ENERGY AWARE GPSR ROUTING PROTOCOL IN A WIRELESS SENSOR NETWORK

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ABSTRACT

Energy is the scarce resource in wireless sensor networks (WSNs), and it determines the lifetime of WSNs. For this reason, WSN algorithms and routing protocols should be selected in a manner which fulfills these energy requirements.

This paper presents a solution to increase the lifetime of WSNs by decreasing their energy consumption. The proposed solution is based on incorporating energy information into Greedy Perimeter Stateless Routing (GPSR) Protocol.

The proposed solution performs better in energy consumption, network lifetime and packet delivery ratio, with a performance gain of Network Lifetime 45.9% - 78.69%. However, the performance is comparatively low in average delay because of computational complexity.

Key Words: *Wireless Sensor Networks, GPSR protocol, Geographical routing protocol, `*
Energy aware routing protocol,

INTRODUCTION

Wireless sensor networks [1] have inspired tremendous researches of interest since the mid-1990s. Advancement in wireless communication and micro electro-mechanical systems (MEMSs) have enabled the development of low-cost, low power, multifunctional, tiny sensor nodes that can sense the environment, perform data processing, and communicate with each other over short distances.

The era of WSNs is highly anticipated in the near future. In September 1999, WSNs were identified by Business Week as one of the most important and impactive technologies for the 21st century. Also, in January 2003, the MIT's Technology Review stated that WSNs are one of the top ten emerging technologies [2].

WSNs are composed of sensor nodes that must cooperate in performing specific functions. In particular, with the ability of nodes to sense, process data, and communicate. They are well suited to perform event detection, which is clearly an important application of wireless sensor networks. On the other hand, energy efficiency has always been a key issue for sensor networks as sensor nodes must rely on small, nonrenewable batteries.

WSNs present tradeoffs in system design [3]. On the one hand, the low cost of the nodes facilitates massive scale and highly parallel computation. On the other hand, each node is likely to have limited power, limited reliability, and only local communication with a modest number of neighbors. These limitations make WSNs unrealistic to rely on careful placement or uniform arrangement of sensors.

Rather than using globally accessible expensive global positioning system (GPS) to localize each sensor, beaconing protocol is used to enable sensors to know their neighbors' positions on demand. The operation of beaconing protocol is based on the measure of received radio signal strength, where this radio information is used to compute ranges. The one with low radio signal strength is shortest to the destination and is selected to forward data.

For example, as shown in Fig. 1, suppose node X has a packet intended to send to node D. First, node X sends Beaconing signal to its neighbors, (N1, N2, N3, and N4). These neighbors in turn reply to node X. The path which received low signal strength is selected, (path X → N4)), to forward packet towards destination D.

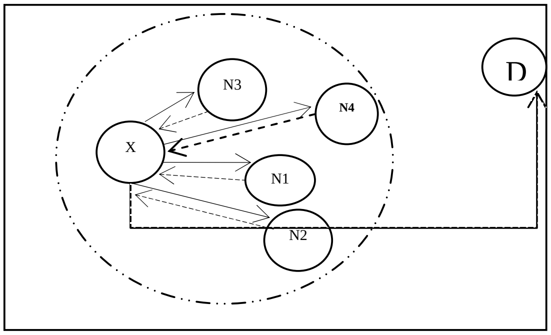

Figure 1 Beacon's working principle

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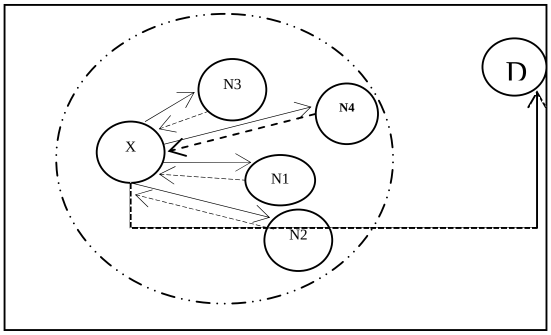

Figure 1 Beacon's working principle

Section 2 presents the different routing protocols in WSNs. Greedy Perimeter Stateless Routing Protocol is explained in Section 3. Section 4 presents related work on energy-efficient routing. The proposed algorithm and its implementation is described in Section 5. Simulation set-up and performance metrics are presented in Section 6. Section 7 discusses the results obtained, while Section 8 concludes the paper.

