

Design and Implementation of Energy Aware Algorithm using Greedy Routing for Sensor Networks

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Abstract

Routing in sensor networks is a challenging issue due to inherent constraints such as energy, memory and CPU processing capabilities. The energy efficiency is one of the key concerns in sensor networks for their better performance, as sensor nodes are limited in their battery power. In this research work, different routing algorithms have been studied and the main focus was on geographic routing in sensor networks. A location based protocol EAGR (Energy Aware Greedy Routing) has been presented for sensor networks to extend the lifetime of the network and to get higher data delivery rate and to balance the energy consumption of nodes. In EAGR, each node makes the local decision to choose its next hop. This algorithm works on forwarding rule based on location and energy levels of nodes. Each node knows its own geographic location and its energy levels and the location and energy level of its neighbors. The transmitting node writes the geographic position of destination into the packet header and forwards it to the destination by establishing the sub-destinations. The sub-destination nodes must be alive and geographically near to the destination node to route the packet by choosing the shortest and reliable path. Simulation has been made by using OMNET++. Simulation results show that the proposed algorithm gives better performance in terms of higher data delivery rate and less number of dead nodes. It has been noted that the ratio of successful packet delivery will increase in EAGR as number of nodes increased in the network. Consequently, the proposed algorithm can scale to thousands of nodes in future sensor networks and can effectively increase the lifetime of the sensor networks.

1. Introduction

Embedded sensing network is a promising technology for applications ranging from environmental/military monitoring to industrial asset management. The development of sensor networks was originally motivated by military applications such as battlefield surveillance or area monitoring. However, sensor networks are now used in many civilian application areas [1-10], including environment and habitat monitoring, healthcare applications, home automation, and traffic control. With the recent advances in the electronics

field the development of low cost, low-power, multifunctional sensor nodes [11] are possible which are small in size (can be imagined as small computers) and can communicate untethered in short distances. From these small sensor nodes, which consist of sensing, data processing, and communication components [11], the idea of sensor networks comes into existence.

A sensor network comprises of probably several hundred sensor nodes, deployed in close proximity to the phenomenon for which they are designed to observe. The position of sensor nodes within the sensor network needs not to be pre-determined. Each node has one or more sensors, embedded processors and low-power radios, and is normally battery operated. Typically, these nodes coordinate to perform a common task. Because of their low cost, small size, and wireless data transfer, these networks might be widely used in the future. A wireless sensor network, WSN, is an ad-hoc network with many sensors deployed in an area for a specific reason.

Sensor networks can be distinguished by their limited onboard energy supply, as well as resources such as storage, communication and processing capabilities. Thus, the power of a sensor network lies in the ability of sensor nodes to pool resources together, optimally direct the resources to tasks at hand, and cooperatively gather and process information while satisfying severe resource constraints.

With the emergence of ad hoc networks the use of battery powered nodes started but the important thing that how limited energy resources affect system lifetime and over performance becomes critical. Therefore, energy is one of the most vital resources among the resource constraints, as sensor nodes are powered through the batteries which are limited in their energy capacity so the lifetime of sensor network depends crucially on energy conservation mechanism. So the energy efficiency is one of the critical issue in sensor network algorithm design. Still many researchers are trying to find out the energy conservation mechanisms at every layer in the traditional algorithm stack, from physical layer up to the transport and application layer.

Energy aware routing is one of the approaches at the network layer to the energy efficiency problem [12-18]. As sensor nodes are powered by batteries which are limited in their capacities. Through the energy aware routing mechanism, routing decisions are made on the basis of energy utilized during the communication and/or the residual energy on each node. The main objective of these algorithms is to minimize the energy consumptions so as to minimize the nodes failure. Hence, maximizing the lifetime of the network. A number of routing algorithms have been deigned which show that the routing techniques provide significant energy savings.

Geographic routing algorithms for sensor networks have been considered in this research work. In sensor networks, geographic routing is one of the approach to energy efficiency among the routing algorithms [19-23]. In this type of routing, each node has information of its own, its neighbors and the destination location on which it makes the routing decisions locally. Generally geographic routing schemes route the packet locally and greedily to the one hop neighbor. Some of the geographic routing algorithms keep nodes residual energy information such as GEAR (Geographic and Energy Aware Routing) [24]. These algorithms use the energy awareness and geography based neighbor selection and route the packet towards the target region, it does not consider the real wireless channel conditions.

The implemented energy aware algorithm makes routing decisions locally based on node energy residual greedily. Simulation results show that the proposed energy aware algorithm is more energy efficient than the greedy routing algorithm which does not consider the property of the energy. In particular, given the same network topology and initial energy to each node,

the proposed algorithm provides higher packet delivery rate and longer lifetime of the network than the greedy algorithm.

