity. However it is possible for a mobile (relay) to hear the information being sent by the source and forward this information to the destination. Because the Source-Relay-Destination and Source-Destination fading paths are statistically independent, this generates spatial diversity. Thus the receiver gets several replicas of the same information via independent channels thereby combating the mitigating effects of fading in a wireless medium.

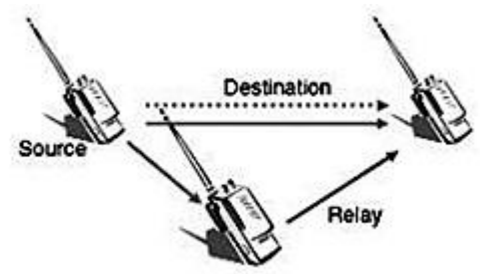


Figure 1. [1] Cooperative communication

II. RELATED WORK

Cooperative communication was first proposed by Nostratinia and Hedayat [2] as a way of achieving of transmit diversity for single antenna wireless devices.

Ahmed S. Ibrahim, Zhu Han and K. J. Ray Liu[3] have proposed a distributed energy efficient cooperative routing algorithm.

Scaglione, Goeckel and Laneman [1] have illustrated cooperative approaches for MANET's.

Liu and Zhang [4] proposed a cooperative algorithm based on symmetric link selection for improving the packet delivery ratio.

Anker, Doleva and Hod [5] have shown the various aspects of cooperation enforcement and reliability with AODV as the underlying protocol.

Dehghan, Ghaderi and Goeckel [6] have shown the throughput and energy performance of cooperative routing in wireless networks that support cooperative beamforming at the physical layer.

Fang, Hui, Ping and Ning [7] show the effect of cooperative nodes selection strategies on total energy consumption.

III. ROUTING IN MANET'S

A. Mobile Ad-hoc Networks

A mobile ad-hoc network (MANET) is a collection of nodes, which have the possibility to connect on a wireless medium and form an arbitrary and dynamic network with wireless links. That means that links between the nodes can change during time, new nodes can join the network, and other nodes can leave it.Thus, each node operates as both a host as well as a router, forwarding packets for other mobile nodes.

B. Classification of Routing Protocols

The routing protocols can be classified as Proactive (Table Driven), Reactive (on-demand) and Hybrid depending on the network structure.

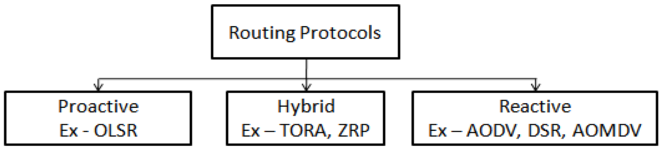


Figure 2. Classification of routing protocols

Reactive protocols are also called as on demand driven reactive protocols. They are mainly used to find the route between source and destination as needed, as per the demand of the source.In proactive protocols each node maintains routing tables which are consistent and up-to-date containing routing information for every node in the network. Whenever a new node is entered in the network or removes from the network, control messages are sent to neighbouring nodes and then they update their routing tables.Hybrid routing protocol have advantages of both proactive and reactive routing protocols.

Proactive protocols have the advantage of providing lower latency in data delivery and the possibility of supporting applications that have quality-of-service constraints. Their main disadvantage is due to the wastage of bandwidth in sending update packets periodically even when they are not necessary, such as when there are no link breakages or when only a few routes are needed. Reactive routing finds the route between source and destination only when there is a demandfor it. The advantage of this on-demand operation is that it usually has a much lower average routing overhead in comparison to proactive protocols. However, it has the disadvantage that a route discovery may involve flooding the entire network with query packets. This route discovery adds to the latency in packet delivery as the source has to wait till the route is determined before it can transmit. Despite these drawbacks, on-demand protocols receive comparatively moreattention than proactive routing protocols, as the bandwidth advantage makes them more scalable. Reactive protocols are also more energy efficient than proactive protocols becauseof the on demand operation.

B. Ad Hoc on Demand Distance Vector Routing (AODV)

The ad hoc on-demand distance-vector (AODV) routing protocol is an on-demand routing protocol [8]. All routes are discovered only when needed, and are maintained only as long as they are being used. Routes are discovered through a route discovery cycle, whereby the network nodes are queried in search of a route to the destination node. When a node with a route to the destination is discovered, that route is reported back to the source node that requested the route.

