International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 9, Sept.-2014, pp: (173-180), Impact Factor: 1.252, Available online at: www.erpublications.com

Geographical and Energy Aware Routing Protocol for Wireless Sensor Networks

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Abstract: A Wireless Sensor Networks (WSNs) which typically consists of a large number of wireless sensor nodes formed in a network fashion, is deployed in environmental fields to serve various sensing and actuating applications. Many routing, power management, and data dissemination protocols have been specially designed for WSNs. The focus has been given to the routing protocols which might differ depending on the application and network architecture. 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. We simulated network sizes from 25 to 200 nodes for variable thresholds of energy level. We categorized our simulation on the basis of threshold of energy level, scalability, and different number of source nodes. Our simulation results indicate that the proposed algorithm gives better performance in terms of higher packet delivery ratio, throughput, energy consumption, delay, and routing traffic overhead.

Keywords: Wireless Sensor Networks; Energy efficient; Position information; Routing protocol.

I. INTRODUCTION

With the integration of sensing devices on the sensor nodes, the nodes have the abilities to perceive many types of physical parameters such as, light, humidity, vibration, etc. about the ambient conditions. In addition, the capability of wireless communication, small size and low power consumption enable sensor nodes to be deployed in different types of environment including terrestrial, underground and underwater. These properties facilitate the sensor nodes to operate in both stationary and mobile networks deployed for numerous applications, which include environmental remote sensing, medical healthcare monitoring, military surveillance, etc. For each of these application areas, the design and operation of the WSNs are different from conventional networks such as the internet. The network design must take into account of the specific applications. The nature of deployed environment must be considered. The limited of sensor nodes' resources such as memory, computational ability, communication bandwidth, and energy source are the challenges in network design. As such, a smart wireless sensor network, able to deal with these constraints as well as to guarantee the connectivity, coverage, reliability and security of network's operation for a maximized lifetime, has been illustrated. Smart sensor nodes are low power devices equipped with one or more sensors, a processor, a memory, a power supply, a radio, and an actuator. A variety of mechanical, thermal, biological, chemical, optical, and magnetic sensors may be attached to the sensor node to measure properties of the environment. Since the sensor nodes have limited memory and are typically deployed in difficult-to-access locations, a radio is implemented for wireless communication to transfer the data to a base station (e.g., a laptop, a personal handheld device, or an access point to a fixed infrastructure). Battery is the main power source in a sensor node. Secondary power supply that harvests power from the environment such as solar panels may be added to the node depending on the appropriateness of the environment where the sensor will be deployed. Depending on the application and the type of sensors used, actuators may be incorporated in the sensors [1, 2].

Wireless sensor networks (WSNs) are being used in a wide variety of critical applications such as military and health-care applications. WSNs are deployed densely in a variety of physical environments for accurate monitoring. Therefore, order of receiving sensed events is important for correct interpretation and knowledge of what actually is happening in the area being monitored. Similarly, in intrusion detection applications (alarm application), response time is the critical performance metric. On detection of intrusion, alarm must be signaled within no time. There should be a mechanism at node for robust communication of high priority messages. This can be achieved by keeping nodes all the time powered up which makes nodes out of energy and degrades network life time [3]. Also, there can be a link or node failure that leads to reconfiguration of the network and re-computation of the routing paths, route selection in each communication pattern results in either message delay by choosing long routes or degrades network lifetime by choosing short routes resulting in depleted batteries [4].Therefore the solutions for such environments should have a mechanism to provide low latency, reliable and fault tolerant communication, quick reconfiguration and minimum consumption of energy. Such networks, which are composed of sensor nodes with limited memory capacity, limited processing capabilities, and most importantly limited energy resources, require routing protocols that take into consideration these constraints. Routing protocols have a critical role in most of these activities. Location- based protocols are most commonly used in sensor networks as most of the routing protocols for sensor networks require location information for sensor nodes. In most cases location information is needed in order to calculate the distance between two particular nodes so that energy consumption can be estimated. Since, there is no addressing scheme for sensor networks like IP-addresses and they are spatially deployed on a region, location information can be utilized in routing data in an energy efficient way. Geographic routing that takes advantage of the location information of nodes, are very valuable for sensor networks [5].

