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BREADTH FIRST BASED SINK MOBILITY MODEL FOR WIRELESS SENSOR NETWORKS

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ABSTRACT

Many research papers proposed deploying mobile sink node or nodes within a wireless sensor network to collect data from static sensor nodes. Thus, the performance of the wireless sensor network can be improved and its life time can be prolonged. In this paper, a new sink mobility model that is based on the breadth first traversal of a graph is proposed. As a result, the mobile sink will traverse the sensor network and visit static sensor nodes to collect data according to movement paths that are calculated based on the breadth first algorithm. After that, the proposed mobility model is simulated using NS-2 simulator and the performance of the proposed model is studied under different network sizes and speeds. Finally, average end-to-end delay, packet delivery ratio and throughput are the performance parameters used to study and investigate the behavior of the network using the mobility model proposed in this paper.

Keywords: *Wireless sensor networks, Mobility, Models, Performance, Routing*

1. INTRODUCTION

Recent advances in microprocessors and communications have made it possible to obtain small and light weight sensor nodes that are capable of providing fine-grained and high precision data through sensing the environment in which sensor nodes are deployed [1][2]. Consequently, wireless Sensor networks (WSNs) consist of hundreds or thousands of small light weight sensor nodes that can be randomly deployed in the area of interest in order to measure specific parameters such as pressure, temperature and so on [3][4]. Therefore, WSNs have drawn the attention of many researchers due to their wide range of applications such as military, agricultural, health care and environmental monitoring [1].

Researchers have addressed several research topics in the area of WSNs like energy efficiency and routing in order to enhance the performance of WSNs and prolong their lifetime. Furthermore, other researchers have proposed using energy rich mobile data sink or sinks the will move between static sensor nodes in order to collect data sensed by them. The reason behind using such a mobile node is to reduce the number of hops data packets go through until they reach the base station. Additionally, because the mobile sink is moving and changing its position, the neighbors of the mobile sink will not deplete all of their energies on forwarding messages originating from other sensor nodes because the neighborhood of the mobile sink is changing which is not the case with the neighbors of the base station. As a result, energy consumption of static sensor nodes may be improved. On the other hand, end to end delay, success rate and throughput and some other parameters must be taken into consideration when using mobile sinks in the network because paths that are used to deliver messages to the mobile sink will be changing depending on the position of the mobile sink, thus affecting the performance of the network [5].

Thus, several research works have proposed using mobile sinks to collect data from static sensor networks. Hence, various mobility models were proposed. According to [5], these mobility models can be divided into two main categories namely homogenous and heterogeneous models. To elaborate, in homogenous mobility models, the sensor network consists of a group of mobile nodes moving according to the same mobility model and collaborate in order to accomplish their task. On the other hand, heterogeneous mobility models are based on having a WSN consisting of static sensor nodes responsible for monitoring the area of interest. Additionally, there exists a mobile node acting as a data sink moving in the network. This mobile sink is responsible for collection sensed data from static sensor nodes and report information to the base station.

The mobility model proposed in this paper can be categorized as a heterogeneous one because it is based on using a single mobile sink to collect information form static sensor nodes. As a result, in this paper we will focus on reviewing research works that fall under the same category. Thus, many heterogeneous mobility model will be reviewed in the related work section. However, homogenous mobility models will not be considered in this work because they can be considered out of the scope of this paper.

In this paper we propose using a single mobile sink that moves within a randomly deployed WSN to collect sensed data from static sensor nodes. Furthermore, a new sink mobility model is proposed that is based on breadth first traversal of a graph. In other words, the mobile sink will visit static sensor nodes based on the breadth first traversal algorithm. Additionally, AODV routing protocol is used and is modified to adapt to changes in the network topology that results from the movement of the mobile sink. The proposed mobility model and routing protocol were simulated using NS-2 simulator and their performance was 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 and the modified routing protocol 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. Modifying AODV routing protocol so that multi hop and single hop routing can be used based on the mobile sink position.
3. Simulating the proposed work and studying the performance of the network according to several performance metrics.

The rest of this paper is organized as follows; in section 2 related work is discussed and reviewed. After that, the proposed mobility model is presented in section 3. Simulation environment, metrics and scenarios are presented in section 4. In section 5 simulation results are discussed. Finally, the paper is concluded and directions of future work are provided in section 6.