The organization of the paper is as follows. Related work has presented in section II. Section III presents motivation, objectives of the proposed research, assumptions and explains the proposed algorithm in detail. Section IV presents the analysis of simulation results and comparison between two algorithms. Conclusions are provided in Section V.

2. Related work

Sensor networks are similar to mobile ad hoc networks to some extent but they have some differences due to which routing algorithms proposed for mobile networks are not applicable to sensor networks. Lots of work has been done in this respect and almost all of the routing protocols of sensor networks can be classified as data centric, hierarchical, location based and QoS awareness.

In sensor networks, most of the routing algorithms 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. Geographic routing, that takes advantage of the location information of nodes, are very valuable for sensor networks. Most of the geographic algorithms are based on greedy algorithms to forward the packets to the destination. In dense uniform networks, greedy forwarding is very efficient approach but it fails in the presence of dead ends i.e. a node has no neighbors near to the destination.

A greedy routing algorithm called GPSR has been discussed to minimize the number of hops [22]. This algorithm selects the neighbor closest to the destination as the next hop. Similar work has been done by other researchers [23] in which the face routing used is actually one type of planar perimeter routing in GPSR. The main objective of the GPSR is to minimize the number of hops in the network and maximize the data packets transmitted successfully. J. Chen et al. [25] has proposed OD-GPSR, which is a data driven geographical routing algorithm customized for sensor networks with the solutions to the problems faced by GPSR for sensor networks.

An energy aware location based routing algorithm known as Geographic Adaptive Fidelity (GAF) is designed primarily for ad hoc networks [26]. It may be applicable to sensor networks as well. GAF conserves energy by turning off unnecessary nodes in the network without affecting the level of routing fidelity.

Yu et al. [24] has proposed a GEAR (Geographic Energy Aware Routing) algorithm which uses energy levels and geographic information of neighbors for selection and route the packet towards the target region. In GEAR, each node has an estimated cost and learning cost of reaching the destination through its neighbors. The estimated cost is the combination of residual energy and distance to destination.

A power aware geographic routing algorithm GPER (Geographic Power Efficient Routing) has been proposed by S. Wu et al. [3]. The GPER is power efficient, highly distributed and scalable protocol for sensor networks.

K. Zeng et al. [27] has studied energy aware routing in lossy wireless sensor networks with environmental energy supply and proposed two protocols GREES-L and GREES-M that combine geographic routing and energy aware routing techniques and address the realistic lossy wireless link conditions.

A clustering based algorithm called LEACH uses the randomize rotation of local cluster heads to evenly distribute the energy among the nodes in the network [28]. Rahul et al. [29] has proposed an algorithm that increases the lifetime of the network to a great extent. This

algorithm is similar to direct diffusion but the difference is instead of maintaining the optimal path, it maintains the set of good paths and chooses them by considering the fact that how low energy will be consumed in that path. So, no single path gets depleted all its energy as different paths are chosen at different times.

3. Energy aware greedy routing (EAGR)

3.1. Motivation

Geographic routing in sensor networks has been a challenging issue for researchers considering the energy constraints in these networks. Deployment methodology also poses challenges in design of routing strategy. Sensors may be deployed deterministically or randomly based on the application for which they are used. For random applications, these sensors should be self-configuring. These random deployments might result in irregular topologies which in turn affect the routing strategy. Sensors perform both data sending and data routing. Inter-sensor communication is usually short ranged. The nodes in the network cooperate in forwarding other nodes' packets from source to destination. Hence, certain amount of energy of each node is spent in forwarding the messages of other nodes. Lots of work has been done in this respect but still energy depletion of sensor nodes is a big challenge in sensor networks. The motivation behind this research work is to present such geographic algorithm for sensor networks which will be simple, easy to implement and efficient in terms of energy consumptions.

3.2. Objective

The main objective of this research thesis is to study and develop understanding of various geographic routing protocols for sensor networks their applications, gauging their efficiency through simulation and carrying out comparative analysis in terms of energy efficiency between greedy algorithm and the proposed algorithm. This research work will explore the paradigm of routing in sensor networks in terms of energy efficiency.

3.3. Problem Statement

When sensor nodes forwards 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 research, 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.

3.4. Assumptions for EAGR

Some common assumptions have been taken in this research work. Sensor nodes are considered to be static or immobile (i.e. Once the node has learned its location, its co-

ordinates do not change). There is a central location database managed by a central entity which enables each of the nodes to discover its position. In the real scenario, each node would learn its location by some kind of GPS system so the above assumptions can be made without the loss of generality. The irregular random topology for sensor networks is considered. Single destination scenario is taken into the account. There are infinite-size buffers at each node to support the incoming and outgoing message packets. Hence, buffer overflows and queuing analysis are not the part of this research. In the proposed system the fixed size of packets are used. So the packet sizes will not be considered during the analysis.

