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EAGRP: Energy Aware Geographic Routing Protocol for Wireless Sensor Networks

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***Abstract*– In this paper, we propose an energy efficient data forwarding protocol called Energy Aware Geographic Routing Protocol (EAGRP) for wireless sensor networks to extend the life time of the network. In EAGRP, both position information and energy are available at nodes used to route packets from sources to destination. This will prolong the lifetime of the sensor nodes; hence the network life time and thus get higher packet delivery ratio and minimal compromise of energy efficiency. The proposed protocol is an efficient and energy conservative routing technique for multi-hop wireless sensor networks. The routing design of EAGRP is based on two parameters: location and energy levels of nodes. Each node knows the location and energy level of its neighbors. The performance measures have been analyzed with variable number of nodes. The simulations are carried out for different number of nodes employing these algorithms considering the different metrics. Simulation results have shown that the EAGRP performs competitively against the other routing protocol in terms of packet delivery ratio, throughput, energy consumption, and delay. Consequently, it can be concluded that EGARP can efficiently and effectively extend the network lifetime by increasing the successful data delivery rate.**

***Index Terms*– Routing Protocol, Wireless Sensor Networks, Energy Aware, Position Information and Life Time**

I. INTRODUCTION

RECENT advances in Micro-Electro-Mechanical Systems (MEMS) and low power and highly integrated digital electronics have led to the development of micro-sensors. These sensors are small, with limited processing and computing resources, and they are inexpensive compared to traditional sensors. These sensor nodes can sense, measure, and gather information from the environment and, based on some local decision process, they can transmit the sensed data to the user. The sensing circuitry measures ambient condition related to the environment surrounding the sensor and transforms them into an electric signal. Processing such a signal reveals some properties about objects located and/or events happening in the vicinity of the sensor. The sensor sends such collected data, usually via radio transmitter, to a command centre (sink) either directly or through a data concentration centre (a gateway) [1].

WSNs have great potential for many applications in scenarios such as military target tracking and surveillance, natural disaster relief, biomedical health monitoring and hazardous environment exploration and seismic sensing.

- In military target tracking and surveillance, a WSN can assist in intrusion detection and identification. Specific examples include spatially-correlated and coordinated troop and tank movements.
- With natural disasters, sensor nodes can sense and detect the environment to forecast disasters before they occur.
- In biomedical applications, surgical implants of sensors can help monitor a patient's health.
- For seismic sensing, ad hoc deployment of sensors along the volcanic area can detect the development of earthquakes and eruptions [2]-[4].

Many routing algorithms for WSNs have been developed but most of them do not take into consideration the limited energy resources for sensor nodes. This is a main drawback in most routing algorithms where they should choose the routes based on the energy available at nodes. This will prolong the lifetime of the sensor nodes and thus the network lifetime.

Geographic routing protocols require only local information and thus are very efficient in wireless networks. First, nodes need to know only the location information of their direct neighbors in order to forward packets and hence the state stored is minimized. Second, such protocols conserve energy and bandwidth since discovery floods and state propagation are not required beyond a single hop [5].

It is based on assumption that the node knows the geographical position of the destination node. This approach to routing involves relaying the message to one of its neighbors that is geographically closest to the destination node of all neighbors, and is geographically closer to the destination. This approach attempts to find a short path to the destination, in terms of either distance or number of hops. It is based on the geographical distances between the nodes. A node that requires sending a message acquires the address of the destination. After preparing the message, it calculates the distance from self to the destination. Next, it calculates distance from each of its neighbors to the destination. The greedy approach always tries to shorten the distance to be traveled to the destination to the maximum possible extent.

Therefore, the node considers only those neighbors that are closer to the destination than itself. The sending node then chooses the node closest to the destination and relays the message onto the neighbor. A node receiving a message may either be the final destination, or it may be one of the intermediate nodes on the route to the destination. If the node is an intermediate hop to the message being relayed, the node will calculate the next hop of the message in the manner described above [6].