Geographic routing algorithms for sensor network have been considered in this research work. For sensor networks, geographic routing is one of the approaches to energy efficiency among the routing algorithms [6, 7]. Geographic routing protocols work on the assumption that every node is aware of its own position in the network; via mechanisms like GPS or distributed localization schemes and that the physical topology of the network is a good approximation of the network connectivity. In other words, these routing protocols assume that if two nodes are physically close to each other, they would have radio connectivity between them, which is true in most cases. Hence the protocols use node location information to route packets from source to destination. Every node having its location information is a fair assumption in most sensor networks since application data frequently needs to be annotated by location information [8, 9]. One big advantage of geographic routing schemes is the fact that there is no need to send out route requests or periodic connectivity updates. This can save a lot of protocol overhead and consequently, energy of the nodes. This is an important consideration for sensor networks where the network size could be on the order of thousands of nodes, but each node has extremely limited memory capacity to store routing tables. 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

Here we discuss three recently proposed routing protocols for reliable and efficient many to one routing in multi-hop WSNs. Dynamic Source Routing (DSR) is a simple and efficient routing protocol designed specifically for use in multi-hop wireless sensor networks of mobile nodes. DSR allows the network to be completely self-organizing and self-configuring, without the need for any existing network infrastructure or administration. The protocol is composed of the two mechanisms of Route Discovery and Route Maintenance, which work together to allow nodes to discover and maintain source routes to arbitrary destinations in the ad hoc network. The use of source routing allows packet routing to be trivially loop-free, avoids the need for up-to-date routing information in the intermediate nodes through which packets are forwarded, and allows nodes forwarding or overhearing packets to cache the routing information in them for their own future use. All aspects of the protocol operate entirely on-demand, allowing the routing packet overhead of DSR to scale automatically to only that needed to react to changes in the routes currently in use. Using DSR, the network is completely self-organizing and self-configuring, requiring no existing network infrastructure or administration. Network nodes cooperate to forward packets for each other to allow communication over multiple “hops” between nodes not directly within wireless transmission range of one another. The key distinguishing feature of DSR is the use of source routing. That is, the sender knows the complete hop-by-hop route to the destination. These routes are stored in a route cache. The complete routing algorithm is described in [10, 11].

Ad Hoc on-Demand Distance Vector Routing Protocol (AODV) is an algorithm for the operation of wireless networks. The AODV routing protocol is one of several published routing protocols for mobile ad-hoc networking. Wireless ad-hoc routing protocols such as AODV are currently an area of much research among the networking community. Thus, tools for simulating these protocols are very important. Each node operates as a specialized router and routes are obtained as needed. AODV adopts a very different mechanism to maintain routing information. It uses traditional routing tables, one entry per destination. This is in contrast to DSR, which can maintain multiple route cache entries for each destination. An important feature of AODV is the maintenance of timer-based states in each node, regarding utilization of individual routing table entries. A routing table entry is expired if not used recently. The complete routing algorithm is described in [12, 13].

Greedy Perimeter Stateless Routing (GPSR) [14] 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 [15]. If the destination is not directly reachable, the source node forwards the data packet to the neighbor node that lies closest to the destination. 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.

During both greedy forwarding and perimeter forwarding, the energy available at the chosen neighbor node to forward the data packet is not considered. In networks of moderate and high density, greedy forwarding happens to be used more than 98% of the time and the need for perimeter forwarding is highly unlikely [14]. This motivated us to optimize the greedy forwarding phase of GPSR by considering the energy available at the neighbor nodes of a forwarding node before deciding the next hop node for transmitting the data packet. Accordingly, 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.

This procedure is repeated at every hop where greedy forwarding is possible. In case, greedy forwarding is not possible, similar to GPSR, EAGRP switches to perimeter forwarding. Both GPSR and EAGRP require each node periodically broadcast a beacon containing its latest location information to its neighbors. A beacon message broadcast by a node includes the node ID, the current X and Y coordinate location of the node (for both GPSR and EAGRP) and the fraction of the initial energy currently available at the node (for EAGRP alone).