2. RELATED WORK

Various research works have proposed mobility models that are used by a mobile sink node to move within a WSNs in order to collect sensed information collected by static sensor nodes. Thus, several sink mobility models for WSNs will be reviewed in this section.

The research work proposed in [4] suggested deploying a single mobile sink that is moving according to the depth first graph traversal algorithm. In other words, the mobile sink can start at any node in the networks. After collecting data, the mobile sink will choose another location and starts moving towards it. This new location is calculated by selecting one of the current node's children based on the depth first traversal algorithm of a graph. Consequently, as the mobile sink keeps selecting the new location by selecting one of the children of the current node; all static sensor nodes will be visited based on the depth first traversal. The authors of [4] have studied the performance of this mobility model according to different network sizes and different speeds of the mobile sink.

A De Bruijn graph based mobility model for WSNs was proposed in [6]. In their work, the authors assumed that the WSNs network is deployed according to De Bruijn graph which has several interesting properties such as bounded degree, small diameter, high connectivity and fault tolerance. As a result, two mobility paths can be derived and calculated based on De Bruijn graph. Hence, the mobility model according to which the mobile sink is moving was divided into rounds. In the first round, the mobile sink will move from node 0 to node n-1 based in one of the two paths mentioned before say path 1. Upon reaching node n-1, the mobile sink will try to move back from node n-1 to node 0 based on the same path. When the mobile sink reaches node 0, the second round of the mobility model is started were the mobile sink will try to move from node 0 to node n-1 based on path 2. After reaching node n-1, the mobile sink will move back to node 0 using path 2. Thus, it can be concluded that the mobile sink keeps alternating between path 1 and path 2 in order to collect information from static sensor nodes. The performance of this mobility model was studied under different network sizes and speeds of the mobile sink.

An Enhanced Data Gathering Protocol for Wireless Sensor Network with Sink Mobility was proposed in [7]. In this work, two protocols or algorithms were proposed. The first one is called

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Sinktrail-s and can be used when it is difficult to schedule the new location of the mobile sink in advance. However, the second one is called Sinktrail that can be used in order to give the mobile sink the ability to adapt to changes in the territory in which the sensor network is deployed without the need for GPS or special land marks. NS-2 simulator was used to study the performance of the work proposed using 30 sensor nodes that were deployed randomly.

Location Predictive and Time Adaptive Data Gathering Scheme with Mobile Sink for Wireless Sensor Networks (LPTA) was proposed on [8]. The sink location is predicted based on inferring time and location formulas along with loose synchronization in time. According to [8], the mobile sink movement was divided into data gathering periods were the mobile sink will be using the same trajectory until the current time period is over. Furthermore, every data gathering period is further divided into data gathering circles. To elaborate, a data gathering period is started when the mobile sink enters the network to collect information and ends when the mobile sink leaves the network. As mentioned before, during the data gathering period the mobile sink will be using the trajectory to move and collect data. Additionally, the movement of the mobile sink is divided into movement periods and pause periods within the data gathering period. On the other hand, data gathering circles can be defined as the procedure followed by the mobile sink to use a specific trajectory starting from node n and ending with the same node. A mobile sink is said to finish a circle if it goes back to the starting node after visiting all the nodes within its trajectory [8].

Instead of having a mobile sink that is obliged to visit all static sensor nodes, the authors in [9] proposed using a neighborhood based weighted rendezvous technique. The proposed technique is based on selecting a subset of the static nodes in the network that will act as data points that are called rendezvous points and all other static sensor nodes report data to these points. After that, the mobile sink will visit these rendezvous points to collect data using single hop communication instead of visiting all the nodes in the network. Rendezvous point are selected in a manner the aims to evenly distribute energy consumption in the network.

Dividing the network into clusters based on hexagonal geometry with R radius was proposed in [10]. After that, the node with the highest energy level within a cluster is selected to be the cluster head. Then, the closest node to the cluster head with second highest energy level is selected as a mobile node within the cluster.

As a result, sensor nodes will send data to the mobile node and the mobile node will forward them to the cluster head. Furthermore, based on the level of residual energy of sensor nodes, the mobile node will give priority to nodes with low energy levels and visit them first in order to prolong their lifetime. Thus, the lifetime of the sensor network is prolonged [10].