Route discovery:

When a source node has data packets to send to some destination, it checks its routing table to determine whether it already has a route to that destination. If so, it can then utilize that route to transmit the data packets. Otherwise, the node must perform a route discovery procedure to determine a route to the destination. To initiate route discovery, the source node creates a Route Request (RREQ) packet. In that packet the node places the IP address of the destination, the last known sequence number for the destination, its own IP address, its current sequence number, and a hop count that is initialized to zero. If there is no last known sequence number for the destination, it sets this value to zero. The source then broadcasts the RREQ to its neighbours. When a neighbouring node, or any other more distant node, receives the RREQ, it first increments the hop count value in the RREQ and creates a reverse route entry in its routing table for both the source node and the node from which it received the request. In this way, if the node later receives a RREP to forward to the source, it will know a path to the source along which it can forward the RREP. After creating this entry, the node then determines its response to the request. The node can send a reply to the request if it either is the destination, or has a current route to the destination. A current route is an unexpired route entry for the destination whose sequence number is at least as great as that contained in the RREQ. If this condition holds, the node creates a Route Reply (RREP) for the destination node. Otherwise, if the node does not have a current route to the destination, it simply rebroadcasts the RREQ to its neighbours.

Route maintenance:

In an ad hoc network, links are likely to break due to the mobility of the nodes and the ephemeral nature of the wireless channel. Hence, there must be a mechanism in place to repair routes when links within active routes break. An active route is defined to be a route that has recently been utilized for the transmission of data packets. When such a link break occurs, the node upstream of the break (i.e., the node closer to the source node), invalidates in its routing table all destinations that become unreachable due to the loss of the link. It then creates a Route Error (RERR) message, in which it lists each of these lost destinations. The node sends the RERR upstream towards the source node. If there are multiple previous hops that were utilizing this link, the node broadcasts the RERR; otherwise, it is unicast. In figure 3, the link between nodes 4 and 5 on the path from 1 to 5 is broken. Node 4 invalidates its route table entries for nodes 5, creates a RERR message, and sends it upstream towards the source.

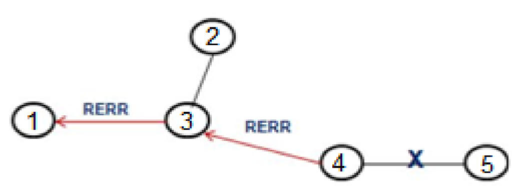


Figure 3. Route maintenance

IV. Cooperative Routing in MANET's

In this section we propose a modified version of the AODV protocol which we call Cooperative AODV (Coop AODV). In this protocol route discovery and route maintenance is done just as in AODV. The only difference arises when the packets have to be routed once the route is established. Consider the network as shown in figure 4. Node 1 wants to send data packets to node 9.

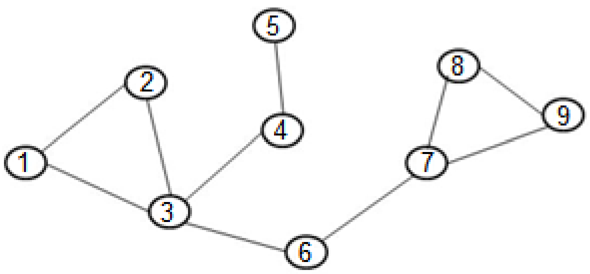


Figure 4. Ad-hoc Network

Figure 5 shows the route established by route discovery. The packets from node 1 take this route to reach node 9 in AODV.