3.5. Principle of EAGR

To cater of the problem faced by greedy routing the concept of neighbor classification based on node energy level and their distances has been used in Energy Aware Greedy Routing (EAGR). Some neighbors may be more favorable to choose than the others, not only based on distance, but also based on energy characteristics. It suggests that a blacklisting/neighbor selection scheme may be needed to avoid the weak nodes. If the geographic forwarding scheme attempts to minimize the number of hops by maximizing the geographic distance covered at each hop (as in greedy forwarding), it is likely to incur significant energy expenditure due to retransmission on the weak nodes. On the other hand, if the forwarding mechanism attempts to maximize per hop reliability by forwarding only to close neighbors with good nodes, it may cover only small geographic distance at each hop. It would also result in greater energy expenditure due to the need for more transmission hops for each packet to reach the destination.

EAGR algorithm works on forwarding rule based on location and energy levels of nodes. Each node knows its own geographic location and its own energy levels as well as the location and energy level of its neighbors. The transmitting node writes the geographic position of destination into the packet header and forwards it to the neighbor which is alive (having energy level above than the set threshold) and has the distance equal to or less than the average distance of all its neighbors and among those neighbors having the maximum energy level. In this regime, packet transmission will go on; each node chooses its next hop by following the specified routing technique. This procedure repeats until the packet reaches the destination node.

Packet can terminate in two ways (i.e. successful termination and unsuccessful termination). In successful termination, packets reach to the destination node. While in unsuccessful termination, there are two possibilities. Either destination node is dead or the packet reaches to a node which has no neighbor alive to forward the packet so in this case the packet will drop.

4. Design and Implementation of EAGR

4.1. EAGR algorithm

The EAGR algorithm is presented below which takes all the above issues into account. Results presented in Section 4 show that EAGR works well, especially for sensor networks than the greedy algorithm [22] and the energy consumption of the resulting routes are efficient than the greedy algorithm in EAGR.

```
Initialize network(numnodes); //randomly deployed nodes in network where numnodes
                                is number of nodes to be deployed in the network.
for every node of network
    find(N); //find the locations of all nodes where N are the nodes specified in
            the network.
    for each node which is alive
        findneighbors(s,d); //detect neighbors of the node and add it to the
                            neighbor table where s is the source and d is destination.
        findavg(n,d); //calculate the average distance of all neighbors of node
                    and sort them in ascending order where n is the node
                    and d is the distance between node and its neighbor.
for(all nodes)
    if(node is alive)
        a. Transmit the message to the neighbor having maximum energy
          among the neighbors whose distance is less than or equal
          to the calculated average distance;
        b. Deducts the energy required to transmit the message from sensor node;
        c. Receive message by the neighbor node;
    else
        Find the node which is alive;
        if( node is alive)
            a. Transmit the message to the neighbor having maximum
              energy among the neighbors and whose distance is less
              than or equal to the calculated average distance;
            b. Deducts the energy required to transmit the message
              From sensor node;
            c. Receive message by the neighbor node;
        Else
            Drop Packet
```

Figure 1. EAGR algorithm for sensor networks

4.2. Work flow of EAGR algorithm

Figure 2 shows the flow chart for the EAGR algorithm. It starts and initializes the network by giving the input of number of nodes and establishes their links with the time delay between each link. Then it locates the position of each node and save it in mapping table. Then it finds the all next hop neighbors of the sending node and calculated their average distance from the sending node. It selects the node among its next hop neighbors which is alive and make the decision i.e. if the neighbor is dead then it will find the neighbor node which is alive. If no node is alive among its neighbors it will drop the packet otherwise it will select the neighbor node whose distance is less than or equal to the calculated average distance plus having maximum energy level among those neighbors and transmit the packet to it by deducting the transmitting energy of the sending node. The selected neighbor will receive the packet and this process will continue until the packet reaches to its destination and all other packets will follow the same procedure.