The research proposed in [11] suggested using quorum algorithm to eliminate redundant paths that can be used by mobile sinks. As a result, a mobile sink can visit static sensor nodes more quickly. The work in [11] is based on using asynchronous protocols to discover neighbors that are based on wake up time scheduling. Hence, according to the used wake up schedule, a quorum graph can be derived. As a result, a mobile node can know the area with the highest number of neighboring nodes and starts moving to it in order to collect the largest possible amount of data.

Using heuristic based solutions in order to direct a mobile node towards areas with high density of sensor nodes was proposed in [12]. The heuristic technique is based on dividing the network into several partitions, then assigning a mobile node or sink to each partition. After that, the mobile sink will be moving within each partition to collect information. Worth noting, the movement of the mobile node within each partition is based on moving to areas with the highest density.

The Gauss Markov mobility model was proposed in [13] in order to make it possible to apply different randomness levels. As a result, more realistic scenarios can be obtained in which a mobile node can change movement speed and direction [14]. According to [13], the movement of the mobile node is divided to time periods. Thus, a movement speed and direction are selected for the mobile node to move according to them for a specific period of time. When the current time period expires, a new movement direction and speed are calculated based on the values of movement direction and speed that were used in the previous time interval.

According to this model and based on the degree of dependency selected with the previous time period, the movement of the mobile sink can be completely random if the degree of dependency is 0. On the other hand, linear mobility can be achieved when the degree of dependency is equal to 1 while, different levels of randomness can be obtained when varying the degree of dependency to be between 0 and 1[15].

The research proposed in [16] is based on dividing the network into clusters and using the amount of remaining energy to select a cluster head for each cluster. After that, that data gathering phase is started where the mobile sink visits a subset of the cluster heads in order to minimize the time required for its tour and meet time constraints that might limit the length on the tour in terms of time. Cluster heads to be visited are selected based on calculating the optimal path where a subset of cluster heads are visited.

A set of algorithms that can be used to decide on when and where to move a mobile sink were proposed in [17]. The proposed algorithms are Sink-Site determination, Neighborhood-Based Sink-Site determination, Coordinate-Based Sink-Site determination algorithm and are used along with Sojourn Time and Movement Criterion.

Sink-Site determination can be used when the area of deployments contains inaccessible part to the mobile sink which makes it very important to select the movement path of the mobile sink in advance. However, if it was difficult to determine the exact boundaries of the deployment area it would be better move the mobile sink based on the coordinates of its neighbors to make sure that it will not move out of the network. Thus, Neighborhood-Based Sink-Site determination can be used [17].

In Coordinate-Based Sink-Site determination algorithm, the deployment area is divided into zones. As a result, nodes are clustered according to these zones. The amount on remaining energy in each cluster is the criterion used by the mobile sink to select which cluster to visit. Finally, in the Sojourn Time and Movement Criterion, the first migration point is selected, by the mobile sink, to be the one with the highest number of nodes i.e. density [17].

Based on energy information that are piggybacked in each packet, the mobile sink will be able to compare the current energy level with the starting energy level. If the difference between the two levels is greater than or equal to one unit, the mobile sink will initiate a procedure in order to choose a new location to be used in the next round and so on [17].

Many previous studies have used Random waypoint mobility model such as [18][19][20][21], where the movement of the mobile node is divided into motion periods and pause periods. At the beginning of every motion period, the mobile node selects a random position or destination and starts to move towards it with a randomly selected speed. Upon reaching the randomly selected destination, the mobile node the pause period starts and the mobile node will pause and stay in its location for a specific period of time. When the pause period expires, a new motion period is started and a new location is selected randomly. After that, the mobile node will move to the newly selected location with a random speed. Consequently, a new pause period is initiated when the new location is reached by the mobile node. Thus, the mobile node keeps switching between those two periods as long as it is functional within the network.

According to [4][22], Manhattan mobility model is used to model and study movement of vehicles in urban areas. In this model the mobile node is based on a grid road topology which has horizontal and vertical roads only. Consequently, a mobile node can move horizontally or vertically. Furthermore, the movement direction of a mobile node can be changed at intersection point only. Upon reaching an intersection point, a mobile node can choose to keep moving horizontally or to change its movement direction and starts moving vertically or vice versa.

Say it in another way, when a mobile node reaches an intersection point, the mobile node can choose to keep moving in the same direction. Additionally, it can decide to turn left or right and change its movement direction [4][22].

