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SINK MOBILITY MODEL FOR WIRELESS SENSOR NETWORKS USING GENETIC ALGORITHM

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ABSTRACT

Wireless sensor networks have been an interesting subject of research and have various types of applications in different areas of interest. Thus, enhancing the performance of these network using mobile sinks is one of the major issues and concerns that must be taken into account. In this paper, a new sink mobility model based on using genetic algorithm is proposed. Genetic algorithm is used to construct the path to be followed by the mobile sink in order to collect data form static sensor nodes. Consequently, the mobile sink will traverse the calculated path in order to visit static sensor nodes and collect data. After that, NS-2 simulator is used to simulate the proposed mobility model. Furthermore, the performance of the proposed model was studied using different simulation scenarios and performance parameters.

Keywords- *Wireless Sensor Networks, Genetic Algorithm, Mobility Model, Performance, Sink Node*

1. INTRODUCTION

Advances in microprocessors and communications have made it possible to develop tiny and lightweight wireless sensor nodes that can be autonomously deployed in the area of interest to form a wireless sensor network (WSN). Thus, WSNs will gather large amounts of information from the deployment area regarding the phenomena being studied such as temperature, humidity, pressure and movement to name a few [1][2]. Hence, WSNs have various applications in different fields such as military, civil and industrial applications. For example, WSNs can be used in battlefield monitoring, industrial control process, home automation and traffic monitoring [3][4].

Furthermore, WSNs are resource constrained and are expected to operate for long periods of time in an unattended manner. Also, sensor nodes are not only responsible for collecting information from the environment and reporting these information to the base station but also, they are required to forward and route messages sent by other sensor nodes until these messages are delivered to their destinations. This approach prolongs the network lifetime by reducing the amount of energy consumed in communication by every sensor node using multi-hop communication. Thus, every sensor nodes communicates with its neighbours only. On the other hand, sensor nodes that are close to the base station might consume most of their energy forwarding messages sent by other sensor nodes. As a result, close sensor nodes will get there battery depleted quickly [5].

Therefore, researchers have addressed different aspects of WSNs such as energy efficiency and routing in order to enhance WSNs performance and prolong their lifetime. Additionally, some researchers have proposed deploying energy rich mobile sink node or nodes that move between static sensor nodes randomly or according to a specific pattern or model in order to collect data. Using those mobile nodes can help in prolonging the lifetime of sensor nodes and enhancing the performance of wireless sensor networks. Also, it will help in reducing the end to end delay because message will go through small number of hops in order to reach the base station. Additionally, static sensor nodes will report data to the mobile sink when the mobile sink is in its communication range. Thus, static sensor nodes will not be acting as routers most of the time. Consequently, sensor nodes' energy is conserved and the network lifetime is prolonged [5][6].

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In this paper, we propose using a single energy rich mobile sink that will move within the WSN according to a specific mobility model to collect data from static sensor nodes. The mobility model proposed in this paper is based on using genetic algorithms in order to construct a specific path that will be used by the mobile sink to visit every static sensor node in order to collect information from them. The proposed mobility model is simulated using NS-2 simulator and its performance is studied under different network sizes and speeds of the mobile sink. End-to-end delay, packet delivery ratio and throughput are the parameters used to study the performance of the mobility model proposed in this paper.

To elaborate the main contribution of this paper can be summarized as follows:

1. Proposing a new sink mobility model that can be used to collect data from static sensor nodes.
2. Simulating the proposed work and studying the performance of the network according to several performance metrics. As a result, the effect of the proposed mobility model will be studied. Also, the most suitable conditions, in terms of mobile sink mode speed and sensor network size, can be highlighted.

In other words, the main contribution of this paper is to adopt using genetic algorithms in order to propose a new sink mobility model that can be used by a mobile sink in order to collect data from sensor nodes. The main motivation behind this work is to propose a sink mobility model that can be used to visit all sensor nodes in the network. The main idea is based on calculating the optimal path to be followed by the mobile sink. As a result, static sensor nodes get visited at reasonable periods of time in order to avoid buffer overflow. Additionally, the adoption of the proposed mobility model should play a major role in enhancing the performance of the network. Say it in another way, when using the proposed mobility model, the sensor network should be able to provide high levels of performance in terms of packet delivery ratio and throughput. Also, low levels of end-to-end delay should be achieved. Finally, the effect of the mobility model on the routing protocol should be minimal in order to avoid increasing the number of control messages exchanged and to avoid performance degradation of the network. Thus, the mobile sink should be moving according to a reasonable speed in order to have enough time to collect information from static sensor nodes and to avoid changes in the routes calculated by the routing protocol.