ROUTING PROTOCOLS IN WSNS

Routing in WSNs is a very challenging task due to the inherent characteristics that distinguish these networks from other wireless networks like cellular or mobile ad hoc networks. Traditional IP-based protocols may not be applied to WSN, due to the large number of sensor nodes and because getting the data is often more important than knowing the specific identity of the source sending it. Furthermore, almost all applications of sensor networks require the flow of sensed data from multiple sources to a particular base station, sink. Sensor nodes are constrained in terms of energy, processing, and storage capacities, thus requiring careful resource management. Sensor networks are strictly dependent on their applications, and the design requirements of a sensor network change with the applications. Furthermore, position awareness of sensor nodes is important since data collection is normally based on their location. Finally, since data collected by many sensors in a WSN are typically based on common phenomena, they are often much correlated and contain a lot of redundancy. Such redundancy needs to be exploited by the routing protocols to improve energy and bandwidth utilization [4].

Flat Routing

In flat networks, sensor nodes typically play the same role and collaborate together to perform the sensing task [5]. The lack of a global identification due to the large number of nodes present in the network and their random placement, typical of many specific wireless sensor network (WSN) applications, make it hard to select a specific set of sensors to be queried.

Hierarchical Routing

In a hierarchical architecture, higher energy nodes can be used to process and send the information while low-energy nodes can be used in monitoring the interested area and gathering data [5]. This means the creation of clusters with the assigning of special tasks to cluster heads, such as data fusion and data forwarding, in order to achieve system scalability, network lifetime increment and energy efficiency.

Geographical Routing

Geographical Routing protocol exploits information about the location of the sensors in order to forward data through the network in an energy-efficient way [5]. The location of nodes may be available directly from a GPS system or by implementing some localization protocol.

The possible advantage is a much simplified routing protocol with significantly smaller or even non existing routing tables as physical location carries implicit information to which neighbor to forward a packet to.

GREEDY PERIMETER STATELESS ROUTING (GPSR)

Greedy Forwarding Rule**:** In GPSR, packets are marked by their originator with their destinations' locations. As a result, a forwarding node can make a locally optimal greedy choice in choosing a packet's next hop. Specifically, if a node knows its radio neighbors' positions, the locally optimal choice of next hop is the neighbor geographically closest to the packet's destination. Forwarding in this region follows successively closer geographic hops, until the destination is reached. An example of greedy next-hop choice appears in Fig. 2.

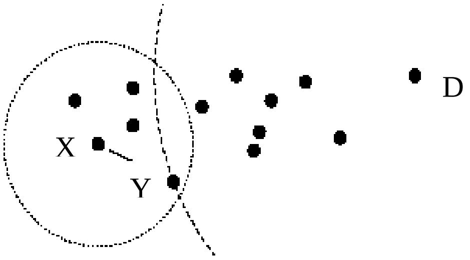

Figure 2 Greedy forwarding examples. Y is X's closest neighbor to D.

Here, X receives a packet destined for *D*. X's radio range is denoted by the dotted circle about X, and the arc with radius equal to the distance between Y and *D* is shown as the dashed arc about *D*. X forwards the packet to Y, as the distance between Y and *D* is less than that between *D* and any of X's other neighbors. This greedy forwarding process repeats until the packet reaches *D*.

Advantage of Greedy Forwarding Protocol is its reliance only on knowledge of the forwarding node's immediate neighbors. The state required is negligible and dependent on the density of nodes in the wireless network, not the total number of destinations in the network. For more details about GPSR's advantage and limitations refer to [6].

RELATED WORK ON ENERGY-EFFICIENT ROUTING

The current work on energy-efficient routing assumes that all the nodes in the network are always available to route all packets. In reality, since nodes consume power even in idle mode, significant overall energy savings can be achieved by turning off an appropriate subset of the nodes without losing connectivity or network capacity. There has been much work on topology control algorithms [7, 8] based on the notion of connected dominating sets that reduce energy consumption precisely by periodically putting some nodes into sleep mode.