The basic geographic routing does not use any data structures stored locally on a node apart from the neighbor table. Thus, no information is stored locally. The sending component does not differentiate between the source of the message and an intermediate node on its route. The receiving component needs to handle two different types of messages; one that says that the node is the destination, and the other that specifies the node to be an intermediate node for relaying the message. Both messages are handled in exactly the same way, without any form of distinction. A typical sensor network consisting of sensor nodes scattered in a sensing field in the vicinity of the phenomenon to be observed is shown in Fig. 1. The nodes are connected to a larger network like the Internet via a gateway so that users or applications can access the information that is sent from the sensor nodes. The dotted circle shows the area where sensor nodes are scattered to sense the specific task and then route the sensed processed data to the gateway. The main focus is on this dotted area and this research has proposed an Energy efficient scheme for inter-sensor nodes communication where information relay between these sensor nodes. Proposed algorithm will provide simple and efficient path to nodes for forwarding their messages which will further conserve total energy of the entire network [7].

When sensor nodes forward messages in the network they use their energy in forwarding mechanism but at some point when node depletes its all energy it fails to transmit further messages resulting in loss of data. Usually, in greedy forwarding, the closest neighbor node will be heavily utilized in routing and forwarding messages while the other nodes are less utilized. This uneven load distribution results in heavily loaded nodes to discharge faster when compared to others. This causes the failure of few over-utilized nodes which results in loss of data, resulting in increase of failed messages in the network. In this paper, the above mentioned problems faced by greedy forwarding approach will be taken care of in sensor networks by proposing an energy efficient routing strategy that will minimize the data loss and maximize the lifetime of the network.

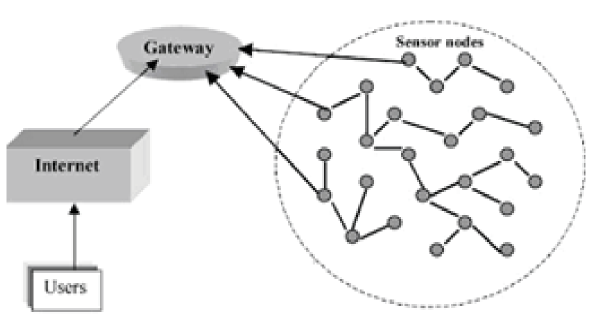

Fig. 1. Sensor nodes connected on a network [7]

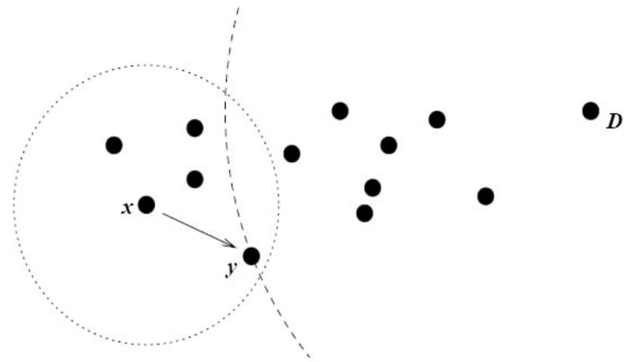

Fig. 2. Greedy routing example

The rest of this paper is organized as follows: Section II presents related work. Section III describes the proposed algorithm. Section IV describes the details of simulation model. Simulation results and discussions are presented in section V. Section VI concludes this paper.

II. RELATED WORK

The position based routing protocols are mostly designed to choose the intermediate forwarding nodes that lie on the shortest path or close to the shortest path from the source to the destination. Greedy Perimeter Stateless Routing (GPSR) [8] is a well-known and most commonly used position-based routing protocol for WSNs. GPSR works as follows: The source periodically uses a location service scheme to learn about the latest location information of the destination and includes it in the header of every data packet [9]. If the destination is not directly reachable, the source node forwards the data packet to the neighbor node that lies closest to the destination (see Fig. 2). Such a greedy procedure of forwarding the data packets is also repeated at the intermediate nodes.