The remaining sections of this paper are organized as follows; in section 2 related work is discussed. Then, the proposed work is presented and discussed in section 3. After that, simulation scenarios and parameters are discussed in section 4. In section 5 the obtained results are reviewed and discussed. Finally, conclusions and future work were addressed in section 6.

2. RELATED WORK

Many researchers proposed enhancing the performance of WSNs by deploying a single mobile sink. This mobile sink will be moving within the network and is responsible for collecting data from static sensor nodes.

As a result, a breadth first sink mobility model was proposed in [5]. In this work the mobile sink moves in a controlled path that is calculated using the breadth first graph traversal algorithm. Also, the proposed sink mobility model is divided into movement periods and sojourn periods where in the movement period the mobile sink moves towards a new location that is calculated based on the breadth first traversal algorithm. Upon arrival to the new location, the sojourn period is started and the mobile sink pauses for a specific period of time in its new location.

Moreover, the authors in [7] proposed a method that can be used to relocate the sink node. The proposed method is based on grouping sensor nodes into clusters based on their distance to the mobile sink. To elaborate, the distance between the sink node and static sensor node is the main parameter to be considered in order to group static sensor nodes into clusters. Thus, static sensor node with similar distance from the mobile sink will be members of the same cluster. Additionally, the repositioning of the sink node is established according to the selected cluster heads and is based on two methods, namely cluster head with minimal distance and cluster head with long distance, where the distance between the sink node and the cluster head helps to determine the method to be used.

Subsequently, a mathematical model for sink node mobility was proposed in [8]. The proposed model aims to extend the lifetime of the network and is based on firstly deploying the mobile sink at the centre of the area of study. Then, the model calculates a number of tentative locations for the mobile sink after that, the new location of the mobile sink is selected among the set to tentative locations.

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In addition, a data gathering protocol that is responsible for designing the trajectories that will be adopted by the mobile sink to move within the network and collect data from static sensor nodes was proposed in [9]. Therefore, the protocol is based on the following phases; data sensing, rendezvous point (RP) selection, trajectory design, and data gathering. Moreover, the movement path of the mobile sink is built according to three algorithms in order to provide support for different types of applications.

A solution for the relay selection problem that is based on k-means clustering method was proposed in [10]. After the clusters are formed, the authors propose deploying and using a mobile sink within each cluster that can be used to collect information from sensor nodes that are members of the same cluster.

Another technique that aims to reduce the delay and enhance the performance of a wireless sensor network by increasing the throughout was proposed in [11]. The proposed technique uses an opportunistic method for data collection from static sensor nodes. Thus, when a sensor node has data to be transmitted to the mobile sink; it first checks whether the mobile sink is in its vicinity. If the mobile sink is within communication range of the sensor node, data will be transmitted directly to it otherwise, the sensor node stores the data it has until the mobile sink gets in range. Hence, data can be communicated via single-hop communication.

Additionally, the research in [12] proposed deploying mobile sink nodes along with clustering in order to reduce energy consumption and prolong the lifetime of the network. In their work the authors proposed moving the mobile sink within a cluster. In addition, the mobile sink has the ability to move between clusters in order to collect data. Therefore, upon its arrival to a new cluster, the mobile sink moves within the cluster in order to collect data from member sensor nodes. After that, the mobile sink will move to a new cluster and so on.

Furthermore, a location based sink mobility model was proposed in [13]. In the proposed mobility model, the movement of the mobile node is dependent on different factors namely; network topology, the distance between the current and previous locations and the distance between the current location of the sink node and the and the newly selected on which the sink nodes may start moving to. In addition, the behaviour of the mobile node is divided into active and inactive phases. Thus, data is transmitted during the active phase. On the other hand, mobile node movement is executed during the inactive phase.

In [14] a mobility model consisting of two algorithms or protocols was proposed. The first part is named Sinktrail-s and can be used when it is not possible to determine the new location of the mobile sink in advance. On the other hand, the second part is called Sinktrail that can be adopted in order to provide the mobile sink with the ability to adapt to changes in the area of deployment without using GPS or special land marks.

A neighbourhood weighted rendezvous technique was proposed in [15] so that, the mobile sink is not obliged to visit all static sensor nodes. Hence, a subset of static sensor nodes is selected to act as data points. As a result, the rest of the static sensor nodes are required to report data to the selected data points. Consequently, the mobile sink is required to visit the data point nodes in order to collect data where single-hop communication can be used. Also, the data point nodes are select in a way so that the energy consumption in the network is distributed evenly.

Moreover, the research in [16] proposed dividing the network into hexagonal clusters with a specified radius. Within each cluster, the node with the highest energy level is chosen to be the cluster head. After that, a mobile node within the cluster is selected according to two conditions; the first one is based on the energy level so that the mobile node is the node with the second highest energy level after the cluster head. The second condition is based on the distance so that the selected mobile node must be the closest on to the cluster head. Thus, member nodes of the cluster will send data to the mobile node which is responsible for forwarding data to the cluster head.