Geographic and Energy Aware Routing (**GEAR**) exploits geographic information while propagating queries only to appropriate regions [9]. It can be classified as a data-centric algorithm with geographic information knowledge. The process of forwarding a packet to all the nodes in the target region consists of two steps. The first one aims at forwarding the packets towards the target region and the second step is concerned with disseminating the packet within the region. However, the GEAR protocol has a limitation, which is not scalable and all nodes are active even though only a part of the network is queried.

Geographic Adaptive Fidelity (GAF) is an energy-aware location-based routing algorithm [8]. The network area is divided into fixed zones to form a virtual grid, as shown in Fig. 3. GAF uses equal areas of square zones, whose size is dependent on the required transmitting power and the communication direction. GAF exploits the equivalence of all nodes inside the same zone by keeping at least one node per zone awake for a certain period of time and turning all the others in that zone into sleep state during that time. With high mobility of nodes there is a high packet loss as nodes may leave the gird without replacing an active node which is the disadvantage of GAF.

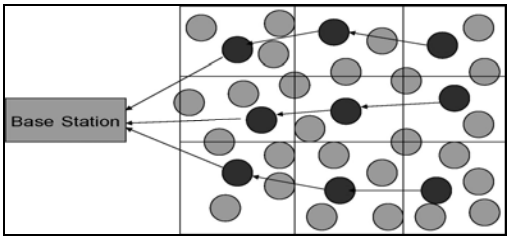

Figure 3 Virtual grid formations in a GAF

Adaptive Self-Configuring Sensor Networks Topologies (ASCENT) adaptively elects "active" nodes from all nodes in the network [8]. Active nodes stay awake all the time and perform multi-hop packet routing while the rest of the nodes remain passive and periodically check if they should become active. To do this, ASCENT has four state transitions: Test, Active, Passive and Sleep. ASCENT depends on the routing protocol to quickly re-route traffic. This may cause some packet loss, and therefore an improvement that has not been implemented is to inform the routing protocol of ASCENT's state changes so that traffic could be re-routed in advance. ASCENT does not work for low density nodes and behaves differently for a different routing protocol which is the limitations of this work.

PROPOSED ALGORITHM AND ITS IMPLEMENTATION

The GPSR routing protocol does consider only the shortest distance to the destination during path selection. However, in wireless sensor network (WSN) energy is a scarce resource, so we are going to consider the remaining energy of nodes, energy for transmission and receiving by making nodes that are not participating in communication to go into sleep mode. As nodes in sleep mode use least amount of energy. Hence, we can reduce energy wastage.

Assumptions

This section presents the basic design of the proposed protocol, which works with the following network setting:

- A vast field is covered by a large number of homogeneous sensor nodes which communicate

- The wireless communication channels are bidirectional. Each sensor node has constrained battery energy.
- After having been deployed, sensor and sink nodes remain stationary at their initial locations.
- Target (source) node moves randomly.

Proposed Solution

GPSR routing protocol uses Greedy Forwarding to route data to neighboring nodes which does not consider either remaining energy of nodes or the transmission energy, so that a packet (a data) reaching to a destination is in question. The proposed solution consists of two-step-solution. The first step is concerned with making nodes which are not participating in either sending or receiving to go into sleep mode. The second one is considering remaining energy of nodes in addition to the shortest path during path selection. Then in wireless sensor network (WSN) there are 3 states of a Node:

Active, Sleep and Idle, as shown in Fig. 4.

The active node consumes more amount of energy while idle node consumes lesser and sleep node consumes the least amount of energy. Hence a good power saving algorithm should make the active number of nodes as little as possible [7].