Another model that takes geographic constraints into account is called pathway mobility model where mobile nodes are restricted to move according to predefined paths derived from the area in which the WSN is deployed [4][23][24].

As a result, a map representing the area of deployment needs to be constructed and it can be obtained according to two methods. The first methods is based on constructing the map randomly. However, the second method is based on careful planning to model a real city. In this method, vertices are used to represent buildings and edges are used to represent streets. After that, when a WSN is deployed and a mobile node needs to move to a randomly selected destination. The shortest path algorithm is applied on the map to find edges that can be used by the mobile node in order to reach its destination. When the movement destination is reached, the mobile node pauses for a specified period of time. After that, a new destination is selected randomly and the mobile node starts moving towards it based on the shortest path algorithm [4][23][24].

3. BREADTH FIRST BASED MOBILITY MODEL

In this section, the original breadth first algorithm is discussed and presented. After that, the proposed mobility model that is based on the breadth first algorithm is presented and explained.

3.1 Breadth First Traversal Algorithm

Breadth first traversal of a graph can start from any node let say node 0. After visiting node 0, we will check all the children of node 0 and add them to a queue data structure and mark them as visited. When all the vertices that can be visited from node 0 have been marked as visited and are added to the queue. The node that is at the head of the queue, let say node 1, is dequeued. Consequently, all nodes or vertices that can be visited directly from node 1 are marked as visited and added to the queue. This process continues until all the vertices in the graph have been visited and the queue is empty. To elaborate, in breadth first traversal the graph is explored layer by layer where layer 0 consists of the starting node only. Layer 1 consists of the children of the starting nodes which can be visited directly from that node. Furthermore, layer 2 will contain the nodes that can be directly visited from the first visited child of the starting node as it will be the first node in the queue and it will be dequeued first [25].

3.2 Proposed Mobility Model

The mobility model proposed in this paper is based on the well-known breadth first traversal algorithm of a graph. We will assume that we have a WSN consisting of N static sensor node. Additionally, there will be an extra mobile and energy rich node to act as a mobile sink and will be visiting the static sensor nodes based on the breadth first traversal algorithm in order to collect data from the static sensor nodes. As a result, the total number of nodes in the network is N + 1. To elaborate, the sensor network will be consisting of N static sensor nodes numbered from 0 to N – 1 and node number N will be the mobile sink that is responsible of collecting data from static sensor nodes. Algorithm 1 shown below is a modified version of the original breadth first traversal of a graph. Form the algorithm it can be observed that N represents the set of static sensor nodes that are deployed in the area of interest. The statics sensor nodes in N are numbered from 0 to n-1. For example if the sensor network consists of 6 static sensor nodes they will be numbered from 0 to 5. Additionally, an extra mobile sink node will be present in the network which is represented by set SN in the algorithm. The number for this node will be n_n which is equal to 6 in our example.

After that the mobile sink selects a random static sensor node as a starting node for the breadth first traversal. Then, the breadth first traversal algorithm is applied. Note, when the mobile sink needs to select a new location to move to, the x and y coordinates of the new location are based on static sensor nodes locations that can be obtained based on the breadth first traversal algorithm.

Algorithm 1: Breadth First Based Mobility

1. Start
2. Initialize a group of nodes: $N = \{n_0, n_1, n_2, \ldots n_{n-1}\}$
3. Initialize a mobile sink node: $SN = \{n_n\}$
4. Select a random starting point node S for the mobile sink where $S \in N$
5. Let Q be queue
6. Enqueue S to Q
7. Mark S as visited
8. While Q is not empty
   - 8.1. Dequeue the first node in the queue and store it in v.
   - 8.2. Get x and y coordinates of v
   - 8.3. Let n_n move to x and y coordinates of v
   - 8.4. Pause in new position for time t
   - 8.5. Collect data
   - 8.6. Find every neighbor, g, of v where $g \in N$
   - 8.7. Enqueue g to Q
   - 8.8. Mark g as visited
9. End While
10. Stop

To make it clear the proposed mobility model will be explained based on the graph shown in figure 1. The sensor network shown in figure 1 consists of six randomly deployed static sensor nodes numbered from 0 to 5. Moreover, a mobile sink is present in this network which is node number 6. In this example we will assume that the mobile sink will start visiting static sensor nodes starting from node 0. As a result, the breadth first traversal of the network will be 0, 2, 1, 3, 4, 5. Hence, the mobile sink will visit all the static sensor nodes in the network based on the specified order or path.