Furthermore, to avoid redundant paths of the mobile sink, a quorum algorithm was proposed in [17]. Hence, asynchronous protocols, which are based on wake up time scheduling, are adopted for neighbor discovery. Thus, a quorum graph can be deduced and the mobile sink can determine the area or node with the largest number of neighboring nodes. As a result, the mobile sink will move towards that area so that a largest amount of information can be collected.

3. PROPOSED WORK

3.1 Genetic Algorithm

Genetic algorithm (GA) is a technique that can be used to obtain results in order to solve problems using a selection procedure that is accomplished naturally. At each phase, individuals are selected from the population and are used in order to generate offsprings to be used by the next generation. After that, using the new generation, better results can be obtained by the population [18]. The process of genetic algorithm consists of the following steps:

a. Population Initialization

In this step, a randomly generated initial population of any size is created. Using random initialization for the initial population is considered one of the most suitable and commonly used approaches in order to generate the population [19].

b. Determine Fitness Function

In order to determine how close a given solution is to the optimal or desired one, a fitness function must be used. As a result, the function according to which the solution will be evaluated must be determined [20]. This step is important for the operation of genetic algorithm because the survivability of a solution is decided based on the value generated by the fitness function.

c. Calculate Fitness Value

According to [19], this step is based on calculating the fitness value for every individual in the population. As a result, this step is important to the operation of the genetic algorithm because it plays a major role to determine the fittest solution to be adopted.

d. Selection, Crossover and Mutation

The selection operator is responsible for choosing individuals with highest fitness values in order to use them to produce more reproductions possibilities to achieve a better solution. In this process, based on the value obtained from the fitness function, two parents are selected in order to derive a new generation or population from them [21].

In crossover, a parent is formed by combining the genes of two individuals. The main concept depends on combining the genes of two parents in order to create a new offspring by alternating parts of the parent genes. As a consequence, new offsprings with higher fitness values can be produced [20][22].

On the other hand, mutation is the process of switching certain genes within the same chromosome thus, other chromosomes can be obtained and used as a new input for the next generation [20].

Crossover and mutation are very important steps of genetic algorithm because through these two steps the genetic algorithm will have the ability to converge and produce new solutions until the most suitable one is provided. The main goal of crossover is to combine and pass the information of the parents, chosen in the selection process, from the current population to the new one. On the other hand, the main goal of the mutation process is to randomly and locally modify selected chromosomes [21].

e. Terminating Condition

After reaching the specified number of generations the GA will terminate.

3.2. Proposed Mobility Model

In this section all the steps of GA discussed in section 3.1 will be discussed to present the mobility model proposed in this paper. The proposed work in this paper is based on a randomly deployed heterogeneous sensor network consisting of N static sensor nodes and an extra node representing the mobile sink node that is responsible for collecting data from the static sensor nodes. Furthermore, the main objective of the proposed mobility model is to use GA to provide the mobile sink with an optimal path in order to visit all static sensor nodes and collect information where the movement of the mobile sink starts and ends at the same node. The proposed mobility model follows the GA steps as explained below:

a. Population Initialization

Since the proposed mobility model is based on a randomly deployed WSN, the initial population for the GA is initialized randomly. In this work, the nodes representing the initial solution are randomly selected. Throughout individual generation, as random number between 0 and n is generated. After that, the algorithm checks whether the randomly generated number exists in the current individual. If the number is found then a new number is generated otherwise, the number is added to the current individual [19].

b. Determine Fitness Function

The main goal of the proposed mobility model is to find an optimal path that can be used by the mobile sink in order to visit every static sensor node exactly once to collect information. Thus, Euclidean distance, D, is adopted in order to calculate the distance i.e. cost between static sensor nodes which can be calculated according to Eq. 1 [19].

$$\boldsymbol{D} = \sqrt{(\boldsymbol{x_1} - \boldsymbol{x_2})^2 + (\boldsymbol{y_1} - \boldsymbol{y_2})^2} \qquad \textbf{(1)}$$

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In Eq.1 x_1 and y_1 represents the coordinates of node *m* while x_2 and y_2 are the coordinated of node *n*. note that the distance between any two nodes is the same in both direction [19].

Furthermore, Eq. 1 is used as the fitness function in order to make sure that the when the genetic algorithm selects the next node to be visited, the selected node will be a neighbor of the current node to being visited. As a result, the mobile sink will be moving in different directions when visiting the static sensor nodes.

c. Calculate Fitness Value

The fitness value is obtained by calculating the sum of the distance in order to get the optimal path for the mobile sink. So that, from the current location of the mobile sink the node with the smallest value of the fitness function is selected as the new location of the mobile sink. As a result the mobile sink will move towards the new location.

