

EAGR: Energy Aware Greedy Routing Scheme for Wireless Ad hoc Networks

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Abstract

This paper presents Energy Aware Greedy Routing (EAGR) scheme for wireless ad hoc networks. In this scheme, the cost metric of a node depends on the following parameters of a neighboring node: (1) Distance from the destination, (2) Fraction of energy consumed, and (3) Rate of energy consumption. When a node has the least cost metric, the packet is forwarded to that node. We evaluate the performance of EAGR in static wireless ad hoc networks by replacing the greedy routing of Greedy Perimeter Stateless Routing (GPSR) protocol with EAGR. Evaluation and comparison of GPSR with EAGR and GPSR (with greedy routing) is done through NS simulation. Results show that GPSR with EAGR outperforms the existing GPSR (with greedy routing) with respect to packet delivery fraction, throughput and energy consumption.

Keywords: Rate of Energy Consumption, Greedy Routing, Wireless Ad hoc Networks

1.. INTRODUCTION

A Wireless Ad hoc Network is an autonomous collection of geographically distributed nodes that communicate over a wireless link. In this paper we present a scalable, Energy Aware Greedy Routing (EAGR) scheme for wireless ad hoc networks. Scalable means protocol performs well in large networks. It has been experimentally [2,3] confirmed that geographical routing protocols are more scalable than Dynamic Source Routing (DSR), Destination Sequence Distance Vector (DSDV), and Ad hoc On Demand Distance Vector (AODV) routing protocols [9]. Moreover, routing decisions in geographical routing algorithms depend upon local decisions. So, there is no need to maintain large enough routing table as in well known link state [10] or distance vector routing schemes [11].

Wireless nodes in ad hoc networks are usually powered by batteries, which provide a limited amount of energy. Therefore, techniques to reduce energy consumption are of considerable interest. If the routing decision depends on a single parameter only, then both scalability and reduction in energy consumption cannot be achieved. In this paper,

we present a routing scheme for wireless ad hoc networks, where a routing decision depends on following parameters of a neighbor node: (1) distance from destination, (2) fraction of energy consumed, and (3) rate of energy consumption. Moreover, a node bases its routing decision on information from its direct neighbors only. So, like other geographical routing algorithm, one of the advantages of the proposed scheme is that a node need not maintain routing entry of every other node in networks.

We evaluate the performance of EAGR by replacing greedy routing scheme of Greedy Perimeter Stateless Routing (GPSR) [1] in static wireless ad hoc networks. GPSR uses greedy routing decision for forwarding the packet and when a packet reaches a region, where greedy routing is not possible, the algorithm recovers by routing around the perimeter of the region. Simulations show that GPSR with EAGR gives higher packet delivery fraction, more throughput and less energy consumption than existing GPSR with greedy routing.

Accurate information of the position of a node is very important for any geographical routing algorithm including the proposed EAGR algorithm. We assume that nodes are able to determine their position with the help of a positioning technique like Global Positioning System (GPS), Ad hoc Positioning System (APS) [15], APS with Angle of Arrival (AOA) [16], Cricket Positioning System [17]. The task of finding the position of destination, which is included in packet header for geographical routing, can be accomplished by location services e.g. Distance Routing Effect Algorithm for Mobility (DREAM), Hierarchical Location Service (HLS) [3], Grid Location Service (GLS) [18] etc.

The remainder of the paper is organized as follows. Section 2 presents the previous work. Section 3 describes advantage of the proposed EAGR scheme over greedy routing scheme. Section 4 describes methodology of the proposed EAGR routing scheme. Section 5 presents simulation environment and metrics used. Finally, section 6 presents analysis of results and conclusions.

2.. PREVIOUS RELATED WORK

This section describes an overview of the previous related work.