III. ALGORITHM DESCRIPTION OF ENERGY AWARE GEOGRAPHIC ROUTING PROTOCOL(EAGRP)

In sensor networks, building efficient and scalable protocols is a very challenging task due to the limited resources and the high scale and dynamics. 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. Second, such protocols conserve energy and bandwidth since discovery floods and state propagation are not required beyond a single hop. It is based on assumption that the node knows the geographical location 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. A node that requires sending a message acquires the address of the destination. After preparing the message, it calculates the distance from itself 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. Usually, in the greedy forwarding the closest neighbor node will be heavily utilized in routing and forwarding messages, while the other nodes are less utilized. Due to this uneven load distribution it 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 increased number of failed/dropped messages in the network. Energy efficient routing scheme should be investigated and developed such that its loads balances the network and prevents the formation of holes.

Let us consider that nodes are randomly distributed according to a homogeneous two-dimensional Poisson point process with κ average density. The probability P (N, k) of finding nodes within the region with radius R is

$$P(N,k)=\frac{e^{-N}N^k}{k!},k\geq 0 \qquad (1)$$

where the mean $\hat{N}=\kappa\pi R^2$. The probability density function (pdf) of the distance r between a transmitter-receiver pair follows

$$f_R(r)=\frac{2r}{R^2},0\leq r\leq R \qquad (2)$$

The relationship between transmitted power Pt and received power Pr is given by

$$\frac{P_r}{P_t}=G_tG_r\left(\frac{\lambda}{4\pi r}\right)^2 \qquad (3)$$

where G_t and G_r are the transmitter and receiver antenna gains respectively, r is the distance between the transmitter and receiver, $\lambda = c / f$ is the wavelength of the transmitted signal, whereas f is its frequency, and c is the velocity of radio wave propagation in free space, which is equal to the speed of light. Using Equation 3, we derive

$$P_r=\frac{\omega}{r^2} \qquad (4)$$

where $\omega = (P_t G_t G_r) / (4\pi / \lambda)^2$. Equation 4 can be further generalized as

$$P_t=\frac{\omega}{r^\alpha} \qquad (5)$$

where α > 1 is known as path loss exponent. For free-space channel, we have seen in Equation 4 that α = 2. Table 1 gives a list of typical path loss exponent values obtained in various radio environments [16]. In many sensor applications, it is assumed that α ranges between 2 and 4, since the sensors have short antennae, which are very close to the ground.

Table 1: Path loss exponents for different environments [17]

Environment	α
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Let μ_t denote the threshold value of receiving signal strength for the successful packet reception. Then, two nodes can communicate directly with each other only when $Pr \geq \mu_t$. Hence, given R_0 as the transmission range in the absence of fading, we have

$$R_0 = \left(\frac{K P_t}{\mu_t} \right)^{\frac{1}{\alpha}} \qquad (6)$$

In geographic forwarding algorithm, there is a predefined forwarding area [18] to choose the relay node. All nodes residing in this forwarding area contend to become the possible next hop relay node. In this thesis, we assume Φ-degree radian forwarding area and employ polar coordinate (r, Θ) as shown in Figure 1, r denotes the distance between the source node and the relay node. We suppose that there is a line to connect the source node and the destination node. EAGRP algorithm chooses the next hop relay node according to the maximal forward progress [18].