To elaborate, the fitness function is used in order to help the genetic algorithm to select the closest neighbor of the current node. As a result, the closest neighbor will be selected as the next node to be visited by the sink node. Thus, the sink node will not be travelling for long distances in order to visit the static sensor nodes. On the contrary, it will be moving from one not to its neighbor in order to collect information.

The advantage behind this strategy is to make node visits more feasible for the mobile sink. Also, the neighbors of the currently visited sensor node can rely on multi-hop communication in order to deliver their data to the mobile sink to avoid buffer over flow.

Say it in another way, since the mobile sink is moving from one node to its neighbor, all neighboring static sensor nodes that are not being visited yet by the mobile sink can use multi-hop communication to deliver messages to the mobile sink. Therefore, those static sensor node can avoid their buffers for getting over followed. Also, data can be communicated in a timely manner rather than keeping the static sensor node wait until it is being visited by the mobile sink

d. Selection, Crossover and Mutation

In this part, selection, crossover and mutation will be explained from a networking perspective and based on the example presented in figure 1.

In this stage multipoint crossover is used. To elaborate suppose we have a network consisting of 5 nodes numbered form 0 to 4. Also, suppose we have two parents that we need to construct an offspring from them. In this crossover method, a subset of the nodes is selected from the first parent. After that, the missing nodes are added from the second parent [23].

Figure 1 shows the nodes from which parent 1 and parent 2 consists from. The subset path taken from parent 1 are 4 and 3 and are added to the offspring. After that, the remaining nodes are taken from parent 2 in the following manner; the first node in parent 2 is node 2 which cannot be found in the offspring. As a result, it is added to the offspring. After that, the second node in parent 2 is node number 3 which already exists in the offspring. Therefore, it will not be added to the offspring as it will be redundant. Then, node 0 is added to the offspring from parent 2 because it cannot be found in the offspring. This process continues until all values in the offspring are filled.

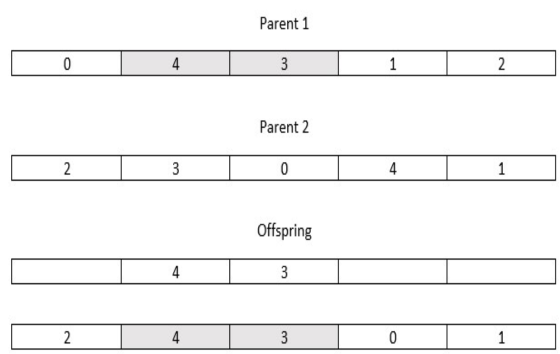

Figure 1 Crossover Example

On the other hand, mutation is the process of swapping two randomly selected entries of the path. For example if the path before mutation is [0, 4, 3, 1, 2]. The path after mutation will be {0, 2, 3, 1, 4} [23].

e. Terminating Condition

After reaching the specified number of generations, the GA will terminate.

After explaining how GA is applied in order to calculate the path to be followed by the mobile sink. The following example will explain the mobility model proposed in this paper.

After explaining the main aspects of the proposed sink mobility model, the following example will explain its operation. Note that, the proposed model is based on a randomly deployed network consisting of N static sensor nodes numbered from n_0 to n_{n-1}. Also, one additional node, n_n, is deployed to act as a mobile sink in order to move between static nodes. To elaborate, consider the network shown in figure 2

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that consists of 5 static sensor nodes numbered from 0 to 4. Also the network contains another node, node number 5, that will act as a mobile sink and move to visit static sensor nodes in order to collect information based on a path that is calculated according to GA through the steps mentioned above in this section.

Nodes number 0, 1, 2, 3 and 4 are randomly deployed and the mobile sink is node number 5. The mobile sink can select the starting node randomly and it is node 1 in this example. After the starting point is selected, the steps of genetic algorithm are applied. As a result, the path to be followed by the mobile sink will be predefined. In the network shown in figure 2, the starting node is node 1 and the path to be followed by the mobile sink is node 1, node 2, node 4, node 0, node 3 and node 1. It can be observed that the calculated path forms the cycle since node 1 is the starting and ending point of the path.

Worth noting, the proposed mobility model is divided into rounds where a round starts from the node selected as the starting point of the path. Additionally, a round finishes when the mobile sink finishes the cycle. In other words, the round is over when the mobile sink arrives to the starting point again after visiting all static sensor nodes. When a round is over, a new round is started using the same path adopted in the pervious round.