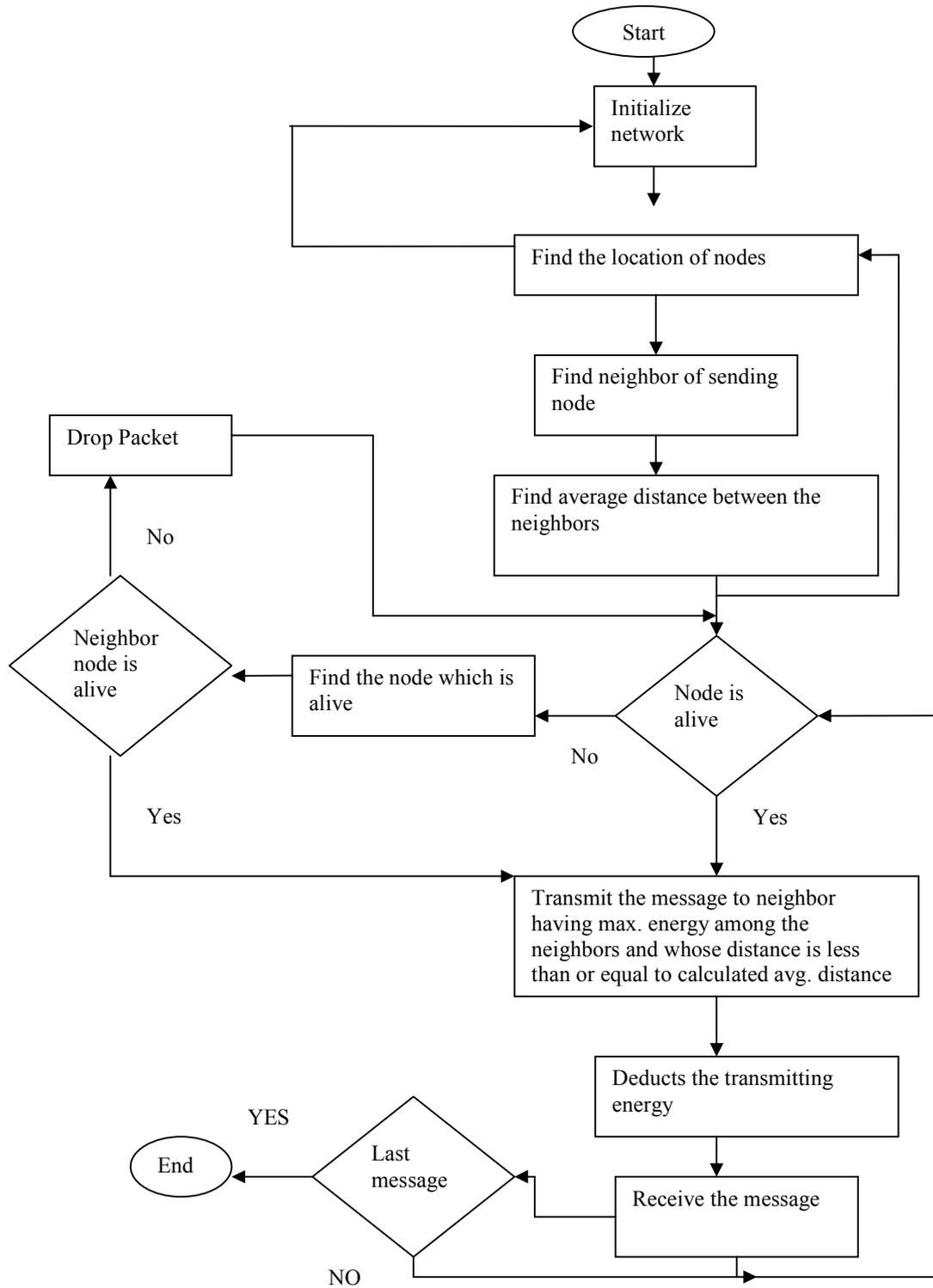


Figure 2. Flow chart for EAGR

4.3. Energy model

For the simulations, a simple energy model has been used in which every node starts with the same initial energy and forwards a packet by consuming one unit of energy. Initially, all nodes have energy level equal to 1 joule [24]. Each node depletes energy in transmitting one packet which is equal to 0.0001joule.

5. Simulation

5.1. Block Diagram of the implemented system

The proposed system is made by using the platform of Visual Studio 6.0 and OMNET++ network simulator. There are four basic modules in the proposed system i.e. network generator, route generator, routing algorithm and router.