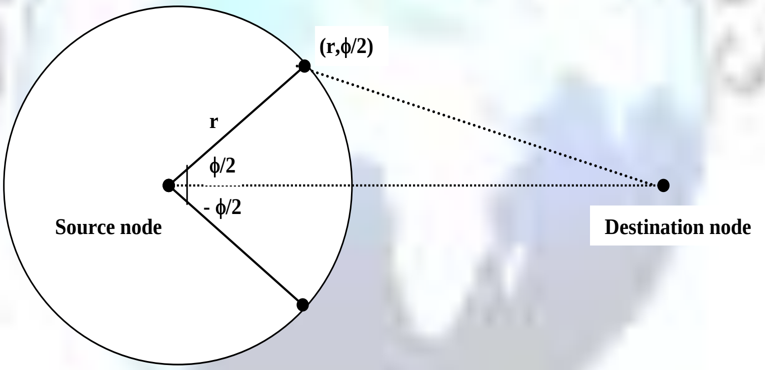

Figure 1: Graph of EAGRP forwarding algorithm

We define the average forward distance as the expected value of the distance r between the sender and relay node onto the line from the source to the destination node. Let ζ denote the average forward distance, and then the probability of ζ ≤ r_0 is the probability that a node has no connection to the neighboring nodes with distance bigger than r_0. With the definition of ϕ being the angle that the relay node should stay within, then we have the ratio of the number of nodes within the specified angle to the number of nodes in the total area denoted as

$$\eta = \frac{\phi}{2\pi} \qquad (7)$$

The average number of nodes $N^{/}$ with radius larger than r_0 and within the specified angles is expressed as

$$N^{/}(r_0 \leq r \leq R_0) = \int_{r_0}^{2DCos(\phi/2)} \lambda \pi R^2 \eta \, f_R(r) \, dr \qquad (8)$$

$$= \int_{r_0}^{2DCos(\phi/2)} \lambda \phi r \, dr$$

where the upper limit of the integral is 2DCos[ϕ/2] according to the criterion that the remaining distance between the relay and the destination node is less than D (i.e. the value of x that satisfies $x^2 + D^2 - 2x DCos[\phi/2] \leq D^2$). Accordingly, we have,

$$\Pr ob(\zeta \leq r_0) = \exp(-N^{/} - (r_0 \leq r \leq 2DCos[\phi/2]))$$

Hence the average forward distance towards the destination node is

$$E[\zeta] = \int_0^D (1 - \Pr ob(\zeta \leq r)) r \, dr \qquad (9)$$

IV. SIMULATION MODEL

1. Simulation Tool (OPNET)

In this section a comparative study between the behaviors of the four routing protocols: EAGRP, GPSR, DSR, and AODV will be given by simulation of WSN chosen to represent application. The well known OPNET simulation tool is used. Different simulations results are presented with different number of nodes in order to check performance of the proposed algorithm. OPNET provides a comprehensive development environment for modelling 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 modelling task. These tools fall into three major categories that correspond to the three phases of modelling and simulation projects: Specification, Data Collection and Simulation and Analysis. The simulation results for the two protocols are compared to each other.

2. Simulation Setup

We simulated network sizes from 25 to 200 nodes for variable thresholds of energy level. We categorized our simulation on the basis of threshold of energy level, scalability, and different number of source nodes. Simulation time for each scenario was set to 800 seconds and repetitive simulations for each scenario were performed to verify the reliability of our results. The packet size is of 128 bytes, and the packet rate is 4 packets /sec. The numbers of nodes chosen are 25, 50, 75, 100, 125, 150, 175 and 200 nodes.

The application type simulated was FTP. Initially, each node has same energy level (1Joule). Any node having energy less than or equal to a set threshold will be considered as dead, this was chosen to be in the simulations presented in this paper. One node is located as the destination i.e. one node is declared as target node for all data receiving as was mentioned in the assumptions that many to one scenario has been considered. In order to check three protocols performance in terms of its effectiveness there are a number of metrics that can be used to compare between them. We used packet delivery ratio, throughput, energy consumption, end-to-end delay, and routing traffic overhead for the evaluation.

V. RESULTS & DISCUSSIONS

We simulated network sizes from 25 to 200 nodes for variable thresholds of energy level. We categorized our simulation on the basis of threshold of energy level, scalability, and different number of source nodes. Simulation time for each scenario was set to 800 seconds and repetitive simulations for each scenario were performed to verify the reliability of our results. The packet size is of 128 bytes, and the packet rate is 4 packets /sec. The numbers of nodes chosen are 25, 50, 75, 100, 125, 150, 175 and 200 nodes.

Packet Delivery Ratio: Figure 2 shows the packet delivery ratio of EAGRP for different thresholds, GPSR, DSR, and AODV protocols for all scenarios.