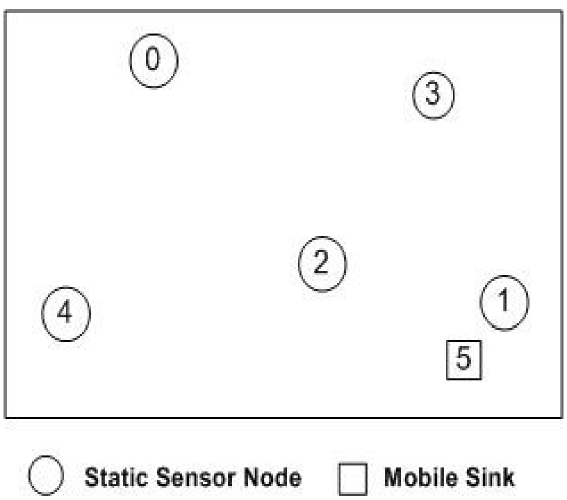

Figure 2. Example Network

Furthermore, the movement of the mobile sink is divided into movement periods and pause periods. In other words, after the starting node is selected and the movement path being calculated, the mobile sink moves near to the position of the starting node and pauses in that position for a specified period of time in order to collect data form it. After the pause period is over, the mobile node moves to the next specified node in the path and pauses in the new position for the same period of time used before and so on until the cycle is complete.

To elaborate, consider the small network shown in figure 2. The starting node is randomly selected to be node 1 and the path is calculated to be 1, 2, 4, 0, 3 and 1. As a result, the sink node, node 5, moves towards node 1 until it gets in node's 1 communication range. After that, node 5 pauses for a specified period of time to collect data from node 1 via single-hop communication. When the pause period is over, node 5 moves towards node's 2 vicinity. Upon arrival to its new position, the node 5 pauses in the new location for the same amount of time used before. This process continues until all the nodes are visited and node 1 is visited again by node 5.

When node 1 is visited, a round is finished. As a result, node 5 pause for the same period of time used before. Then, a new round is started where node 5 visits all the nodes is the same order used in the previous round i.e. following the same path.

Worth noting, in this paper single-hop and multi-hop communication are used. Therefore, if a static sensor node has data to be sent to the mobile sink, it first checks whether the mobile sink is in its communication range. As a result, single-hop communication will be used to send data to the mobile sink if the mobile sink was within communication range. On the other hand, if the mobile sink was out of communication range of that node, multi-hop communication will be used in order to send data to the mobile sink. Algorithm 1 shows the proposed mobility model.

Algorithm 1: GA BASED MOBILITY MODEL

1. **Start**
2. **Initialize a group of nodes: N = {n_0, n_1, n_2, … n_{n-1}}**
3. **Initialize a mobile sink node: SN = {n_n}**
4. **Let Q be queue**
5. **Generate random population of P individuals for nodes in N**
6. **Calculate fitness f(x) of each individuals x in P**
7. **Repeat steps 7.1, 7.2 and 7.3 until all parents are selected and mated**
   - 7.1. **Select two parents from P**
   - 7.2. **Use crossover operator over the selected parents to create new offsprings**

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7.3. Apply mutation to mutate new offsprings
8. Use newly generated population to replace the old population in P
9. Calculate fitness f(x) of each individuals x in P
10. If the terminating condition is met,
10.1. While p not empty
10.1.1. Enqueue node form P to Q
10.1.2. Remove node from p
11. If the terminating condition is not met go to step 7.
12. Dequeue the first node in the queue and store it in v.
13. Get x and y coordinates of v
14. Let n_n move to x and y coordinates of v
15. Pause in new position for time t
16. Collect data
17. While Q is not empty
17.1. Dequeue the first node in the queue and store it in v.
17.2. Get x and y coordinates of v
17.3. Let n_n move to x and y coordinates of v
17.4. Pause in new position for time t
17.5. Collect data
18. End While
19. Stop

From algorithm 1 it can be observed that the proposed mobility model is divided into two phases; the first phase is initiated before the mobile sink is deployed. As a result, genetic algorithm is applied based on the static sensor nodes and their positions in order to find the best path that can be traversed by the mobile sink in order to visit the static sensor nodes. Consequently, in the second phase, the mobile sink will start its movement by visiting the starting node in the path. After that, the mobile sink will move to the next node as indicated in the path generated by the genetic algorithm that was applied in the first phase. Upon arrival to the new position the mobile sink node will enter the pause period in order to collect data. This process continue until all nodes specified in the path are visited where the last node visited is the starting node.

In other words, the calculated movement path to be adopted by the mobile sink node is a cycle where the starting node is the ending node too.