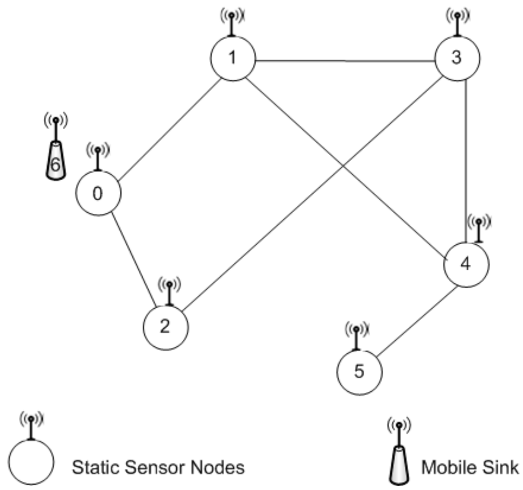

Figure 1: Example Network

Moreover, the mobility model proposed in this paper consists of movement periods and sojourn periods. Thus, when the mobile sink is deployed in the network it will be in the neighborhood of node 0 based on figure 1. Therefore, the sojourn period is started and the mobile sink will pause in its current position for a specific period of time. At the end of the sojourn period, the movement period is started where the mobile sink chooses to move to one of the direct neighbors of node 0 based on the breadth first traversal which is node 2 in figure 1. Upon reaching node 2 the mobile sink enters a new sojourn period and pauses for the same specified period of time used in the previous sojourn period. When the sojourn period expires, a new movement period is started and the mobile sink will be moving to node 1. This process is repeated until all the nodes in the network are visited. When the last node in the network is visited which is node number 5 in figure1. This node will be considered as a starting point for a new traversal of the network based on the breadth first algorithm.

Furthermore, AODV routing protocol has been used and adjusted to adapt to the presence of a mobile sink in the network. As a result, when a static sensor node has data that needs to be reported to the mobile sink. The sensor node first checks whether the mobile sink is in its vicinity. In other word, the static sensor node checks if the mobile sink is one of its neighbors or not. Consequently, single hope communication is used if the mobile sink is a neighbor to it. On the other hand, if the mobile sink is not a neighbor of that sensor node, multi hop communication will be used. Thus, AODV routing protocol will be used to route packets through a set of intermediate nodes until the mobile sink receives the packets. Worth mentioning that AODV has been modified in this manner in order to guarantee the delivery of up to date information to the mobile sink. Also, if the static sensor node is a the end of the movement path of the mobile sink it will have large quantities of data stored in its memory waiting for the mobile sink to visit that node which may cause buffer overflow for the static sensor nodes. Say it in another way, AODV routing protocol has been modified in order to guarantee timely delivery of data and avoid buffer overflow cases for nodes that fall at the end of the movement path of the mobile sink. Note that AODV is adopted to be used in this paper because of its reactive nature as it is capable of establishing routes in a quick manner. Thus, AODV can utilize the available bandwidth efficiently [26][27]. Algorithm 2 shows the approach according to which AODV was adapted in order to combine the use of single hop and multi hop communications.

Algorithm 2: AODV Routing Protocol Usage

1. Start
2. Initialize a group of nodes: N = $\{n_0, n_1, n_2, \dots n_{n-1}\}$
3. Initialize a mobile sink node: SN = $\{n_n\}$
4. Generate a packet from node n where n ∈ N to node n_n
5. If n_n is a neighbor to n
    5.1. Send packet via single hop
6. Else
    6.1. Use AODV routing protocol
7. Stop

4. SIMULATION

4.1 Simulation Environment and Parameters

In order to study the performance of the proposed mobility model using AODV routing protocol, NS-2 simulator was used to conduct the required experiments. NS-2 was selected because it is one of the mostly used simulators to study wired and wireless networks. Furthermore, AODV is the routing protocol used in order to deliver messages using multi hop delivery. Note AODV will be used according to the approached explained previously. The simulation area was set to 1000 * 1000 flat grid and the number of nodes within the network was changed according to the following values 26, 51, 76, 101, 126, 151, 176 and 201. Worth mentioning that 26 nodes network consists of 25 static sensor nodes and one extra node to represent the mobile sink node. This applies to network sizes given before. Static sensor nodes are generating constant bit rate (CBR) traffic destined to the mobile sink which is responsible for delivering received packets to the base station. Moreover, the performance of the proposed mobility model was studied under different movement speeds of the mobile sink namely 5, 10, 15 and 20 m/s. Since the movement of the mobile sink is divided into movement periods and sojourn periods; the mobile sink will pause for 5s upon arriving to the new position or location. Table I summarizes the simulation parameters that were used in order to obtain results.