In case, a forwarding node could not find a neighbor that lies closer to the destination than itself, the node switches to perimeter forwarding. With perimeter forwarding, the data packet is forwarded to the first neighbor node that is come across, when the line connecting the forwarding node and the destination of the data packet is rotated in the anti-clockwise direction. The location of the forwarding node in which greedy forwarding failed (and perimeter forwarding began to be used) is recorded in the data packet. We switch back to greedy forwarding when the data packet reaches a forwarding node which can find a neighbor node that is away from the destination node by a distance smaller than the distance between the destination node and the node at which perimeter forwarding began.

III. EAGRP ALGORITHM

We propose an Energy Aware Geographic Routing Protocol (EAGRP) that operates as follows:

- Source node first determines a candidate set of neighbor nodes; the nodes that lie closer to the destination than itself.

- The weight of each such candidate neighbor node is then computed to be the sum of the fraction of the initial energy currently available at the neighbor node and the progress (i.e., the fraction of the distance covered between the forwarding node and the destination) obtained with the selection of the neighbor node.
- The candidate neighbor node that has the largest weight value is the chosen next hop node to receive the data packet.

Let (X_D, Y_D) and (X_S, Y_S) respectively denote the locations of the destination node D and the source node S that has the data packet addressed to the destination node D.

Fig. 3 illustrates the pseudo code for the proposed greedy algorithm used at a source node in EAGRP. We first form a candidate set of neighboring nodes, Candidate-Neighbor-List (S), which is a subset of the Neighbor-List (S). For every neighbor I ∈Neighbor-List (S), I∈ Candidate-Neighbor-List (S), if and only if, the distance between the neighbor node I and the destination node D is less than the distance between the Source node S and D. For every neighbor node I ∈ Candidate-Neighbor-List (S), we then compute a Weight (I), defined as the sum of the:

- Fraction of the initial energy currently available at I, referred to as Residual Energy (I).
- Fraction of the distance covered with the potential selection of I, referred to as Progress (S, I), which would be the difference in the distance between S and D and the distance between I and D divided by the distance between S and D.

Among such neighbor nodes, the neighbor node that has the maximum Weight value is chosen by S as the next hop node to forward the data packet. If the forwarding node S could not find a neighbor node that lies closer to the destination than itself, the Candidate-Neighbor-List is empty and the node switches to perimeter forwarding.

With the above described energy-aware approach, the neighbor node that lies farthest away from the forwarding node need not be always selected as the next hop node and a neighbor that has a relatively larger available residual energy and located relatively closer to the destination, compared to the forwarding node, could be chosen as the next hop. This could significantly maximize the time of first node failure, where there are no significant neighborhood changes. The energy-aware neighbor selection of EAGRP has the potential to very well balance the forwarding load among all the neighbor nodes rather than always using the neighbor node that lies farthest away from the forwarding node and closest to the destination. Note that the percentage of time instants a node gets into perimeter forwarding is the same in the case of both GPSR and EAGRP. In other words, if greedy forwarding is successful in GPSR, greedy forwarding would also be successful in EAGRP and vice-versa.

Input: Source Node S, Destination D, Neighbor-List (S)
Auxiliary Variables: Progress (S, I) where I ∈ Neighbor-List (S) , Candidate-Neighbor-List (S), Residual Energy (I), Available Energy (I), Initial Energy (I), Weight(I), I ∈Candidate-Neighbor-List (S), Maximum-Weight
Output: Next-Hop-Node // if Greedy forwarding is successful NULL // if Greedy is not successful and perimeter forwarding is needed
Initialization: Next-Hop-Node = NULL, Maximum-Weight ← 0.0
Candidate-Neighbor-List (S) ← Φ
Begin EAGRP Algorithm