4. SIMULATION

4.1 Simulation Scenarios

The performance of the proposed mobility model was studied through simulation using NS-2 simulator. Also, different scenarios were generated and different parameters were measured. As a result, different network sizes 26, 51, 76 and 101 were used in order to study the performance of the mobility model. Worth noting, 26 nodes network consists of 25 static sensor nodes and one extra node representing the mobile sink node and this applies for all network sizes. The main goal behind using different network sizes is to study the performance of the mobility model under different network densities.

Furthermore, for each network size, the performance was tested under different speeds of the mobile sink, 5, 10, 15, 20 m/s. For example, the performance of the mobility model was studied for 26 nodes network with 5 m/s speed for the mobile sink. After that, the movement speed of the mobile sink was increased to 10 m/s under the same network size and so on for all network sizes. Hence, it can be concluded that the performance of the sink mobility model was studied under different network densities and speeds of the mobile sink. Worth mentioning, the movement of the mobile sink is divided into movement periods and pause periods. As a result, when arriving to its new location, the mobile sink pauses for 5 seconds. Also, all static sensor nodes are generating traffic according to a constant rate.

Table I Simulation Parameters

Parameter	Value
Simulation Time	1000 seconds
Number of Nodes	26, 51, 76, 101
Pause Time	5 Seconds
Simulation Area	1000*1000
Traffic Type	CBR
Mobile Sink Speed	5, 10, 15, 20 m/s

In addition, NS-2 simulator was used to conduct the simulation scenarios and AODV routing protocol was used to route packets when multi-hop communication is required. Moreover, each simulation scenario was run for 1000 seconds and the deployment area for all network sizes was

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1000*1000. Table I summarizes all the parameters used to conduct the simulation scenarios.

4.2. Simulation Parameters

In order to study the performance of the proposed mobility model under different simulation scenarios, average end-to-end delay, throughput, packet delivery ratio parameters and normalized routing load were used in order to evaluate the performance of the mobility model proposed in this paper.

4.2.1 Average End-To-End Delay

Is defined as the time involved to deliver data packets from their original source to their destination based on the time a packet has first left its source [24]. According to [25], this performance metric can be calculated according to Eq. 2.

$$\textit{Average End to End Delay} = \frac{\sum(\textit{Time Received} - \textit{Time Sent})}{\sum \textit{data packets received}} \quad (2)$$

4.2.2. Throughput

According to [24], this metric is calculated by dividing the total number of successfully received packets by the total simulation time and can be measured in bits/sec. Thus, the higher the value obtained for this metric the better the performance of the proposed model. This metric is calculated based on Eq. 3

$$\textbf{Throughput} = \frac{\textbf{Number of Packets Delivered} * \textbf{Packet Size} * 8}{\textbf{Total Simulation Time}} \quad (3)$$

4.2.3. Packet Delivery Ratio

According to [24][25], this metric can be defined as the number of data packets that are received successfully divided by the total number of data packets sent and is calculated based on Eq. 4

$$\textbf{Packet Delivery Ratio} = \frac{\sum \textbf{data packets received}}{\sum \textbf{data packets sent}} \textbf{X100} \quad (4)$$

4.2.4. Normalized Routing Load

According to [25] normalized routing load (NRL) is calculated by dividing the total number of routing or control packets sent by all nodes over the total number of the received data packets as shown in Eq. 5.

$$\textbf{Normalized Routing Load} = \frac{\sum \textbf{routing packets sent}}{\sum \textbf{data packets received}} \quad (5)$$

The effect of the mobility model, presented in this paper, on AODV routing protocol will be studied under different network sized and movement speeds of the mobile sink.

5. RESULTS

In figure 3 the average End-to-End delay has been evaluated for the proposed mobility model under different network sizes and speeds of the mobile sink. It can be observed that for all network sizes the proposed mobility model obtained low values of End-to-End delay for low speeds of the mobile sink and these values increased when the speed of the mobile sink was increased. Furthermore, the performance of 51 and 76 nodes networks was almost stable and the increase in the values obtained was in an acceptable range for different speeds of the mobile sink which can be regarded to the size of the network. In other words, for 51 and 76 nodes network, the mobile sink will visit the static sensor nodes at acceptable frequencies. As a result, most of the packets are delivered to the mobile sink using single hop while multi-hop communication is rarely used.