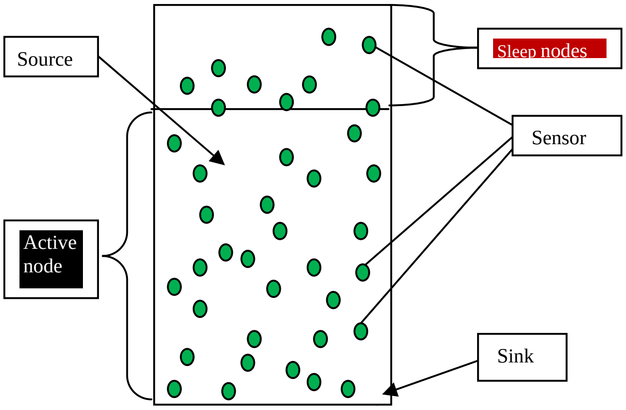

Figure 4 Proposed scheme

Step I

If nodes are farther away from a sink node than source node, they will enter Sleep mode to save energy and will stay till next communication. All other nodes will be in active mode and will participate in sending and receiving a packet. During a communication cycle, we set a timer. At the end of the communication cycle, the timer is reset and all the nodes in a grid are set to active mode.

Step II

Minimum weight function is an important key to make the routing decision by a source node to a destination. In this section we will formally define how to calculate the value of minimum weight function and using this weight to evaluate the proposed protocol.

Minimum weight function contains two factors, the distance from a source node to the destination and the remaining energy level of neighbor nodes. The minimum weight function W_i, of neighbor node $x(i)$ is defined as follows:

$$W_i = \min_{i \in N}\left[(d(x(i), y) + \frac{1}{E_{rfi}}\right] \qquad (1)$$

Where

- Wi is the minimum weight value among the N neighbors of a source node
- x(i) is the position of the ith neighbor node of a source node
- d(x(i),y) is the Eculidean distance between the ith neighbor node and the destination y
- Erfi is the remaining energy factor

$$E_{rfi} = \frac{E_{oi} - E_{ci}}{E_{oi}} \qquad (2)$$

Where

- E_{oi} is the initial energy of node *i*
- E_{Ci} is the consumed energy of node *i* [10].