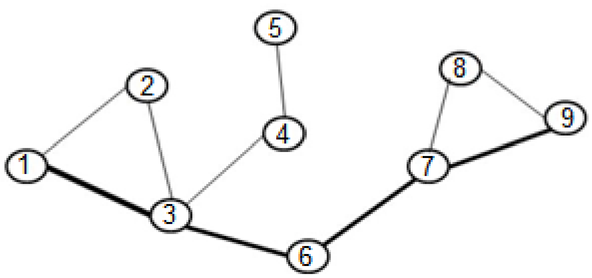


Figure5. AODV route

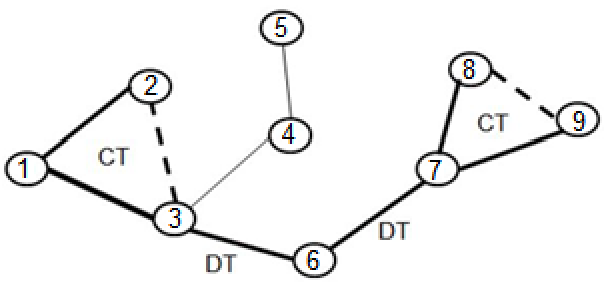


Figure 6. Cooperative AODV route

Figure 6 shows the route packets take in Coop AODV.The route is composed of direct transmission (DT) and cooperative transmission (CT) blocks. Wherever possible the protocol goes for cooperative transmission. The protocol makes use of the wireless broadcast advantage. That means that when node 1 is transmitting to node 3, node 2 can also hear the transmission. No extra power is required to transmit to node 2 which behaves as a relay node. For example in figure 6, in the first CT block node 1 (source) needs to send the packet only to node 3 (destination) but node 2 (relay) can also hear the transmission from node 1 because node 2 and node 1 are neighbors. So node 1 broadcasts the packet to both node 2 and node 3. Node 2 will store this packet and will only send it to node 3 when the initial transmission from node 1 to node 3 fails. This mechanism is taken care of in the data link layer protocol which we describe later. For the cooperative transmission to work the relay and destination nodes must both be neighbors as in the case of node 2 and node 3.When a relay is not available the protocol goes for direct transmission.

A.Cooperative AODV algorithm

This algorithm will run once the route is established through route discovery, or if a route is already available.

Assumptions:
Each node is aware of its neighbours through the periodic broadcast of hello packets and is also aware of the neighbours of its neighbours which is also communicated through hello packets.

Consider a node 'x' which has to send a data packet to some destination node. Here node 'x' can be the source of the data packets or it can be one of the intermediate nodes between the source and destination nodes. Node 'z' is the next hop the data packet will make from node 'x' on the way to the destination node.
Let N(x) be the set of neighbours of x.
The following algorithm details how node 'x' will choose a relay to aid in its communication with node 'z'. This relay will be called node 'y'.

Algorithm to find relay y:

1. Start
2. Set flag=0
3. For each neighbour p∈ N(x), p!=z of node x
4. {
5. For each neighbour q∈ N(p) of node p
6. {
7. If (q==z)
8. {
9. set flag =1
10. y=q
11. break loop
12. }
13. }
14. If(flag==1) break loop
15. }
16. If (flag==1) broadcast the packet to z and y //cooperative transmission
17. Else send the packet to z //direct transmission
18. End

In the above algorithm we have assigned the first available node which is neighbour of both the source and destination as the relay. It may be possible that there is more than one such node but we are only choosing the one which comes first in the flow of the algorithm.

B. Energy Aware Cooperative Routing

Here we propose an energy aware cooperative routing protocol which we call Energy Efficient with 2 levels of transmit power Cooperative AODV (EE2 Coop AODV). This protocol is a modification of Coop AODV. While Coop AODV chooses any random relay EE2 Coop AODV chooses a relay more wisely keeping energy efficiency in mind.In designing this protocol we have made the same assumptions that we have made in Coop AODV, in addition to that we have assumed the nodes to be capable of transmitting with variable power.

The concept of variable transmit power is not new it has been implemented in some protocols. Raghavendra and Vasundara [9] have proposed the PAMEERR algorithm which varies the transmission power of the packet in accordance with the distance of the destination node from the transmitting node. Gomez and Campbell [10] show that variable range transmission approach can outperform common range transmission approach in terms of power savings and increased capacity. Huang, Huand Yu [11] have proposed a cross layer power control protocol based on AODV. Ren, Feng, Hu and Cai [12] have proposed an Energy Saving AODV protocol that gets started at the route discovery stage itself. The effectiveness of power control in AODV in terms of energy saving has been shown [13]. The performance comparison of AODV and DSR with power control was also done [14]. Shi Liu [15] have proposed a power efficient location based cooperative routing algorithm which selects the optimum next hop node and relay based on minimum power.