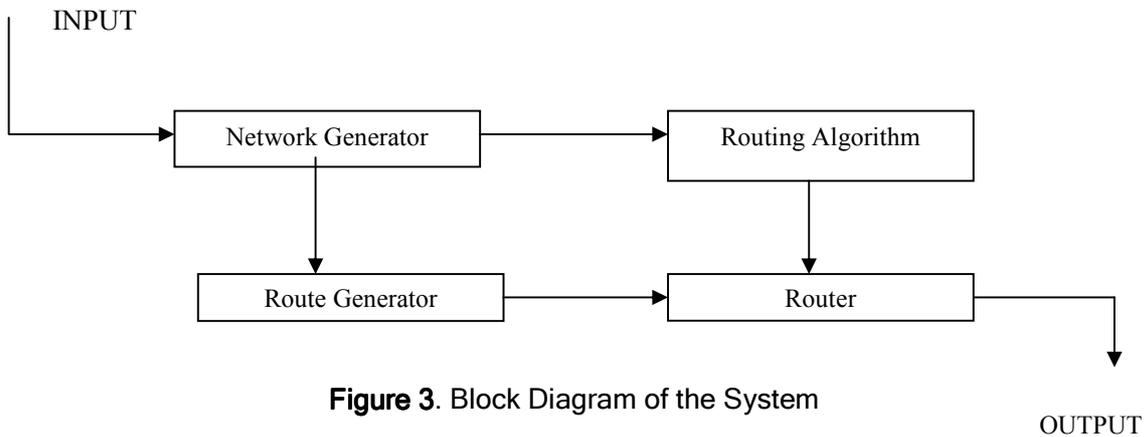


Figure 3. Block Diagram of the System

5.1.1. Network generator: Network generator generates the network. Network generator has two type of parameters i.e. data rate and number of nodes. Network generator includes a sub module network node which defines structure of single network node. Sub module network node has three types of parameters i.e. address of the node, then number of stations which is equal to number of nodes in this case and data rate. Two types of gates are defines for each node i.e. in gate and out gate. Gates are the input and output interfaces of modules; messages are sent out through output gates and arrive through input gates. In Network generator links are defined for all nodes and the time delay between each link from one node to another node is defined. Network generator module specifies the number of nodes and their links as the input.

5.1.2. Route generator: This module takes address of each node and specifies the source and destination for the data sending and receiving. Each node randomly sent the massages to the destination node.

5.1.3. Routing algorithm: Routing algorithm module takes location information of nodes in the network and set their weights. Then it chooses the next hop on the basis of EAGR

algorithm. In EAGR it first calculates the average distance of all the neighbors of transmitting node and checks their energy levels. Finally, it selects the neighbor which is alive (i.e. having energy level above than the set threshold) and having the maximum energy plus whose distance is equal to or less than the calculated average distance among its entire neighbors.

5.1.4. Router: Router module routes the processed packet to other nodes and generates the next hop destination map which comes from routing algorithm and then route/forward the received packet to the selected neighbor nodes. This map gives the complete information to each node about its own location and location of its neighbor nodes with their energy levels which are being updates after every transmission. Finally, router module gives the output in the form of packets delivered successfully, packet dropped, remaining energy level and status of the node.

5.2. Simulation model and tools

In simulation model, the numbers of nodes chosen are 20, 40, 60, 90 and 100 sensor nodes. Location of nodes was taken randomly in the simulation network. The immobile sensor network has been considered, so every sensor node is static. Initially, each node has same energy level as specified in energy model. Any node having energy less than or equal to set threshold will be considered as dead. One node is located as the destination node for all nodes i.e. one node is declared as target node for all data receiving as mentioned in assumptions that one destination scenario has been considered. The packet with fixed size of 562 bytes is generated by each sensing node randomly. Total simulation time is 500 seconds and each scenario is repeated ten times with different randomly deployed nodes.

The discrete even driven simulator OMNET++ has been used in this research work for simulation and MatLab for analyzing and evaluating simulation results..

5.3. Evaluation metrics

Four performance metrics have been used to measure performance (i.e. number of packets delivered successfully, number of packets dropped, number of nodes alive and number of nodes dead) of the proposed algorithm. Also a comparison between the average time delays of packets at the nodes for both algorithms will be made.

Figure 4 shows the sample network with 16 nodes. Initially each node has energy of 1J. Nodes start sending packets randomly to destination node by choosing the neighbor nodes on the basis of EAGR algorithm. EAGR algorithm calculates the average distance of all neighbor nodes of the sending node and checks their energy levels. Then, it selects the neighbor which is alive (i.e. having energy level above than the set threshold) and having the maximum energy plus whose distance is equal to or less than the calculated average distance among its entire neighbors. This process will continue until the packet reaches to the destination node.