A. Greedy Routing and GPSR

In greedy routing [1,2,3], a node announces its presence and position to its neighbors (other nodes within radio range) by broadcasting periodic HELLO packets. Each node maintains the table of its direct neighbors that contains ID (Unique identification number of node to identify each node) and geographical positions of neighbor nodes. Each time a node receives a HELLO packet, it updates the information about that neighbor, if neighbor ID is already present in the table; or adds a neighbor information, if it is a new neighbor. The header of the packet destined to a particular node contains the destination ID as well as its geographical position. When a node (say A) needs to forward a packet to destination (say B), it consults its neighbor table and forwards the packet to the neighbor which is closest to B. Only the neighbors closer to destination are considered; otherwise, the greedy routing fails. Here, all the neighbor nodes are closer to node A, and not to node B. This indicates that there is a hole in the geographical distribution of nodes.

Recovering from dead-ends is possible from the same neighbor table used in greedy routing. Karp and Kung proposed GPSR [1], a geographic routing protocol that uses a planar subgraph of the wireless networks graph to route around holes. GPSR uses the greedy routing as soon as it recovers from dead-ends.

B. Energy Aware Routing

Present focus of researchers, is to develop a routing protocol which reduces the energy consumption of communication subsystem and increases the life of nodes. These researchers believe that energy efficient routing decision is more important than simple shortest path routing. Therefore, many protocols have already been proposed with the aim to reduce energy consumption of the node. Power aware routing [6] suggests the use of different energy aware metrics when determining a routing path. The Localized Energy Aware Routing (LEAR) protocol [7] has been proposed whose direct aim is to control the energy consumption. This protocol is based on DSR protocol, where the route discovery requires flooding of route request messages. When a routing path is searched, node relies on local information on its remaining power level to decide whether or not to participate in the selection process of a routing path. Upon receiving a route-request message, each node has the choice to determine whether or not to accept and forward the route request message. When the remaining power level of the node is higher than a threshold

value, the route request message is forwarded; otherwise, the message is dropped. Span protocol [8], which works above link and Media Access Control (MAC) layer, and interacts with the routing protocol, allows most of the nodes to enter into a power saving sleep mode without significantly diminishing the capacity or connectivity of the networks. Energy consumption speed-based routing [4] has been proposed that integrate expected residual life time of node in basic AODV protocol. In the multi-cost routing protocol [5], each link in the network is assigned a cost vector that consists of several cost parameters. This multi-cost uses three metrics of the path: (1) number of hops, (2) minimum remaining energy left on nodes and (3) maximum or sum of transmission powers of path nodes. EAGR [14] for sensor networks has been proposed where packet is forwarded to the neighbor which is alive i.e. having energy level above than threshold and has distance equal to or less than the average distance of all its neighbor and among those neighbors having maximum energy level.

In this paper, we propose a multi-cost routing protocol where we have integrated greedy routing with energy efficient parameters. We calculate an estimate which depends upon distance of neighbor node to destination and energy efficient parameters.

3.. DEFICIENCIES OF EXISTING GREEDY ROUTING

Routes in the greedy routing protocol are based on a single metric i.e. minimum distance from destination. It has a drawback that usually only one path for each source-destination pair is selected. This consideration of single metric (distance from destination) might have a bad effect when nodes in a communication network have limited energy. Same group of nodes might be chosen repetitively for routing the packet to the same source and destination. Now, if the node that participates in this route establishment has very low energy, the path using same group of node will break down soon. Moreover, this can also have a bad effect on network connectivity because some of the nodes will be dead faster than others. Those dead nodes may be backbone of the communication networks i.e., there may be some of the nodes in networks which depend on only these dead nodes for routing the packet. This effect is more visible in limited energy static networks.

Therefore, to address above problems, we propose an energy aware greedy routing scheme. Here, our aim is to discover a path which forwards the packet with more reliability, less energy consumption, balanced delay, balanced overhead, and increased throughput.

4.. METHODOLOGY OF EAGR SCHEME

Keeping in mind the different problems and constraints described in the last section, we propose energy aware greedy routing scheme for wireless ad hoc networks. First we describe different parameters used in the scheme which is followed with the EAGR algorithm.

A. Rate of Energy Consumption

Rate of energy consumption is the energy consumption per unit time. It is calculated after each HELLO period, H_p .