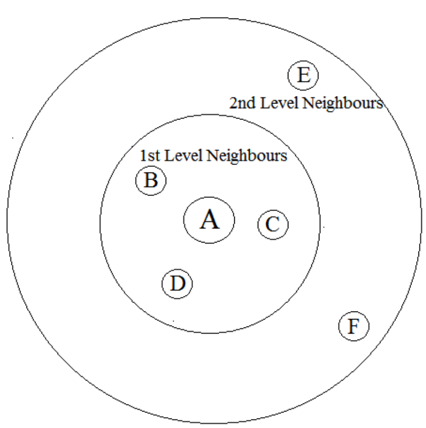


Figure 7. Various levels of neighbours

This protocol which we propose requires a node to be able to transmit at two discrete levels of power namely full power and half power.Consider a node capable of transmitting at P and P/2 levels of power with P being its maximum transmit power. In figure 7, the node A can reach all of its neighbours with its full transmit power. But at half transmit power because of free space attenuation it can reach only few of its neighbours.The set of nodes that can be reached with half transmit power are called its 1^{st} level neighbours. The rest of the neighbours other than the 1^{st} level ones are called 2^{nd} level neighbours. Every node maintains a list of these neighbours.

The following lines detail the basic algorithm behind relay selection.If the next hop belongs to the 1^{st} level of neighbours then a relay will be chosen only from this set itself so that the node can transmit at half power and reach both the relay and next hop. If a relay were to be chosen from 2^{nd} level of neighbours then there would be unnecessary wastage of energy as the node would have to transmit at full power to reach both the relay and next hop.If the next hop belongs to the 2^{nd} level of neighbours then a relay can be chosen from any level as the node has to any way transmit at full power to reach the next hop.

Once we have established from which level of neighbours to choose the relay, we further discriminate among the relays by examining whether the next hop belongs to the 1^{st} or 2^{nd} level of neighbours of the relay. Preference will be given to that relay which has the next hop as its 1^{st} level neighbour. If no such relay is available then we move on to the relay which has the next hop as its 2nd level neighbour.

This algorithm will run once the route is established through route discovery, or if a route is already available.Let N(x) be the set of neighbours of x. Then N1(x) and N2(x) will be the set of the 1^{st} and 2^{nd} level neighbours of ‘x’ respectively.The following algorithm details how node ‘x’ will choose a relay to aid in its communication with node ‘z’. This relay will be called node ‘y’.

Algorithm to find relay y:

```
Start
set flag=0
if(z∈N1(x))
{   for each neighbor p∈N(x), p!=z  of node x
        {
            if(z∈N1(p))
              {   for each neighbour q∈N1(p) of node p
                      {
                          if(q==z)
                            { set flag =1
                              set y=q
                              break loop
                            }
                      } If (flag==1) break loop
        }    }
     if(flag==0)
        { for each neighbor p∈N(x), p!=z  of node x
             if(z∈N1(p))
              {    for each neighbour q∈N2(p) of node p
                      {
                          if(q==z)
                            { set flag =1
```

```
23.                         set y=q
24.                         break loop
25.                       }
26.                  } If (flag==1) break loop
27. }     }    }
28. if(z∈N2(x))
29. {   for each neighbor p∈N(x), p!=z  of node x
30.      {
31.           {   for each neighbour q∈N1(p) of node p
32.                  {
33.                     if(q==z)
34.                       { set flag =1
35.                         set y=q
36.                         break loop
37.                       }
38.                   } If (flag==1) break loop
39.      }    }
40.    if(flag==0)
41.      { for each neighbor p∈N(x), p!=z  of node x
42.           if(z∈N1(p))
43.            {    for each neighbour q∈N2(p) of node p
44.                  {
45.                     if(q==z)
46.                       { set flag =1
47.                         set y=q
48.                         break loop
49.                       }
50.                  } If (flag==1) break loop
51. }     }    }
52. if (flag==1) broadcast the packet to z and y
    //cooperative transmission
53. else  send the packet to z      //direct transmission
54. End
```

V. Cooperative Data Link Layer Protocol

In this section we describe the protocol that needs to be used in the data link layer to support reliable cooperative communication which is initiated in the network layer. We have proposed a modified version of the automatic Repeat Request (ARQ) protocol for implementation in the data link layer for a cooperative network. This modified version of ARQ will be used whenever a cooperative transmission occurs, for direct transmission the general ARQ can be used.

The transmitter (TX) makes use of the wireless broadcast advantage, that is the packet sent by the transmitter is heard by the relay (R) and receiver (RX) both. When the packet sent by transmitter is successfully received by the receiver it sends back an acknowledgement (ACK) to both the relay and transmitter.