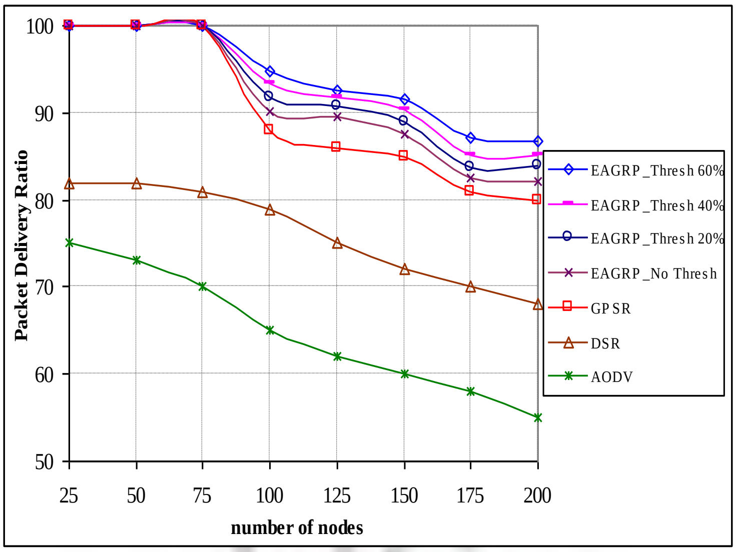

Figure 2. The packet delivery ratio for different thresholds

When the number of nodes increases the load or (traffic) increases, so the chances of losing the packet increases and therefore the packet delivery ratio decreases. From Figure 2 as the threshold increases, the source node sends to a closer node (i.e. smaller distance) so that the probability of error decreases. Hence, the packet delivery ratio increased.

Throughput: Figure 3 presents the throughput for all protocols. As the number of nodes increases, the load increases and hence the throughput increases (i.e. the utilization increases) but if the traffic increases too much, the lost packet ratio increases. Therefore the net throughput decreases (i.e. after the threshold reaches a peak).

For certain number of nodes as the threshold increases more and more nodes goes out from being router, consequently the source node will send to nodes farther from destination than normal. As a result each transmission will take more hops and then the bandwidth is shared and constant so the net throughput will be reduced.

Energy Consumption: Figure 4 presents the energy consumption for all protocols. As the number of nodes increases each node will be used for routing more frequently (often) and so the consumed energy will be increased. For certain number of nodes, as the threshold increases the nodes will come out of the routing table and will be used only for its own traffic. Which means the energy consumption will not depend on the increase of the number of nodes more and more (the energy consumption will be constant with respect to number of nodes). With small number of nodes (i.e. before the energy consumption becomes constant). As mention earlier the threshold indicate routing table update more than usual so the energy consumption increases as the threshold increases.

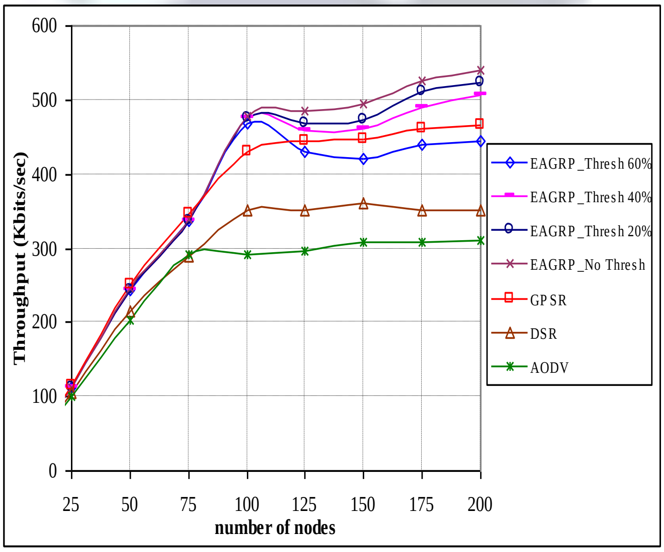

Figure 3. The throughput for different thresholds.