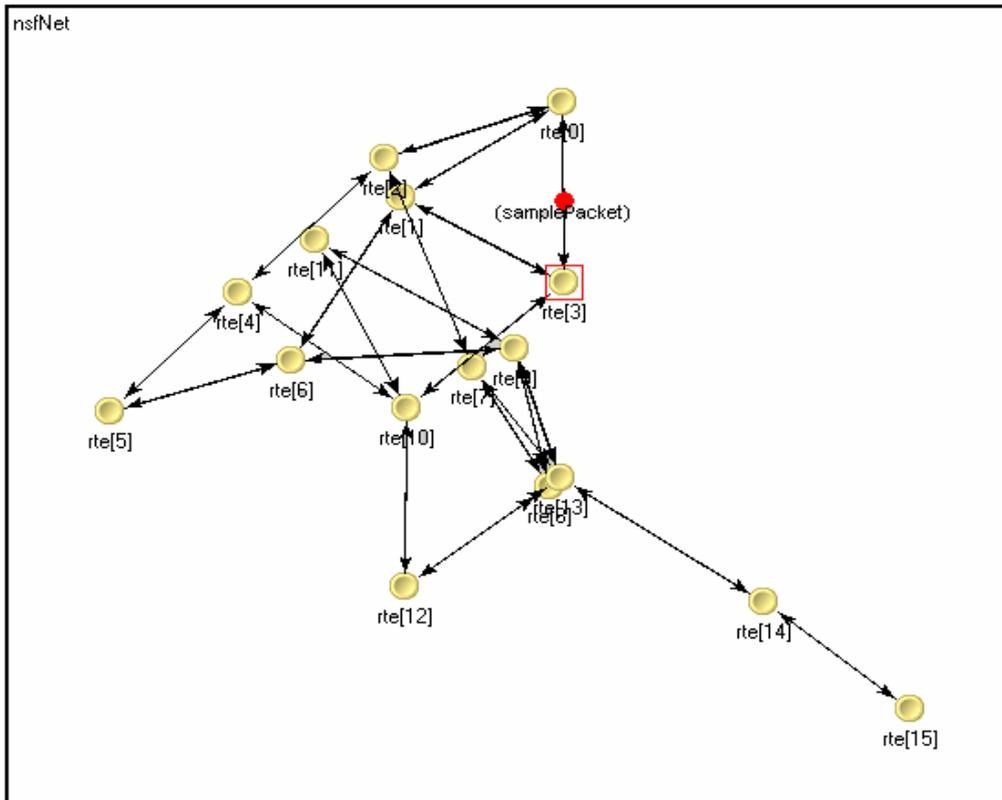


Figure 4: Sample Simulation environment with 16 nodes

The Table 1 shows the results of simulation for network size of 16 nodes. Each node initially has energy equal to 1J. From the simulation results, it is clear that EAGR algorithm provides better packet delivery rate as compared to Greedy Algorithm. Results also show that EAGR algorithm is more reliable by having more number of nodes alive, thus results in longer life of the network as compared to the Greedy Algorithm.

Total Packets Generated: 8,000

Table 1. The Simulation Results with Network Size of 16 Nodes

	Packets Successfully Delivered	Packets Dropped	Nodes Dead	Nodes Alive
Greedy	5000	3000	4	12
EAGR	7910	90	1	15

It is evident from Table 2 that the proposed EAGR algorithm provides better data delivery rate than the Greedy algorithm. The successful packet delivery of EAGR is 90% while Greedy algorithm has 72% on average. The main focus is on varying size of network by keeping other parameters constant. The main aim is to design an algorithm that can scale to thousands of nodes in future sensor networks, therefore the research has been focused on how the algorithm scales and perform better with networks of different sizes. It has been observed that the difference of amount of packets delivered successfully is getting larger as the number of nodes increases. It means that EAGR improves the performance much more as the number of source nodes increases. Also EAGR algorithm is more reliable in terms of energy consumption as it has less number of nodes dead as compared to Greedy algorithm. Hence, it provides longer the life to the sensor network as compared to the Greedy algorithm.

Table 2. The simulation results with network size of 16, 25, 30, 40, 50, 60, 70, 80, 90 and 100.

Number of nodes		Packets Successfully Delivered	Packets Dropped	Nodes Dead	Nodes Alive
16	Greedy	5000	3000	4	12
	EAGR	7910	90	1	15
25	Greedy	9502	2998	2	23
	EAGR	12500	0	0	25
30	Greedy	10500	4500	2	28
	EAGR	14536	464	1	29
40	Greedy	17500	2500	2	38
	EAGR	20000	0	0	40
50	Greedy	18452	6548	6	44
	EAGR	21484	3516	3	47
60	Greedy	31019	1481	1	64
	EAGR	32500	0	0	65
70	Greedy	24877	10123	7	63
	EAGR	29287	5713	3	67
80	Greedy	27773	12227	2	78
	EAGR	40000	0	0	80
90	Greedy	26008	18992	5	85
	EAGR	42666	2334	1	89
100	Greedy	32237	17763	5	95
	EAGR	40445	4555	2	98

5.4. Simulation results and performance comparison

Greedy communication [22] paradigm has been used as the basic comparison model. Greedy algorithm is purely geographic based and does not consider the energy consumption

of the nodes. As per the minimum criteria, proposed communication algorithm should be having greater successful packet delivery than Greedy algorithm and should have less number of dead nodes.