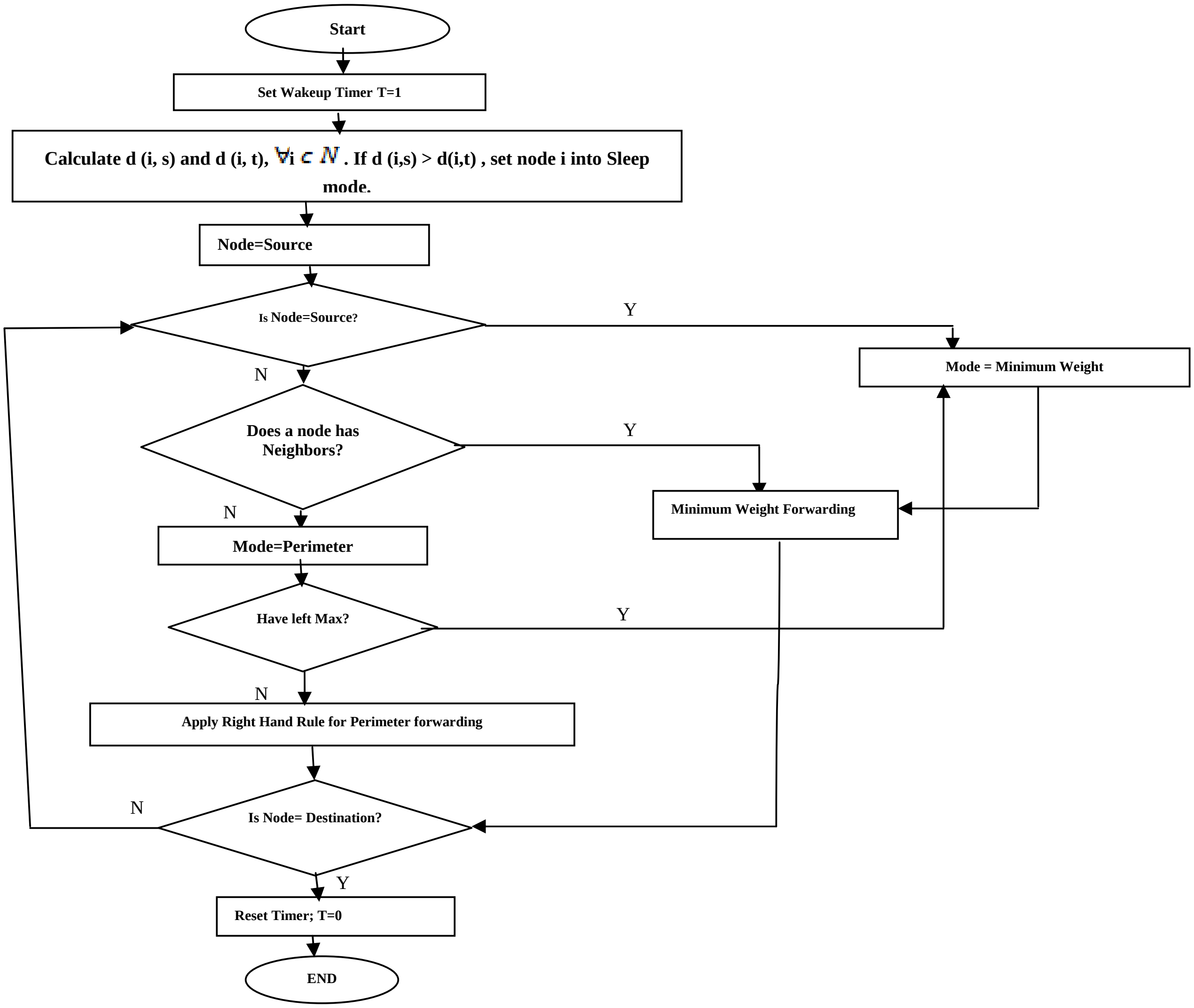

Figure 5 Flow chart

The flow chart in Fig. 5 represents the two step solution, where it first sets a timer to make nodes either sleep or active by calculating distance d (i,s) and d(i,t).

If d (i,s) > d(i,t), node i will go into sleep mode otherwise it will be active.

- d(i,s) is the Euclidean distance of each node i to a sink node s and
- d(i,t) is the Euclidean distance of each node I to a target (source) node t.

The original GPSR routing protocol uses Greedy Forwarding when there is a neighbor node and Perimeter Forwarding when the source node has no neighbor or when its neighbor's distance is shorter than itself to a destination. Whereas our proposed algorithm uses Minimum Weight Forwarding (shortest distance plus residual energy) instead of Greedy Forwarding and Perimeter Forwarding to come out of no neighbor problem until it reaches a destination. If the forwarding node is a destination, wakeup timer (T) will be reset and all nodes become active and this process is repeated again.

SIMULATION SETUP AND PERFORMANCE METRICS

The proposed algorithm is implemented by J-Sim simulation. J-Sim have the following features:

- As it is implemented in Java, makes J-Sim a truly platform-independent and reusable environment.

- It is a dual-language simulation environment like NS-2 in which classes are written in Java and scripts using Tcl/Java (Jacl).

- Only the public classes/methods/fields in Java can be accessed in the Tcl environment instead of exporting explicitly all classes/methods/fields like other simulators, e.g. NS-2.

- J-Sim exhibits good scalability for the memory allocation to carry out simulation of length 1000. It is at least two orders of magnitude lower than that in NS-2 [11].

The simulation is done on different performance metrics, to compare the performance of the proposed algorithm against the original GPSR routing protocol.

The implementation has the following assumptions:

- The sensor nodes are deployed in a random manner.

- Node density, target (source) speed may represent a moving tank, and percentage of number of node failures are varied during simulation.

Simulation Setup

To explore the results, we conduct a detailed simulation using a J-Sim simulator. In our simulation up to 450 sensors are scattered over to a 350 × 350 m^2 sensor field. Other simulation parameters are listed in Table 1, most of which are taken from white papers of commercial products vendors.