$$Distance_{S-D} = \sqrt{(X_S - X_D)^2 + (Y_S - Y_D)^2}$$

for every neighbor node I ∈ Neighbor-List (S) **do**

$$Distance_{I-D} = \sqrt{(X_I - X_D)^2 + (Y_I - Y_D)^2}$$

if ($Distance_{I-D} < Distance_{S-D}$) **then**
Candidate-Neighbor-List(S) ← Candidate-Neighbor-List(S)U{I}
end if
end for
for every neighbor node I ∈ Candidate-Neighbor-List (S) **do**

$$\text{Residual Energy (I)} = \frac{Available\ Energy(I)}{Initial\ Energy(I)}$$

$$\text{Progress (S, I)} = \frac{Distance_{S-D} - Distance_{I-D}}{Distance_{S-D}}$$

Weight (I) ← Residual Energy (I) + Progress (S, I)
if (Maximum-Weight < Weight (I)) then
Maximum-Weight = Weight (I)
Next-Hop-Node ← I
end if
end for
if (Maximum-Weight > 0.0) **then**
return Next-Hop-Node
else
return NULL
end if
End EAGRP Algorithm

Fig. 3. EAGRP Algorithm

IV. SIMULATION MODEL

A. Simulation Tool (OPNET)

The well known OPNET simulation tool is used, and the scenarios of simulation are described. OPNET provides a comprehensive development environment for modeling and performance evaluation of communication networks and distributed systems. The package consists of a number of tools, each one focusing on particular aspects of the modeling task. These tools fall into three major categories that correspond to the three phases of modeling and simulation projects: Specification, Data Collection and Simulation and Analysis.

B. Simulation Setup

This scenario represents a motionless network. The main goal of analyzing the behavior of a network whose nodes maintain their position over the time is to determine the improvements of the main features of each protocol. In the simulation, all nodes generated data packets that are routed to the destination node. Random topology has been considered in this implementation.

Simulation time for each scenario was set to 500 seconds and repetitive simulations for each scenario were performed to verify the reliability of our results. The network was modeled on an area having dimension of 300 x 300 meters. The packet size is of 512 bytes, and the packet rate is 2 packets /sec. All nodes in this network are considered as source nodes communicating with constant bit rate 1 Mbps.

The numbers of nodes chosen are 25, 40, 50, 65, 75, 90 and 100 nodes. The input parameters used for all scenarios were the same as shown in Table I except the number of nodes.

TABLE I. SIMULATION PARAMETERS

Simulation time	500 sec
Simulation area	300 m x 300m
Number of nodes	25, 40, 50, 65, 75, 90, 100
Packet size	512 bytes
Packet rate	2 packets/sec
MAC type	IEEE802.11
Data Rate	1 Mbps
Initial node energy	1 Joule

Fig. 4 shows a sample network with 40 nodes. The Process model for EAGRP is shown in Fig. 5.