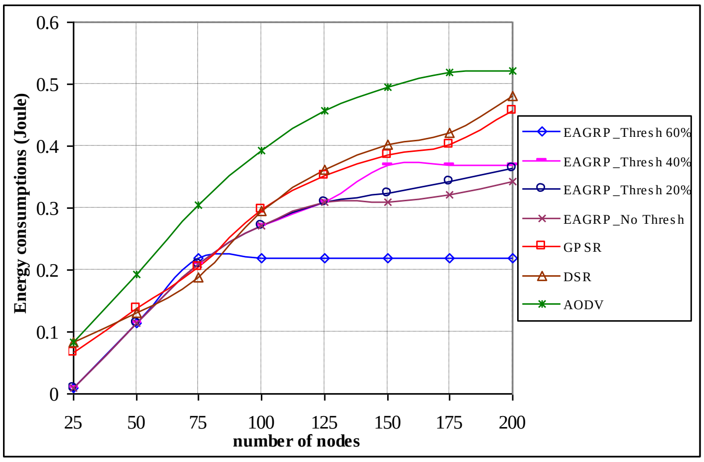

Figure 4.The energy consumption for different thresholds.

Delay: It is evident from figure 5 that as the number of nodes increases, the traffic increases so the delay increases. For certain number of nodes, when the threshold increases some nodes is prevented from being routers. So the situation equivalent to network with smaller number of nodes which leads to reduction of delay.

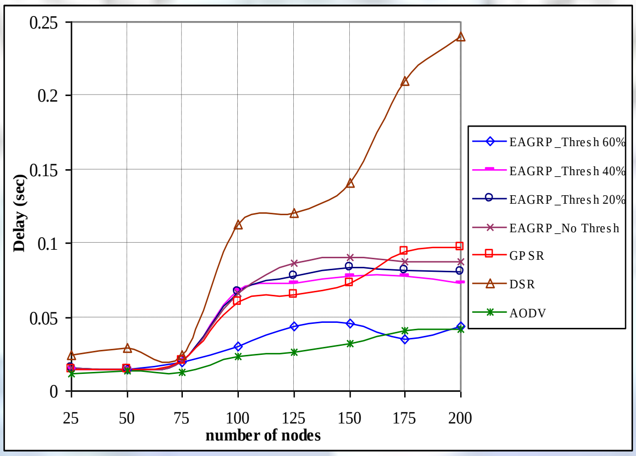

Figure 5. The delay for different thresholds.

Routing Traffic overhead: Figure 6 present the routing overhead encountered by all routing protocols during the simulation period for all scenarios. When the number of nodes increases, the routing tables size increases and the overhead due to routing traffic increases also. As the threshold increases the nodes will come out of the routing table sooner than the normal which is equivalent to topology change (i.e. leads to routing table update), as a result the routing traffic overhead increases.

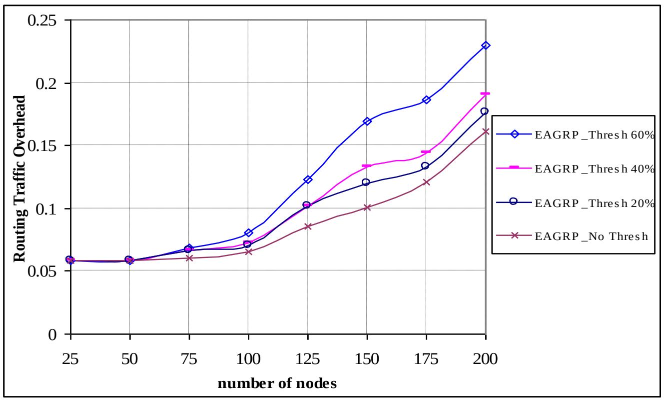

Figure 5.The routing traffic overhead for different thresholds

VI. CONCLUSION

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. In this research geographic routing has been implemented and its performance has been compared with those of GPSR, DSR and AODV protocols. 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, routing overhead, and delay. Consequently, it can be concluded that EGARP can efficiently and effectively extend the network lifetime by increasing the successful data delivery rate.

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