Table 1: Simulation parameters

Variables	Values
Communication Rage	15 m
Simulation Time	200sec
Simulation Area	350 x350 m^2
Target node Speed	10 m/s and 15m/s
Number of Nodes	450
Node receiving power	14.88mW
Node transmitting Power	12.50mW
Node Idle mode power	12.36mW
Node Sleep mode power	0.016mW

Performance Metrics

Although different researchers propose different performance metrics to evaluate the performance of routing protocols, we use the following metrics for evaluating the efficiency of the proposed routing protocol.

- **Average *Energy Consumption*:** The average energy consumption is calculated across the entire topology. It measures the average difference between the initial level of energy and the final level of energy that is left in each node. Let E_i and E_f be the initial energy and final energy level of a node respectively and N the total number of nodes in the network. Then

$$EC=\frac{\sum_{k=1}^{N}(E_{ik}-E_{fk})}{N} \qquad (3)$$

- **Average Data Delivery Ratio***:* This represents the ratio between the number of data packets that are sent by the source and the number of data packets that are received by the sink.

$$R=\frac{\text{Number of packets received by Sink}}{\text{Number of Packets send by Source}}$$

- **Average Delay:** It is defined as the average time difference between the moments of data packets received by the Sink node and the moments of data packets transmitted by the Source node. This metric defines the freshness of data packet.

$$AD=\frac{\sum_{i=2}^{N}\left(Time\ \ packet\ \ recived_i - Time\ \ packet\ \ sent_i\right)}{Total\ \ number\ \ of\ \ packets\ \ received}$$

N: number of packets

- **Network Lifetime (NL):** This is one of the most important metrics to evaluate the energy efficiency of the routing protocols with respect to network partition. In wireless sensor networks (WSN), especially in those with densely distributed nodes, the death of the first node seldom leads to the total failure of the network. When the number of dead nodes increases, the network is partitioning too. Network Lifetime can be defined in the following ways
    - It may be defined as the time taken for K% of the nodes in a network to die.
    - It can also be the time for all nodes in the network to die.
    - The lifetime of the network under a given flow can be the time until the first battery drains-out (dies) [12]

We adopt the third definition for the analysis of this work. Here, a node with less than 20% of its full battery capacity is considered as a dead node based on the definition in [2].

SIMULATION RESULTS AND DISCUSSIONS

We deploy the nodes in a region of size 350 x 350 m^2. Sensor nodes are deployed randomly; Sink node is fixed at the lower right corner of the grid and target (Source) node deployed at the center of grid and moves with a speed of 10 m/s. There are one sink node, one target node and 450 sensor nodes in our simulation environment.

Each target node generates stimuli every 1.5 seconds and sensing radius is 15m. The number of nodes in the region is controlled by increasing nodes from 50 to 450 with step of 100. The simulation time is 200 seconds and the parameters are affected by the number of nodes used in the simulation, simulation time and node failures. We consider two scenario designs. All the experiments are conducted on a dual processor Intel 2.66 GHz machine running Windows XP Professional with 2 GB RAM. Each data point reported below is an average of 20 simulation runs, [13].

Scenario-1:

This Scenario follows parameters shown in Table 2.

Table 2: Scenario 1 parameters

Variables	*Values*
Target Speed	10 m/s
Number of Nodes	450
Sink Location	(350,0)
Target Location	(150,150) and moves
Sensor Location	Randomized and stay static
Random Node Failure	With no Failure

Scenario-1 Results

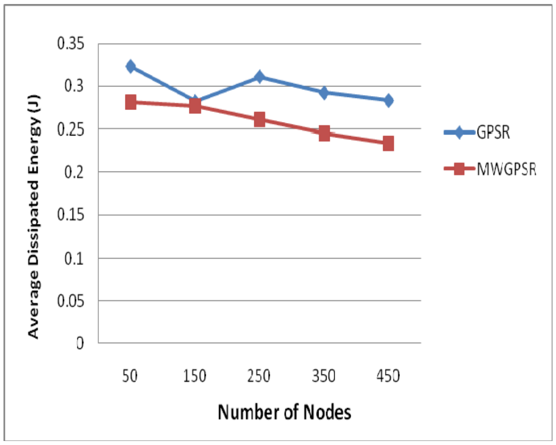

Figure 6 Average energy consumption (no node failure, speed 10m/s)