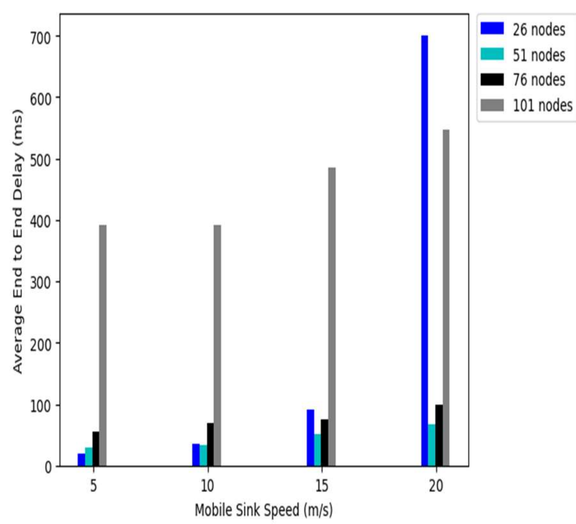

Figure 3: Average End-to-End Delay

On the other hand, for 26 nodes networks there was a dramatic increase in the End-to-End delay when the mobile sink movement speed is equal to 20 m/s because the mobile sink is moving at a high speed which makes it difficult to route packets of non-neighboring nodes to the mobile sink. As a result, these packets have to go through long routes

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and may visit and get routed through some nodes more than once as they keep following the mobile sink. Also, 101 nodes networks obtained high results in terms of End-to-End delay because the number of nodes is large and it will take the mobile sink some time to visit all static sensor nodes. Thus, a lot of data packets will be routed via multi-hop rather than single-hop and packets have to go through relatively long paths.

To summarize, the mobility model achieved good end-to-end delay values for medium size networks under low speeds of the mobile sink because for large size networks static sensor nodes cannot be visited at the same frequency of the medium size network. As a result, static sensor nodes will use multi-hop routing in order to deliver messages to the mobile sink which affects and increases the end-to-end delay. On the other, for small size network, static sensor nodes get visited at higher frequencies by the mobile sink. Thus, when some static sensor nodes get visited they might not have data to be transmitted to the mobile sink. Consequently, these static sensor nodes might have data to be transmitted to the mobile sink after they get visited. As a result, multi-hop routing is used by these nodes which increases the end-to-end delay.

Figure 4 and figure 5 present the results acquired from studying the performance of the mobility model based on packet delivery ratio and throughput parameters. It can be seen that 51 and 76 obtained high and stable results for packet delivery ratio and throughput and the results obtained were better than other network sizes.

The reason behind such behavior can be regarded to the network size and the frequency according to which static sensor nodes are visited by the mobile sink. Say it in another way, the mobile sink can visit the static sensor nodes more frequently and collect data in a timely manner.

On the other hand, for 26 node network the mobile sink might visit a static sensor node when it does not have stat to be reported to the mobile sink. As a result, when a sensor node has data to be transmitted to the mobile sink, multi-hop routing is being used and because the sink node is mobile routing gets more difficult as packets keeps wandering around in the network until their time to live parameter expires and they get dropped. Hence, low values of packet delivery ratio and throughput are obtained.

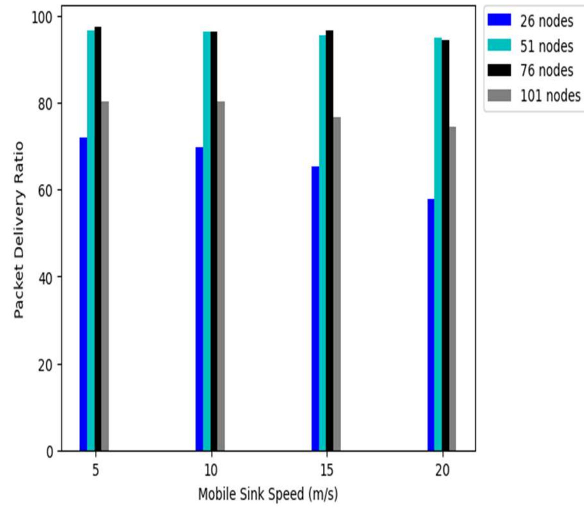

Figure 4: Packet Delivery Ratio

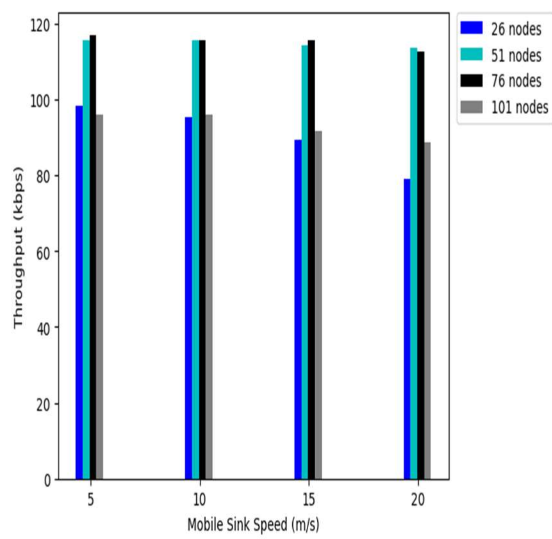

Figure 5: Throughput For Different Network Sizes

Moreover, 101 nodes networks obtained lower results than 51 and 76 nodes networks because the number of nodes is high and the mobile sink will take long time to visit some static sensor nodes. As a result, multi-hop routing is used where some static sensor nodes might form a bottleneck and some packet my get dropped and affect the packet delivery ratio and the throughput of the network.