Each node keeps the track of number of HELLO periods occurred. We now calculate the rate of energy consumption of a node at the start of n^{th} periodic interval. Let E_{i0} be the energy at the start of the n^{th} periodic interval and E_{in} be the initial energy of the node i . Energy consumption of the node i till the start of n^{th} periodic interval is given by $(E_{i0} - E_{in})$. Number of periodic intervals that elapsed till the start of n^{th} periodic interval is $(n - 1)$. Therefore, total time elapsed is $(n - 1) \times H_p$. Thus, the rate of energy consumption after n^{th} periodic interval, R_{in} , is given by equation (1).

$$R_{in} = \frac{E_{i0} - E_{in}}{(n - 1) \times H_p} \quad (1)$$

B. Fraction of Energy Consumption

Fraction of energy consumption is defined as the total energy consumption per unit initial energy of node. Like rate of energy consumption, fraction of energy consumption is also calculated after each H_p .

It is assumed in the proposed scheme that for n^{th} periodic interval, value of fraction of energy consumed is F_{in} till the start of $(n + 1)^{th}$ periodic interval. Fraction of energy consumption of node i , F_{in} , is calculated using equation (2).

$$F_{in} = \frac{E_{i0} - E_{in}}{E_{i0}} \quad (2)$$

C. Cost Computation Parameter

When node A needs to forward the packet to node B , and the distance of node A to node B is D and distance of its neighbors (which are in the radio range of A) to B is $d_1, d_2, d_3, \dots, d_k$, then reasonable fairness of energy at nodes can be achieved if the packet is forwarded to the node, which has least fraction of energy consumption (F_{in}). Further, reasonable fairness of number of hops traveled can also be achieved if the packet is forwarded to the node which is at the minimum distance from the destination.

The value F_{in} is always less than or equal to 1 and for $d_i < D$, the value of $\frac{d_i}{D}$ is less than 1. Thus for the above

condition, fractions F_{in} and $\frac{d_i}{D}$ can be added for the equal fairness of fraction of energy consumed or number of hops traveled.

We aim at a scheme so that a packet should be forwarded to a node which also has minimum rate of energy consumption.

We propose the cost metric as

$$C_{in} = R_{in} \times \left(\frac{d_i}{D} + F_{in} \right) \quad (3)$$

D. Overview of Proposed EAGR Scheme

The header of the packet destined to B contains the B 's ID as well as its geographical position. In EAGR, node A confirms from its neighbor table that whether B belongs to its neighbor or not. If it belongs then it forwards the packet directly to B . If it does not belong to its neighbors then for those neighbors, which are in radio range of A and whose $d_i < D$, it calculates the C_{in} . The packet is forwarded to the node whichever has least value of C_{in} .

But if more than one node have zero value of rate of energy consumption (R_{in}) then more than one node are eligible for the next hop. Under this condition, node A forwards the packet to the least d_i neighbor node among the neighbors that contain zero value of rate of energy consumption (R_{in}).

E. Algorithmic Approach of EAGR

EAGR algorithm requires each node i to advertise its location (i_x, i_y, i_z) , fraction of energy consumption (F_{in}) and rate of energy consumption (R_{in}). We fill all this information in EAGR HELLO packet. See Table 1 for EAGR HELLO packet information.

TABLE I. HELLO packet for EAGR. First two fields are greedy routing HELLO information.

Node ID
Node Location (i_x, i_y, i_z)
Fraction of Energy Consumption (F_i)
Rate of Energy Consumption (R_i)

Each node broadcasts HELLO packets to all its neighbors that are in its communication range. And also, each node in EAGR maintains the table of its direct neighbors. Each row of the table contains following information of a neighbor node: (1) Identification number (ID), (2) Geographical location, (3) Fraction of energy consumption and (4) Rate of energy consumption. When a node receives the HELLO packet, it updates the information of the neighbor if neighbor ID is already present in table, or adds a neighbor information, if it is a new neighbor.