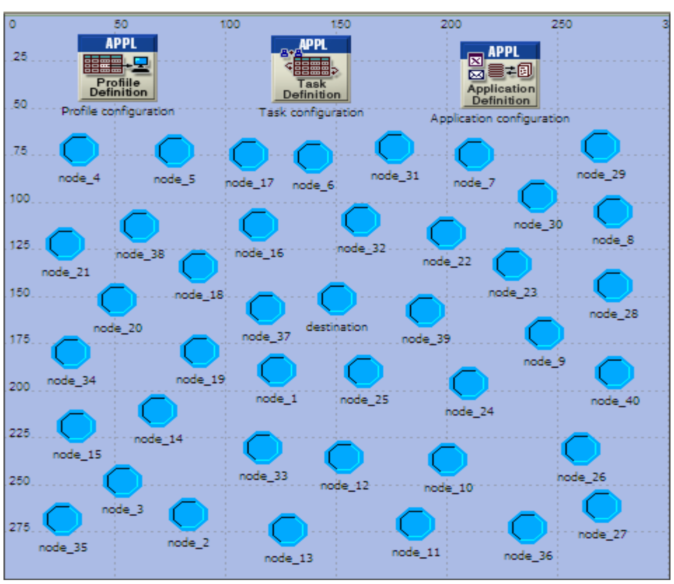

Fig. 4. Sample network with 40 nodes

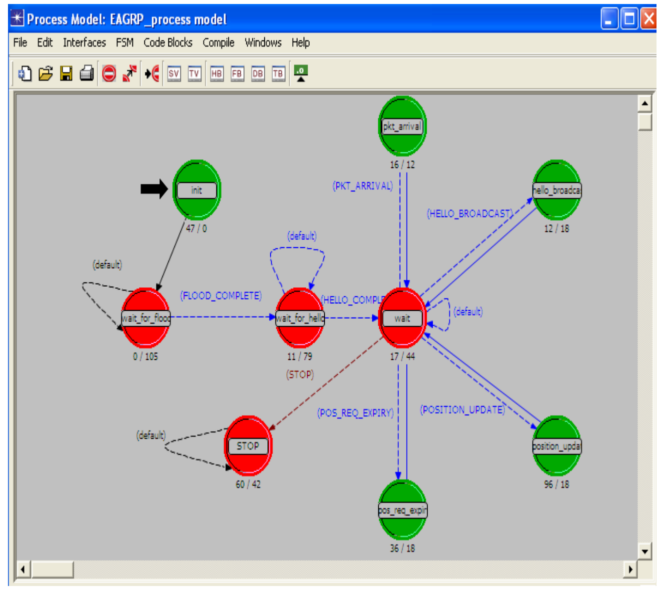

Fig. 5. EAGRP process model

C. *Performance Metrics*

We used packet delivery ratio, end-to-end delay, energy consumption, and throughput for the evaluation. The metrics that we selected are defined as follow:

- *Packet delivery ratio (PDR):* Measures the percentage of data packets generated by nodes that are successfully delivered.
- *Throughput:* The throughput reflects the effective network capacity. It is defined as the total number of bits successfully delivered at the destination in a given period of time. Throughput shows protocol’s successful deliveries for a time; this means that the higher throughput the better will be the protocol performance.
- *Energy consumptions:* Efficient energy consumption is one of the most important design constraints in wireless sensor network architecture. The life of each sensor node depends on its power dissipation. In applications where the sensors are not equipped with energy scavenging tools like solar cells, sensors with exhausted batteries cannot operate anymore [10]. During the life cycle of a typical sensor node, each event or query will be followed by a sensing operation, performing necessary calculations to derive a data packet and transmitting this packet to the destination. In addition, sensor nodes often relay data packets received from other sensors. The energy metric is taken as the average energy consumption per node calculated through simulation time.
- *End to End Delay of data packets:* This metric measure the average time it takes to route a data packet from the source node to the destination node. The lower the end-to-end delay the better the application performance. If the value of End-to-end delay is high then it means the protocol performance is not good due to the network congestion.

V. RESULTS & DISCUSSIONS

A. Packet Delivery Ratio

It is evident from Fig. 6 that the proposed EAGRP algorithm provides better data delivery rate ratio than GPSR algorithm. The successful packet delivery ratio of EAGRP achieved about 93% on average compared to 87% for GPSR. The main focus is on varying size of network by keeping other parameters constant. The objective is to design an algorithm that can scale with networks of different sizes, therefore the work has shown that the algorithm scales and performs better with networks of different sizes than GPSR. It has been observed that the amount of packets delivered ratio is larger for all the network size. It means that EAGRP improves the performance much more as the number of nodes increases.