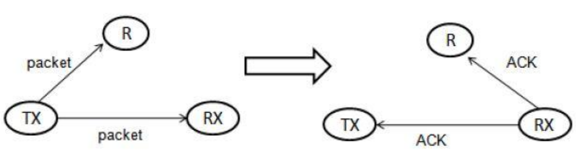


Figure8. Cooperative ARQ

When the packet from the transmitter does not reach the receiver due to fading, the transmitter waits for a time out after which it sends a cooperative relay negative acknowledgement (CRNACK) to the relay. The relay responds by sending the stored packet to the transmitter. The receiver then sends an acknowledgement to the relay which in turn forwards it to the transmitter

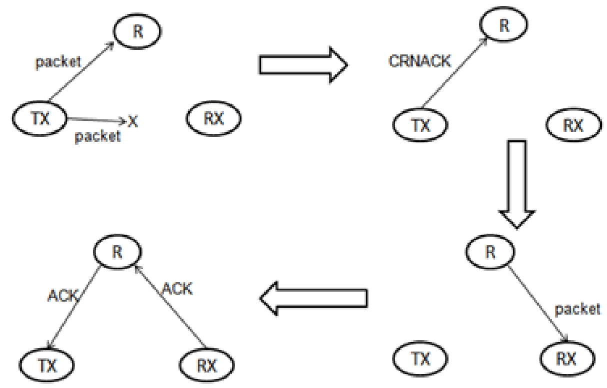


Figure 9. Cooperative ARQ with fading

When the initial transmission fails it means the path between TX and RX is in deep fade, this is the reason why the TX-R-RX path is used for the communication process. When both the paths are in deep fade, that is when there is no response from the relay even after sending the CRNACK, then the TX waits for a time out and repeats the whole process again by re-broadcasting the packet to both the receiver and relay.

VI. Simulation Results

In this section we present the results of our simulations on the proposed protocols. We have used MATLAB to carry out simulation of these protocols.

Table 1. Protocol Stack

Layer	*Description*
Application Layer	CBR
Transport Layer	UDP
Network Layer	AODV, Coop AODV,EE2 Coop AODV
Data Link Layer	Cooperative ARQ
Physical Layer	Rayleigh Fading wireless channel

Table 2. Simulation parameters

Parameter	*Description*
Simulator	MATLAB
Antenna type	Omni-directional
Simulation area	800 x 300
Number of nodes	25

All the nodes have fixed transmit power. Hence the packets take multiple hops from the source node to reach the destination node. All the on demand activities characteristic of AODV have been simulated in MATLAB. The only restriction is that there can be only be a single pair of source and destination nodes per simulation.We first show the network on which the protocol has been simulated, along with the route taken by the data packets for each protocol.

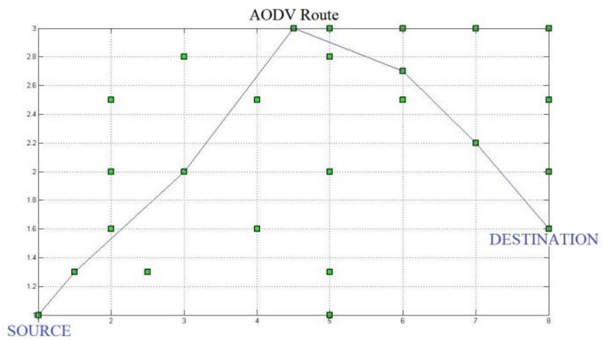
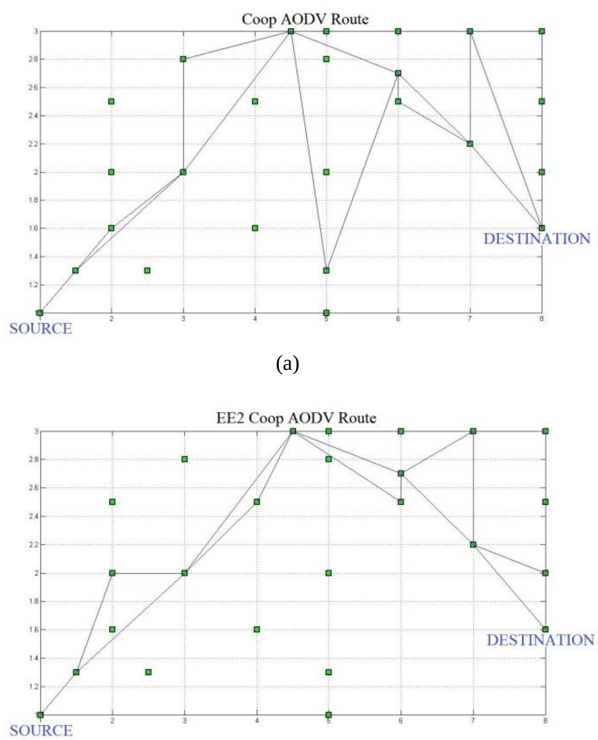