EAGR algorithm is given below:

EAGR Algorithm

```

1.  next_hop = -1
2.  counter = true
3.  D = distance from ( $my_X, my_Y, my_Z$ ) to ( $B_X, B_Y, B_Z$ )
4.  for each row of neighbor table {
5.    if row.NodeID equals B.NodeID {
6.      return B.NodeID
7.    }
8.     $d_i$  = distance from ( $row.X, row.Y, row.Z$ ) to ( $B_X, B_Y, B_Z$ ) (equation (4))
9.    if  $d_i < D$  {
10.     if  $row.R_{in}$  equals 0 {
11.       keep the row entry of table in Record
12.     }
13.     if counter equals true {
14.       leastCompuParameter =  $C_{in}$  from (equation (3))
15.       next_hop = row.NodeID
16.       counter = false
17.       continue
18.     }
19.     CompuParameter =  $C_{in}$  from (equation (3))
20.     if CompuParameter < leastCompuParameter {
21.       next_hop = row.NodeID
22.       leastCompuParameter = CompuParameter
23.     }
24.   }
25. }
26. if Record.size() > 1 {
27.   next_hop = ID from the Record which is at a least distance from Destination.
28. }
29. return next_hop

```

Let (my_X, my_Y, my_Z) be the location of node A and (B_X, B_Y, B_Z) be the location of node B. Distance between two points, say, between A and B, can be calculated by equation (4).

$$\sqrt{(my_X - B_X)^2 + (my_Y - B_Y)^2 + (my_Z - B_Z)^2} \quad (4)$$

When packet destined to node B reaches node A, node A consults each and every row of neighbor table [line 4 of EAGR algorithm] for forwarding the packet to the next hop. First, it checks in each row that ID of node in row is equal to B's ID or not [line 5 of EAGR algorithm]. If it is equal then EAGR returns with B's ID [line 6 of EAGR

algorithm] and packet is forwarded to node B directly. Else it calculates the distance of node i (d_i) from the destination B [line 8 of EAGR algorithm]. After that it checks whether d_i is less than D (node A distance from B) [line 9 of EAGR algorithm]. If it is less than D then EAGR checks whether value of rate of energy consumption (R_{in}) present in row is zero or not [line 10 of EAGR algorithm]. If its value is zero, then it keeps the data of this row [line 11 of EAGR algorithm] in variable Record. Lines 13 to 23 in EAGR algorithm are used to find the neighbor which has least value of cost computation parameter (C_{in}). This is checked for each row of the table.

Now, if the node finds that the size of variable Record is greater than 1 [line 26 of EAGR algorithm] i.e. there exists more than one node whose value of rate of energy consumption is zero. Then, it assigns the node ID from the record which is at a least distance from B, to next_hop [line 27 of EAGR algorithm].

Line 29 returns the ID of the node where the packet is to be forwarded.

EAGR algorithm fails when value returned by the above algorithm is -1. This is a case when A's all neighbor's distance from B is more than A's distance from B (Similar to greedy routing). Like greedy routing, at this point node A thinks that there is a hole in the geographical distribution of nodes.

In the implementation of EAGR, we recover from this situation by applying Karp and Kung's solution (GPSR) [1] that uses a planar subgraph of the wireless networks graph to route around holes.

5.. SIMULATION ENVIRONMENT AND METRICS

This section describes the simulation environment and metrics. We calculate the performance of EAGR by replacing greedy routing of GPSR with the EAGR scheme. NS-2 network simulator environment [13] is used for the simulations.

A. Simulation Environment

We simulated GPSR by using Ke Liu's NS code of GPSR (provided on his website [12]). We modified greedy routing (C++ code) of GPSR for the implementation of the proposed EAGR scheme. Simulation environment used is for static wireless ad hoc networks.

To compare the performance of GPSR with EAGR and existing GPSR (with greedy routing), we simulate 100 node networks in the square region of $200 \times 200 m^2$. The

position of 100 nodes are chosen uniformly at random from $0 \times 0 \text{ m}^2$ to $180 \times 180 \text{ m}^2$. Nodes are static and IEEE 802.11 is used as the MAC layer protocol. The maximum communication radius is fixed to 40 meters. Simulations last 250 seconds, where CBR traffic flows from 10 seconds to 200 seconds. Total of 3 CBR connections are taken to forward the packet from source to destination. Source and destination nodes are situated at the left or right end of area i.e if the source is at left end then destination is at right end and vice versa. Nodes forward the CBR flow to another node, and each CBR flow sends packets of 128 byte length. To obtain the performance of EAGR, very small energy is given to the nodes of network scenarios. The energy given is 2.0 joules.