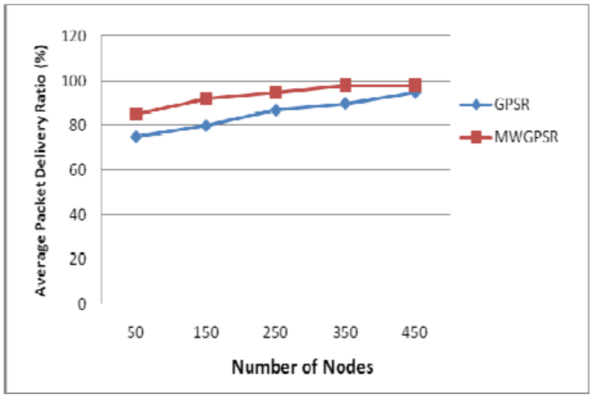

Figure 7 Average packet delivery ratio (no node failure, speed 10m/s)

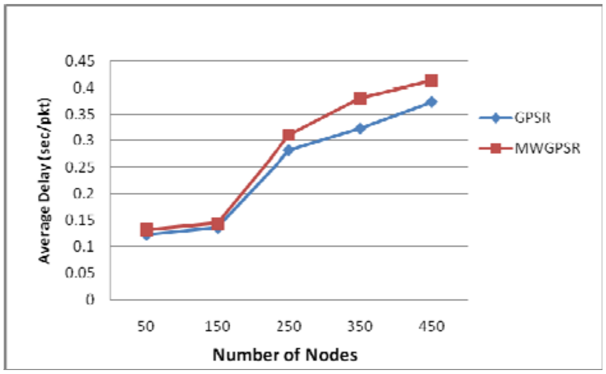

Figure 8 Average delay (no node failure, speed 10m/s)

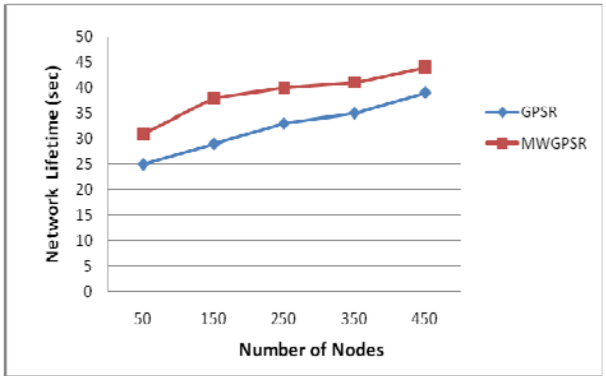

Figure 9 Network lifetime (no node failure, speed 10m/s)

Scenario-1: Discussion of Results

Figures 6, 7 and 9, show that the proposed solution performs better in energy consumption and packet delivery ratio than the original GPSR protocol and hence the Network Lifetime is improved significantly. As the aim of our interest is to increase the lifetime of the network, the goal is achieved by considering residual energy in the proposed solution which reduces individual node failure and network partition. Moreover, making nodes which are not participating in transmission or receiving into sleep mode reduces overall node failures. Hence the number of node failure and energy wastage decrease, i.e. the lifetime of the network increases.

Whereas Fig. 8 shows that the average delay of the proposed solution is larger as compared to the original GPSR protocol because the proposed solution checks not only the shortest distance but also the residual energy and distance calculation to make nodes either in sleep or in active mode. The proposed algorithm uses a number of parameters to select a route than the original GPSR protocol. The cause of the delay is due to computational complexity.

Scenario-2

This Scenario follows parameters shown in Table 3.