The results shown in the Table 2 are presented in form of graphs to show the comparison between the EAGR and Greedy algorithm, which shows that proposed EAGR algorithm has performance clearly better than Greedy algorithm.

Figure 5 shows the total number of packets that are successfully delivered in both algorithms. From the graph it is clearly shown that the proposed EAGR algorithm has much higher successful delivery rate than the Greedy algorithm.

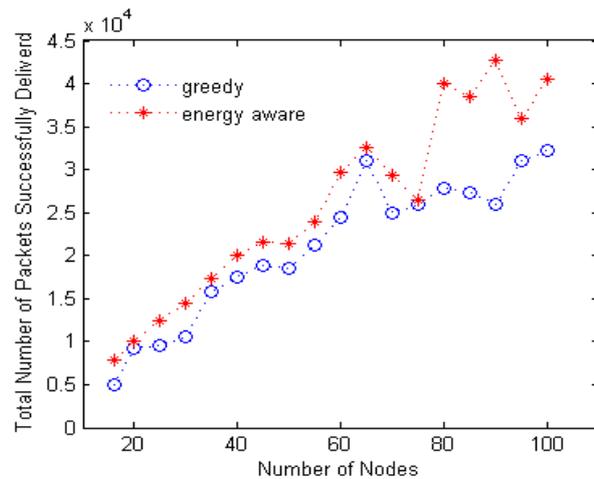


Figure 5. Comparison of total number of successful packet delivery in EAGR and Greedy algorithm.

Figure 6 also indicates that the packet drop rate is very less in EAGR algorithm as compared to the Greedy algorithm. Hence, EAGR algorithm conserves more energy and more efficient than Greedy algorithm.

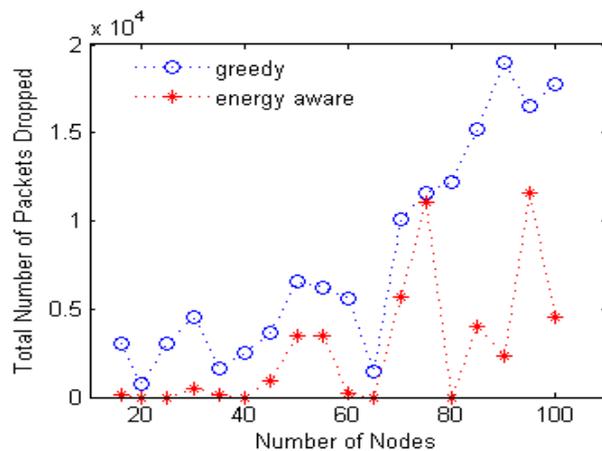


Figure 6. Comparison of total number of packets dropped in EAGR and Greedy algorithm.

In Figure 7 it is clear that EAGR algorithm is more reliable and results in longer life of the network as the total number of nodes which are alive are greater as compared to Greedy Algorithm.

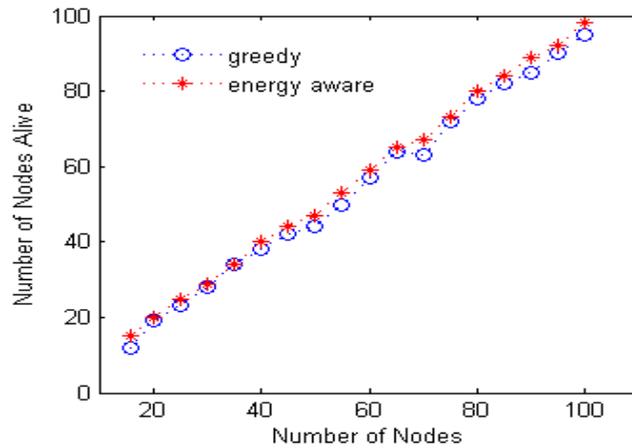


Figure 7: Comparison of total number of nodes alive in EAGR and Greedy algorithm.

Figure 8 show that Greedy Algorithm has greater number of dead nodes as compared to EAGR algorithm. So network lifetime is greater for EAGR than the greedy Algorithm.