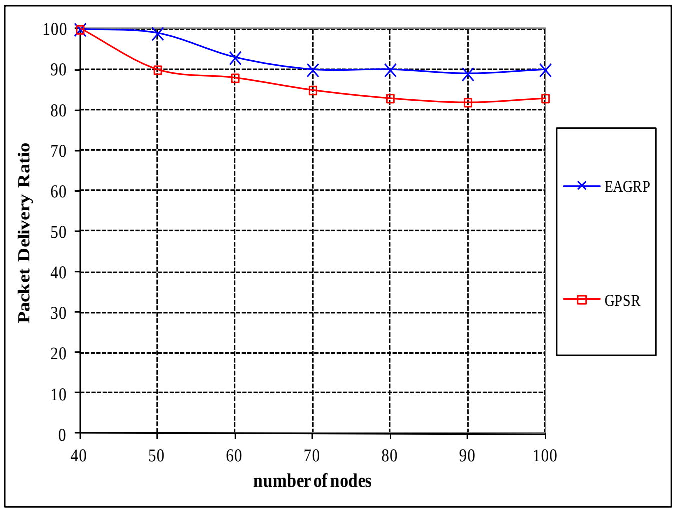

Fig. 6. The packet delivery ratio versus number of nodes

B. Throughput

Fig. 7 shows the throughput of EAGRP, GPSR protocols for all scenarios. The throughput depends on the simulation parameters regarding data generation and request for delivery. It can be observed that the two protocols have different throughput, but when the traffic load is increased we can see that EAGRP leads to more throughput than GPSR.

C. Energy Consumption

Fig. 8 presents the energy consumption for the two protocols. EAGRP yields significantly small values for the energy consumption, compared to GPSR. This can be attributed to the equal importance given to the residual energy available at a neighbor node as well as the progress made on the distance covered, from the forwarding node to the destination node, through the neighbor node. EAGRP fairly balances both of these measures does not excessively use neighbor nodes that have the maximum progress as the forwarding nodes and at the same time does not significantly increase the hop count by always picking the neighbor node with the maximum residual energy. For a given network, the difference in the energy consumption between EAGRP and GPSR increases with increased in the offered traffic load. EAGRP takes into consideration the available residual energy at the neighbor nodes of a forwarding node before deciding on the next hop node. This helps to significantly extend the lifetime of the nodes in heavy traffic scenarios rather than always choosing the node with the maximum progress (i.e. distance covered) as in GPSR, EAGRP helps to extend the lifetime of nodes that are close to be completely depleted of their battery charge. Energy overheads of EAGRP are competitive with that of GPSR. It is also indicated that the packet drop rate is very small in EAGRP approach as compared to the GPSR. Hence, EAGRP approach conserves more energy and is more efficient than GPSR algorithm.