Table I. Simulation Parameters

Parameter	Value
Simulation Time	1000 seconds
Number of Nodes	26, 51, 76, 101, 126, 151, 176, 201
Pause Time	5 Seconds
Simulation Area	1000*1000
Traffic Type	CBR
Mobile Sink Speed	5, 10, 15, 20 m/s

4.2 Performance Metrics

Average end-to-end delay, packet delivery ratio and throughput are the performance metrics used to study and evaluate the performance of the proposed mobility model. These performance metrics can be defined as follows:

1. Average end-to-end-delay is the time required by a data packet to arrive to its destination from the time it first left it source. In order to calculate the average end-to-end delay for the whole network, all data packets transmitted between all sources and destinations must be averaged [28]. This performance metric is calculated according to the equation shown below which is adapted from [28]:

$$T_{AVG} = \sum_{i=1}^{N} \frac{(H_r^i - H_t^i)}{N} \qquad (1)$$

Note that, H_r^i represent the received instance of a packet while H_t^i represent the emitted instance of the packet. Also, the overall number of packets received is represented by N [28]. Furthermore, the proposed model must aim to achieve small values of this metric because small values of average end-to-end delay indicate good performance [15].

2. Packet delivery ratio is the total number of successfully delivered packet, P_{rs}, divided by total number of transmitted packets, P_{sent_i} [15]. This performance metric is calculated according to the equation shown below which is adapted from [15]:

$$Packet\ Delivery\ Ratio = \frac{P_{rs}}{\sum_{i=1}^{n} P_{sent_i}} \qquad (2)$$

3. Throughput represents the total number of successfully received or delivered packets divided by the total simulation time and it can be measured in bits/sec. Note that the higher the values obtained for throughput the better the performance of the network [28]. According to [15] throughput can be calculated based on the following equation:

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

4.3 Simulation Scenarios

The mobility model proposed in this paper was implemented using NS-2 simulator. After that, the performance of the mobility model presented in this paper was studied and analyzed by conducting various simulation scenarios. Therefore, different network sizes namely, 26, 51, 76, 101, 126, 151, 176, 201 were simulated. Worth mentioning, each network consisted of static sensor nodes and a single mobile sink nodes. For example, for the network consisting of 26 nodes, 25 nodes, 0 to 24, are static sensor nodes and node number 25 represents the mobile sink node that is responsible for collecting data from static sensor nodes.

Additionally, different movement speeds of the mobile sink for each network size were used to study the performance of the proposed mobility model. In other words, the movement speed of the mobile sink was varied according to the following values 5, 10, 15, 20 m/s. After that, the performance of the mobility model was studied when the mobile sink was moving based on 5 m/s speed for all network sizes. Then, the speed of the mobile sink was changed 10 m/s and the performance of the mobility model was studied for all network sizes. This approach was applied on all different speeds for all network sizes. Finally, AODV routing protocol was used to deliver messages to the mobile sink according to the approach mentioned in algorithm 2.

5 SIMULATIOIN RESULTS

In this section the results obtained from simulating the proposed mobility model are presented and discussed. Furthermore, the performance of the proposed mobility model was studied according to different scenarios in order to obtain results regarding end-to-end delay, packet delivery ratio and throughput. It is worth noting that every case in the scenarios was run 10 times. Thus, the simulation results were obtained from averaging the result of the 10 run for each case.