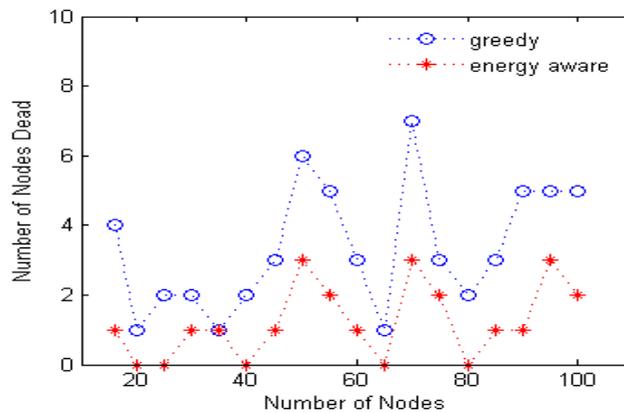


Figure 8: Comparison of total number of nodes dead in EAGR and Greedy algorithm.

Figure 9 indicates that the average time delay at each node for forwarding packet is almost same in both algorithms. Only at very few nodes (because of more packet drop at those nodes) Greedy Algorithm shows more delay than the EAGR algorithm. So EAGR is also successful in terms of time delay and consumes less energy of nodes therefore nodes died after very long time. Hence, increase the lifetime of the network.

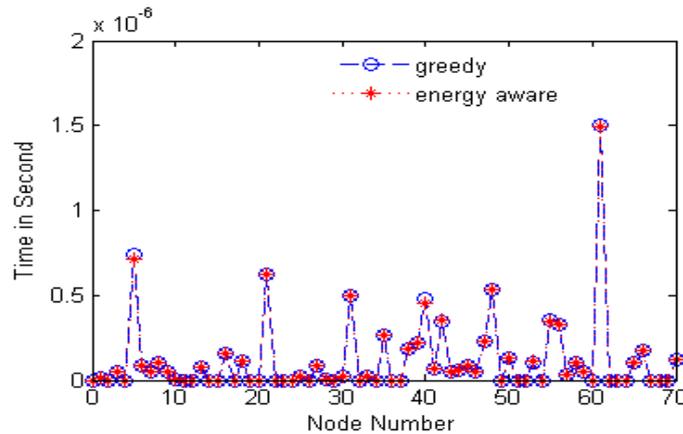


Figure 9: Comparison of average time delay at each node in EAGR and Greedy algorithm.

5.5. Discussion

Both the greedy and EAGR algorithms have been run by using different number of sensor nodes with the same energy per node initially. It has been found that energy aware algorithm as compared to the greedy algorithm gives better results in terms of successful packet delivery i.e. 20% more than greedy algorithm and less number of dead nodes. It is also noted that as compared to other energy aware algorithms EAGR is very simple algorithm having results nearly to those algorithms. Further more, average time delay in forwarding message is same in both algorithms, except at some nodes (more precisely dead nodes) where time delay is more because of higher packet drop rate in greedy algorithm as compared to EAGR algorithm. Hence, proposed energy aware algorithm is more reliable as compared to greedy algorithm and results in longer lifetime of the network.

6. Conclusion and future work

Geographic routing in sensor networks has been a challenging issue for researchers considering the energy constraints in these networks. Deployment methodology also poses challenges in design of routing strategy. Sensors perform both data sending and data routing. Inter-sensor communication is usually short ranged. The nodes in the network cooperate in forwarding other nodes' packets from source to destination. Hence, certain amount of energy of each node is spent in forwarding the messages of other nodes. Lots of work has been done in this respect but still energy depletion of sensor nodes is a big challenge in sensor networks. Sensor nodes use their energy in forwarding messages in network but at some point when node deplete its all energy it fails to transmit the further messages resulting in loss of data (formation of holes). In this research work, the geographic routing thorough 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 be balance the load of the network and prevents the formation of holes. Therefore in this research work Energy Aware Greedy Routing (EAGR)

algorithm has been proposed for geographic routing in sensor networks. The simple Greedy algorithm and EAGR algorithm have been implemented and simulation results have been obtained which shows that our proposed EAGR algorithm performs better and efficiently than the simple Greedy routing. The simulations based upon the different number of nodes by employing these two algorithms considering different parameters (i.e. the successful packet delivery and number of nodes alive as the performance criterion). It has been observed that EAGR has less average time delay at the single node as compared to the Greedy algorithm because of the fact that EAGR algorithm has more alive nodes. The performance of EAGR algorithm is much better than the Greedy algorithm in the defined parameters. Consequently, it can be concluded that EAGR can effectively extend the network lifetime and increase the successful data delivery rate.

Sensor networks are an emerging field with a lot of potential for research. In this research work, fixed sizes of packets have been utilized, therefore using very simple energy model for energy computation purposes. This work can be extended by considering the variable length of packets and the changing distance of transmitting node from its neighbors. Therefore there is a need of such an energy model that can calculate the energy consumption of nodes based on their sizes and distances.

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