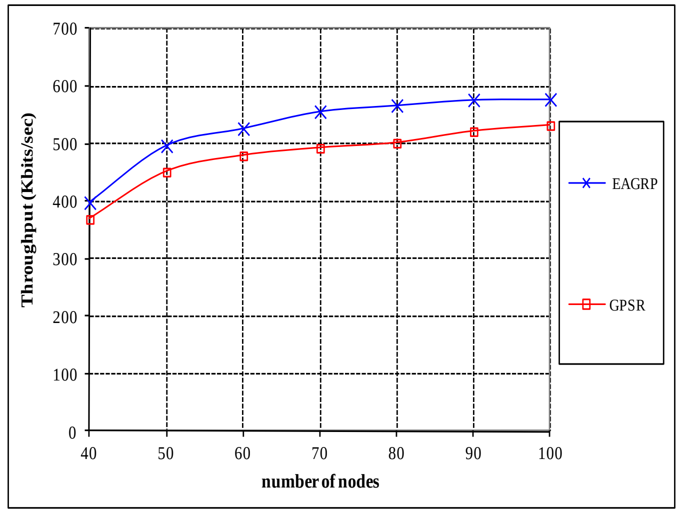

Fig. 7. The throughput versus number of nodes

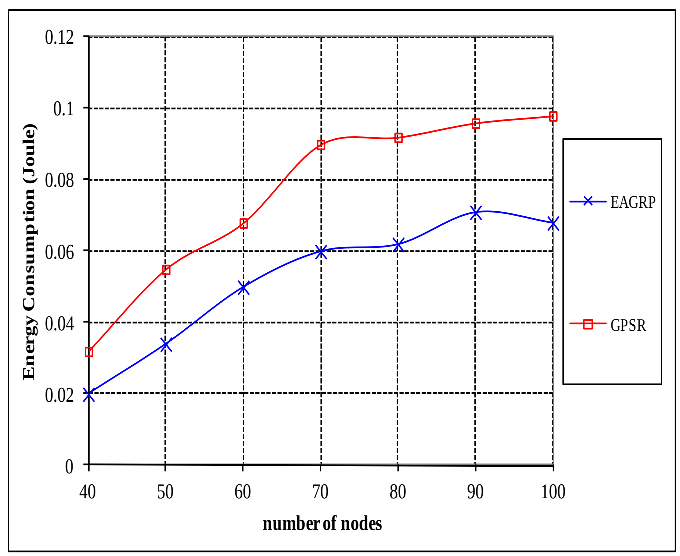

Fig. 8. The energy consumption versus number of nodes

D. Delay

Fig. 9 presents the delay encountered by the two routing protocols during the simulation period for all scenarios. It indicates that EAGRP has always the smallest delay than

GPSR even when the number of nodes is increasing. So EAGRP is successful in terms of time delay.

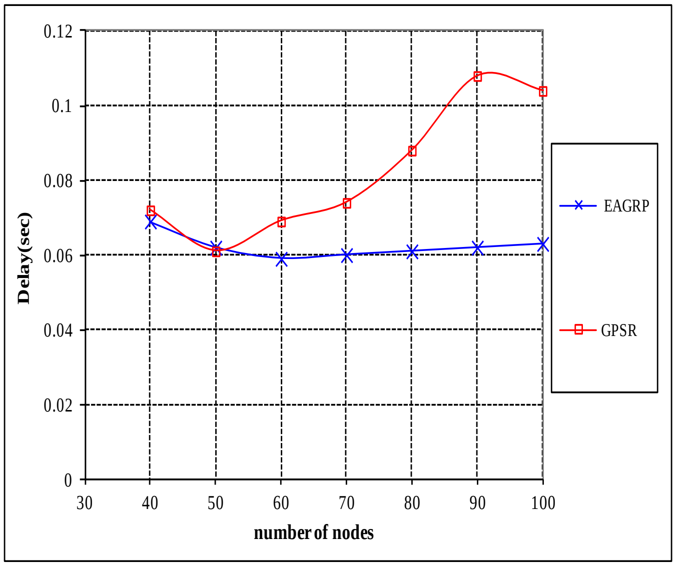

Fig. 9. The delay versus number of nodes

VI. CONCLUSION

In this research work, the geographic routing through the greedy forwarding has been considered for implementation. In greedy forwarding uneven load distribution results in heavily loaded nodes to discharge faster when compared to others. This causes few over-utilized nodes which fail and result in formation of holes in network, resulting in increase of failed messages in the network. So there was a need of such energy efficient routing strategy that should balance the load of the network and prevents the formation of holes. Also many excellent protocols have been developed for ad hoc networks. However, sensor networks have additional requirements that were not specifically addressed. Here, we explored how node mobility might be exploited to create enhanced greedy forwarding techniques for Energy Aware geographic routing protocol.

This paper has proposed new routing algorithm EAGRP for efficiently and reliably routing data packets from source nodes to sink through a multi-hop wireless sensor network. The simulations are carried out for different number of nodes employing these algorithms considering the different metrics. Simulation results have shown that the EAGRP performs competitively against the other three routing protocols in terms of packet delivery ratio, throughput, energy consumption, and delay. Consequently, it can be concluded that EGARP can efficiently and effectively extend the network lifetime by increasing the successful data delivery rate.

The successful packet delivery ratio of EAGRP achieved about 93% on average compared to 87% for GPSR. The improvement in the throughput for EAGRP compared to GPSR is 10%.The improvement in energy consumption for EAGRP versus GPSR is 14%. The percentage improvement in the end to end delay for EAGRP compared to GPSR is 12%.

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