To obtain the performance of EAGR, we vary the packet sent interval from 0.33 seconds to 2.64 seconds. Packet sent interval of 0.33 seconds implies that about 3 packets are sent per second.

B. Simulation Metrics

We analyze several Quality of Service (QoS) metrics to evaluate the performance of our approach. The following metrics are obtained:

- 1) **Packet Delivery Fraction:** It is measured as the ratio of the number of packets delivered to destination and the number of packets sent by source.
- 2) **Average Throughput:** It is measured as bytes received by destination per second.
- 3) **Percentage of Energy consumed per received packet:** It is measured as the ratio percentage of total energy consumed per unit received packets.
- 4) **Average Latency:** It is measured as average delay of one packet to reach at destination.
- 5) **Routing Overhead:** It is measured as number of routing data packets transmitted per unit received packets.

6.. RESULTS and CONCLUSIONS

In this section, EAGR is the proposed scheme and greedy routing means existing GPSR. Figure 1 shows that packet delivery fraction of EAGR is much more than existing greedy routing. Percentage of increase in packet delivery by EAGR than greedy routing varies from 10.5% to 30.5%

Greedy routing always selects the node for the next hop which is at the least distance from the destination. It does not matter for greedy routing that how much energy a node has and how frequently energy is consumed from the node. So even the node which has very less energy, greedy routing can forward the packet to that node. Now let us discuss the situation when node has the energy to receive the packet