Table 3: Scenario 2 parameters

Variables	Values
Target Speed	15 m/s
Number of Nodes	450
Sink Location	(350,0)
Target Location	(150,150) and moves
Sensor Location	Randomized and stay static
Random Node Failure	15% Failure

Scenario-2 Results

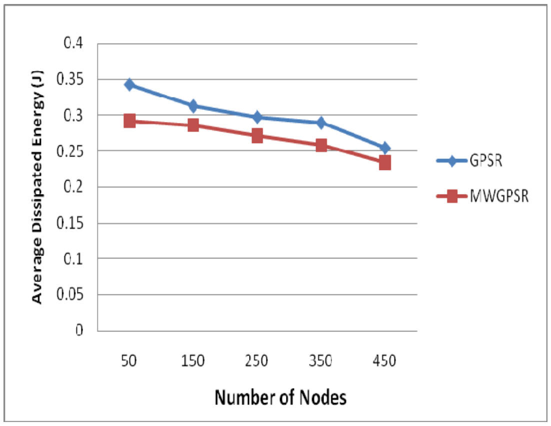

Figure 10 Average energy consumption (15% node failure, speed 15m/s)

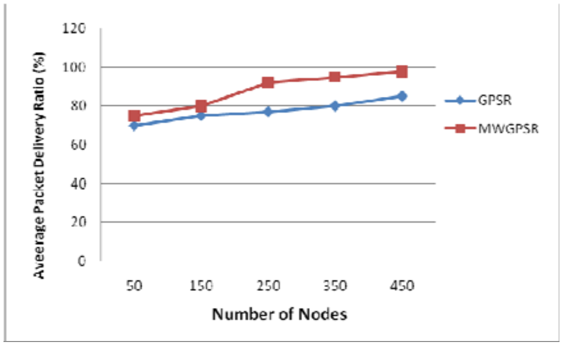

Figure 11 Average packet delivery ratio (15% node failure, speed 15m/s)

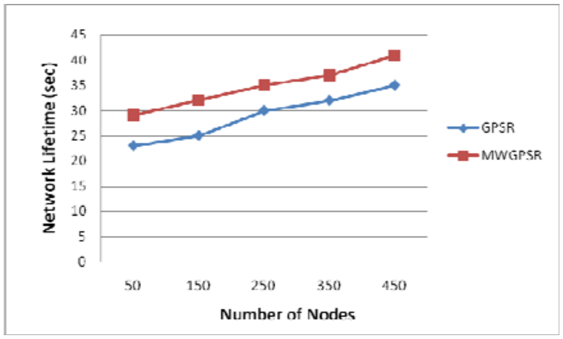

Figure 12 Network lifetime (15% node failure, speed 15m/s)

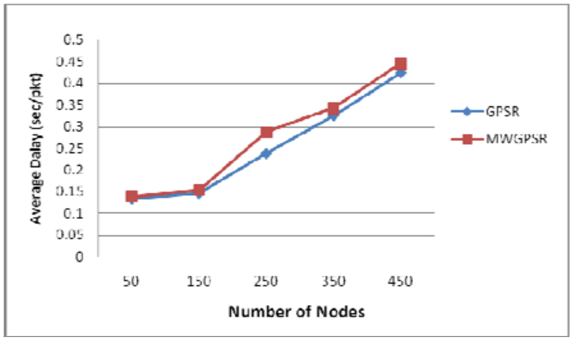

Figure 13 Average delay (15% node failure, speed 15m/s)

Scenario-2: Discussion of Results

Figures 10, 11, and 12 show that the proposed solution performs better in energy consumption and packet delivery ratio than the original GPSR protocol and hence there is an improvement in Network Lifetime. As Figures 13 shows, the average delay is low too.

In scenario 2 as compared with scenario 1, the average energy consumption, average packet delivery ratio and Network Life time is comparatively low. This is because in scenario 2, target speed is more which incur routing over-head. Further, due to node failure, less number of nodes will be available for routing i.e. there is more energy consumption.

CONCLUSIONS

In this paper, we have studied GPSR routing protocol, which is a geographical routing protocol and uses a greedy forwarding whenever possible and perimeter forwarding, if not possible. It considers only distance during packet routing. In order to increase the lifetime of a network, we added energy information and making nodes, which are not participating in sending or receiving packets, in to sleep mode.

To show the performance gained, the proposed solution was compare with the original GPSR routing protocol using J-sim simulation software. The simulation output indicates that, there is a performance gained in average energy consumption, average packet delivery ratio and network lifetime from 45.9% to 78.69%. However, the proposed solution increases the average delay due to high computational complexity.

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