Figure 10. AODV route

Figure 10 shows the route taken by AODV to reach the destination node from the source.As can be seen from the below figures we can make out the difference in routes between the protocols. The triangular blocks are the cooperative transmission blocks.



(a)

(b)

Figure 11.Cooperative routes (a) Coop AODV (b) EE2 Coop AODV

The plots below show the throughput and energy consumed against the specified number of packets sent from source towards destination.The number packets vary from 10 to 100 in increments of 10.

The throughput has been expressed as a percentage as shown below. EE2 Coop AODV and Coop AODV perform much better than AODV. Coop AODV performs slightly better than EE2 Coop AODV.

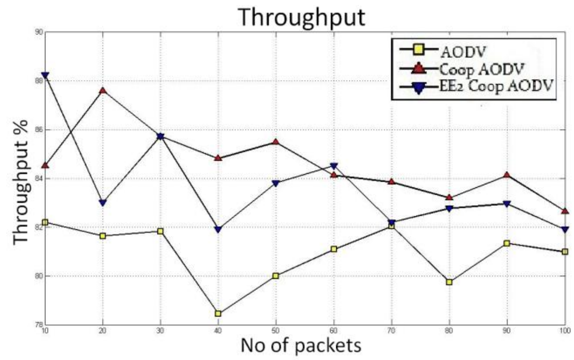


Figure 12. Throughput

The energy has been calculated in a crude way by considering the number of packet transmissions and assigning weights to different packet sizes. The packet with a larger size has a higher weight because more energy would be required to transmit it than a packet with a lesser size. The energy in the plot is not the actual energy. The calculation of actual energy will require a proportionality factor that depends on the node transmit power.Energy consumption of EE2 Coop AODV is lower than AODV and Coop AODV.

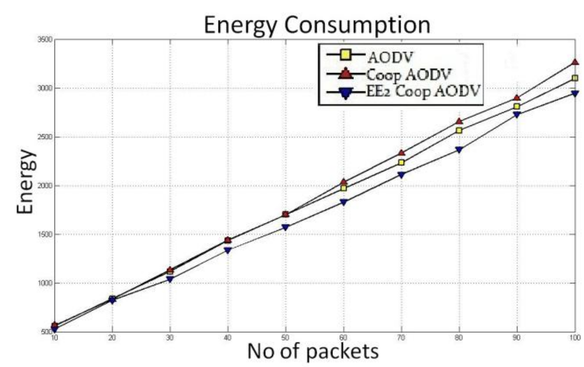


Figure 13. Energy Consumption

VII. CONCLUSION

In this paper we have proposed a simple cooperative routing algorithm which is modified version of the AODV routing protocol. This algorithm was further modified keeping energy efficiency in mind. We have also proposed a data link layer protocol which supports the cooperative communication which is initiated in the network layer.From the simulations we have determined that Coop AODV gives better throughput than AODV but consumes more energy than AODV. The throughput of EE2 Coop AODV is on par with Coop AODV at the same time it has the least energy consumption of all three. Therefore we conclude that EE2 Coop AODV is an optimum protocol for cooperative routing.

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Authors Profile

H. Srikanth Kamath received the **B.E.** degree in electronics and communication engineering from M. S. Ramaiah Institute of Technology, Bangalore University, Bengaluru, India, in 1992. He received his **M.Tech**in electronics and communication engineering (Communication Systems) fromMalnad College of Engineering, Mysore University, Hasan, India. His research interest includes Wireless Communication,Wireless Networks and Computer Networks.

Krishna Chaitanya Marriis a final year undergraduate student pursuing his **B.E.** in electronics and communication engineering at Manipal Institute of Technology, Manipal, India. His areas of interest include Computer Networks, Wireless Networks and Neural Networks.