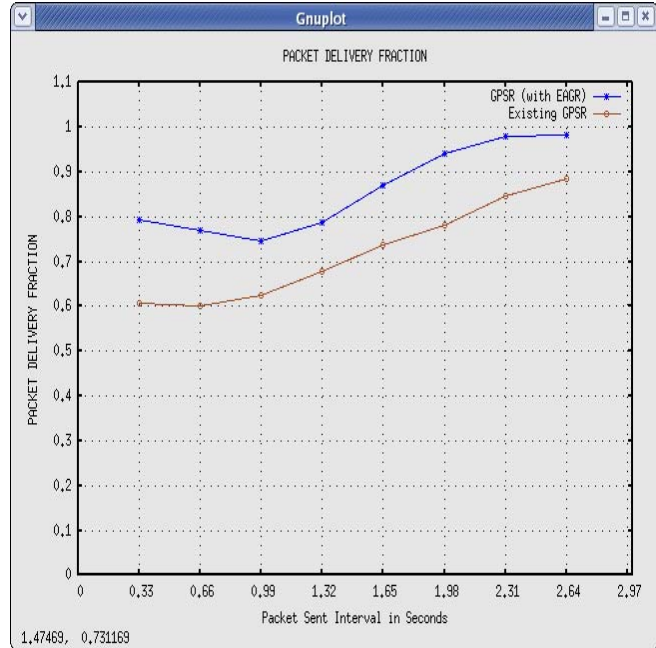


Fig. 1. Comparison of Packet Delivery Fraction

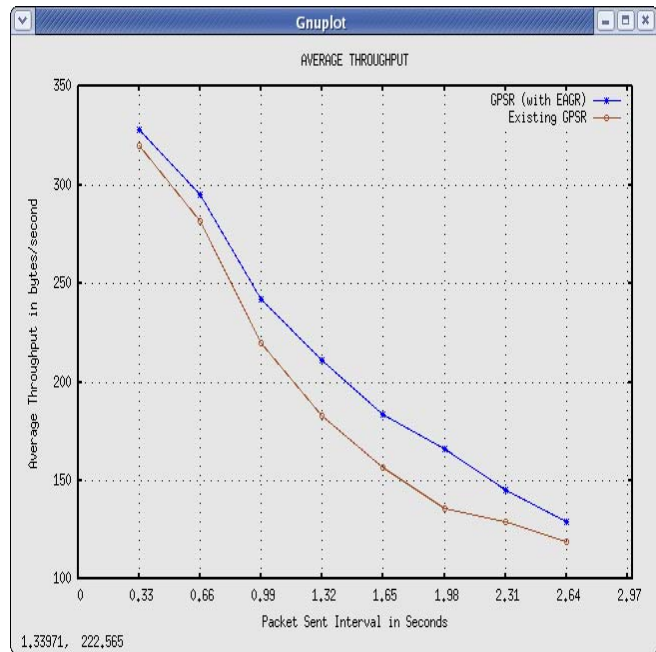


Fig. 2. Comparison of Average Throughput

(node needs less energy to receive the packet) and after receiving the packet it does not have energy to transmit it (node needs more energy to transmit the packet); then the packet drops in the greedy routing. But in EAGR, if the other node is available which has more energy, it forwards

the packet to that node.

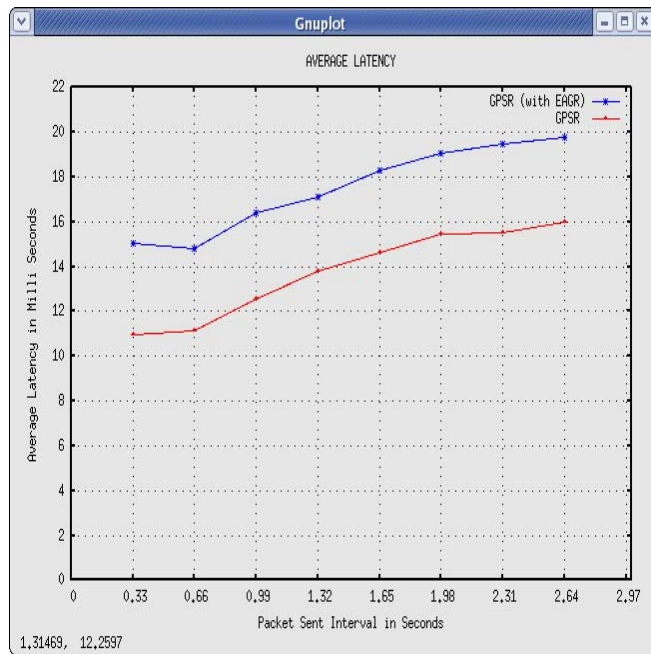


Fig. 3. Comparison of Latency

The node with high rate of energy consumption cannot be relied for packet forwarding. High rate of energy consumption means more number of nodes depend upon it for routing the packet. We can also say that node which has high rate of energy consumption is very important for the connectivity of the networks. Moreover, if we forward the packet to that node only then energy of that node will deplete very soon and it will be dead sooner than other nodes. More specifically, low rate of energy consumption informs that the node does not participate much in communication that includes transmitting, receiving, and forwarding. The EAGR algorithm takes care of those nodes whose rate of energy consumption is more than other nodes, by not forwarding the packet to those nodes. So, by doing this, EAGR increases the connectivity of networks. Therefore, more packets will be delivered to destinations. Thus it is asserted that packet delivery of EAGR is always more than existing greedy routing in energy limited ad hoc networks.

EAGR balances well between distance from destination and energy of the node. It finds the path which is good in terms of distance from destination as well as energy consumed. This is confirmed by results of Figures 2 and 3. Figure 2 shows the average throughput comparison and Figure 3 shows the average latency comparison. Obviously path traveled by greedy routing will take lesser time to

reach the destination because it only sees the minimum distance from destination. Although EAGR takes more time to reach the destination, bytes received per second by the destination are more in case of EAGR (Figure 2). We found an increment of 2.5% to 24.4% in average throughput by EAGR compared with greedy routing.