Figure 6 present the results obtained from studying the performance of the mobility model based on normalized routing load parameter in order to study the effect of the mobility model on the AODV routing protocol.

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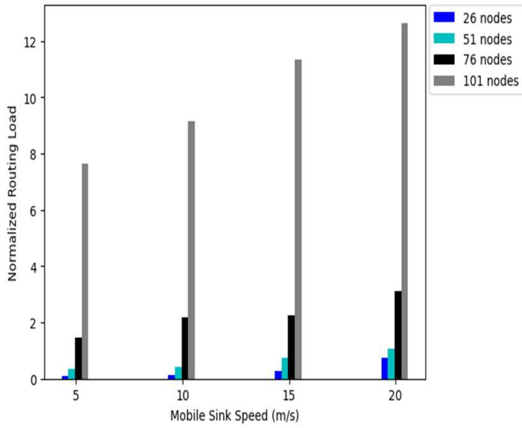

Figure 6: Normalized Routing Load For Different Network Sizes

From figure 6, it can be observed that the normalized routing load increases when the network size is increased. Also, for the same network size the normalized routing load increases when increasing the movement speed of the mobile sink. The reason behind such behavior can be regarded to the use of multi-hop routing. To elaborate, when the network size is increase the mobile sink will need more time to visit static sensor nodes, thus some static sensor nodes need to use multi-hop communication in order to send data to the mobile and avoid buffer overflow. Also, when increasing the movement speed of the mobile sink, static sensor nodes might not have enough time to send data directly to the mobile sink. Consequently, multi-hop routing will be used. Furthermore, many control information has to be communicated among static sensor nodes in order to know the current and new locations of the mobile sink in order to route data packets properly.

Since networks consisting of 51 and 76 nodes achieved the best and the most stable performance, the detailed results obtained from these two network sizes are presented in table II and table III respectively.

Table II Performance of 51 Nodes Network

Mobile Sink Speed m/s	End-to-End Delay (ms)	Packet Delivery Ratio	Throughput (kbps)
5	29.06	96.59	115.45
10	33.97	96.42	115.44
15	50.88	95.51	114.22
20	66.95	95.01	113.68

Table III Performance of 76 Nodes Network

Mobile Sink Speed m/s	End-to-End Delay (ms)	Packet Delivery Ratio	Throughput (kbps)
5	54.31	97.48	116.96
10	70.08	96.39	115.58
15	74.18	96.46	115.62
20	99.15	94.35	112.69

Tables II and III show the performance of networks consisting of 51 and 76 nodes respectively under different speeds of the mobile sink. It can be observed that the performance of these networks for the three performance parameters being studied is almost stable without having dramatic increase or decrease in the performance when changing or increasing the speed of the mobile sink node.

Also, it can be observed that the best performance was achieved by these networks when the mobile sink was moving at a low speed i.e. 5m/s because static sensor nodes will have enough time to communicate their data to the mobile sink. Also, the mobile sink is capable of visiting the static sensor nodes at moderate frequencies. As a result, static sensor nodes will not suffer from buffer overflow. Furthermore, single-hop communication is used more frequently by the static sensor nodes which plays a major role in order to achieve low values in terms of end-to-end delay and higher values in terms of packet delivery ratio and throughput can be achieved.

6. CONCLUSIONS AND FUTURE WORK

A sink mobility model based on using genetic algorithm was proposed in this paper. The main contribution of this paper was providing a sink mobility model that provides a calculated path to be used by the mobile sink in order to visit static sensor nodes and enhance the performance of the sensor network. The performance of the proposed model was studied under different network sizes and speeds of the mobile sink. Also, different performance parameters were used to study the performance and NS-2 simulator was used to conduct the study and obtain the results.

The results obtained show that the proposed mobility model is suitable to be used with medium sized networks under low speeds of the mobile sink i.e. networks consisting of 51 and 76 nodes because these networks obtained better results for all

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parameters when the mobile sink movement speed was equal to 5 m/s. The results show 97% and 98% packet delivery ratio were obtained for 51 and 76 nodes respectively.

For future work, the performance of the proposed mobility model can be tested using different routing protocols. In addition, other parameters might be taken into consideration such as energy consumption and network lifetime. Finally, the same scenarios can be used in order to study and compare the performance of the mobility model proposed in this paper with the performance of other mobility models.

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