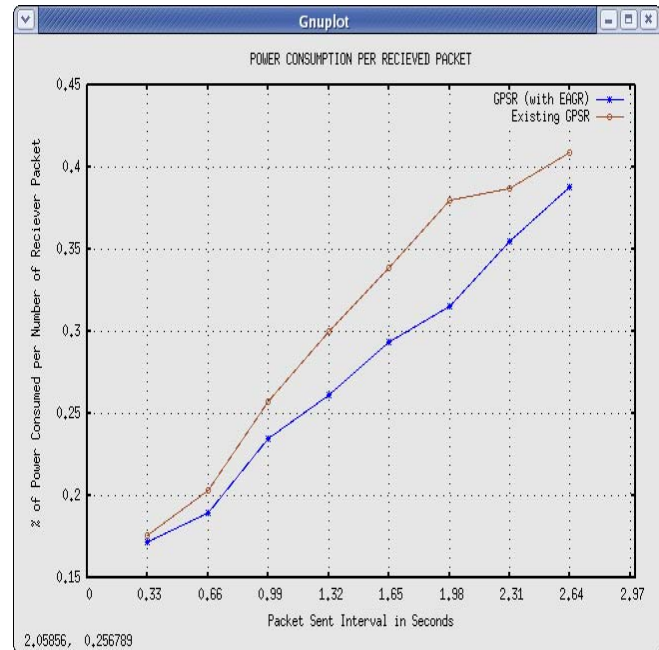


Fig. 4. Comparison of Energy Consumption

To demonstrate the efficiency of the proposed scheme regarding energy consumption, we calculate the percentage of energy consumed per unit number of packets received. Figure 4 shows the difference of percentage of energy consumed by EAGR and greedy routing. Energy consumed per received packet by EAGR is always less than the greedy routing.

Greedy routing selects and uses the same path for the entire duration, or until the energy of any node on the path is depleted. As a result, small number of nodes participate in routing the packets. But in EAGR, rate of energy consumption and fraction of energy consumption change over the time, so path selected may not be the same for all the time. Thus traffic is spread over a large number of nodes.

It may happen that while moving to destination, a packet drops at some point. This wastage of energy from source to that point which is less in EAGR. Overall this leads to lesser energy consumption compared with greedy routing.

Figure 5 shows the routing overhead in EAGR and

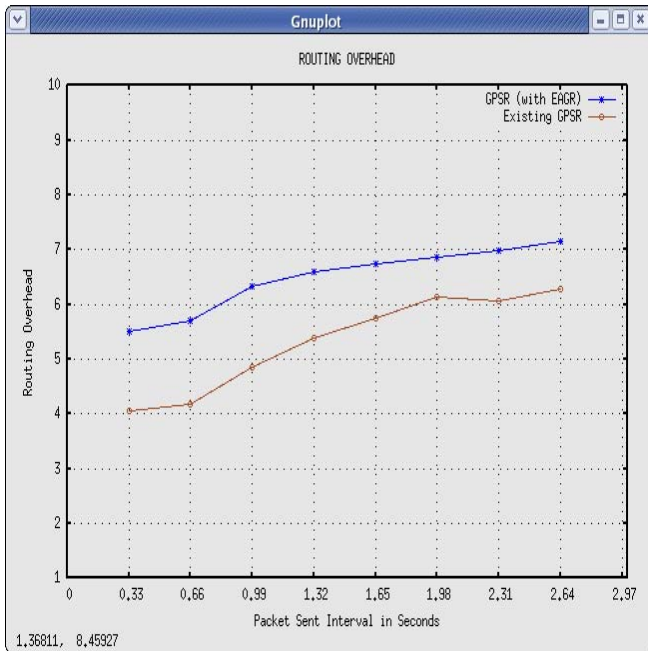


Fig. 5. Comparison of Routing Overhead

greedy routing. As the number of hops traveled by EAGR is more, routing overhead of EAGR is more than that in greedy routing. But overall throughput in EAGR is still better than greedy routing.

To summarize, in comparison with greedy routing, EAGR has higher packet delivery and average throughput and lesser energy consumption but more routing overhead.

ACKNOWLEDGMENT

This research project was supported by Department of Science and Technology, India under grant number RP01907.

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Biography

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