Figure 2 shows end-to-end delay results for different network sizes while the mobile sink is moving according to the breadth first mobility model under different movement speeds. From figure 2 it can be observed that low and stable end-to-end delay values were gained for small size networks consisting of 26 nodes under different speeds of the mobile sink because static sensor nodes will get visited more frequently by the mobile sink. Thus, single hop communication will be used more frequently than multi-hop communication. On the other hand when the network size was increase to 51, 76 and 101, the values obtained for end-to-end delay were much higher than that obtained for 26 nodes network because, movement paths that have to be followed by the mobile sink get longer. As a result, static sensor nodes have to wait for longer periods of time until it get visited by the mobile sink. Also, static sensor nodes can use multi-hop communication to avoid buffer overflow which plays a major role in increasing the amount of time required to route messages to the mobile sink when compared to single hop communication. Since nodes density has direct impact on the performance of the network, figure 2 shows that networks consisting of 76 and 101 node obtained better results than 51 nodes network. In other words, because the number of nodes is higher for 76 and 101 nodes networks, the number of neighbor nodes for each static sensor nodes is higher. As a result, when the mobile sink visits a static sensor node, the number of neighbor nodes that can report data to the mobile sink using very short multi-hop path is higher when increasing the network size. Therefore, networks consisting of 76, 101 and 126 nodes obtain better results than networks consisting of 51 nodes.

Furthermore, from figure 2 it can be observed that 176 nodes networks performed better than 151 nodes networks especially at low speeds of the mobile sink, 5 and 10 m/s because, at these speeds the mobile sink is not moving at very high speeds. Thus, data packets can be routed using long enough multi-hop routing paths to the mobile sink without creating routing loops. On the other hand, when the mobile sink is moving at 15 and 20m/s speed, it will be moving very quickly from one location to another. As a result, routing loops might occur as data packets need to keep following the movement of the mobile sink which may cause routing the same packet multiple time by the same intermediate node which increase the delay. Finally, for large networks sizes e.g. 201, the amount of the results obtained for end-to-end delay were very high for all cases, because static sensor nodes are visited less frequently and routing paths are very long.

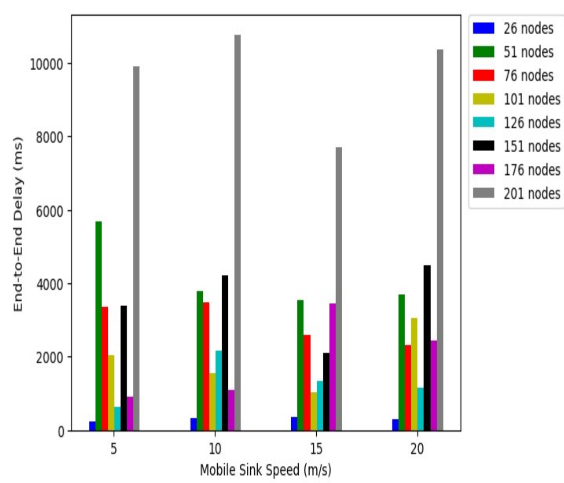

Figure 2: Average End-to-End Delay for Different Networks Sizes

Additionally, figure 2 shows that better end-to-end delay results can be obtained when the mobile sink movement speed is low even for small network sizes because at low speeds the mobile sink spends more time in the vicinity of a static sensor node. To elaborate, we have mentioned before that the movement of the mobile sink is divided into movement periods and sojourn periods. When the mobile sink decides on the next movement location, the movement period is started and the mobile sink moves toward that location with a specific speed. Upon arrival to the new location the sojourn period is started and the mobile sink will stay in that location for a specific period of time. Consequently, when the mobile sink is moving at low speeds, the amount of time required for it to reach its location is higher than high speed. However, when the

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mobile sink enters the vicinity of the static sensor node to be visited, more time is spent from entry time until the new location to be visited is reached. As a result, the static sensor node and it neighbors will have enough time to send many data packets before a new movement period is started. On the contrary, when the mobile sink is moving according to high speeds this period of time gets shorter and the static sensor nodes need to use multi-hop communication. Furthermore, when moving at high speeds the multi-hop routing paths required to deliver data to the mobile sink get longer because the mobile sink will cause the network topology to be highly dynamic. As a result, by the time a static sensor nodes take a routing decision to route messages to its neighbor because the mobile sink is in its vicinity, the mobile sink might enter the movement period and leave the vicinity of that node quickly before receiving packets. Thus, packets have to be routed to the next hop.

Note that the fluctuations in the performance of some networks such as the network consisting of 101 nodes in figure 2 is due to the random deployment of the static sensor nodes which may result in a random distribution of the static sensor nodes in the area of deployment. Consequently, some parts in the deployment area might have higher density of nodes than other parts. As a result, for high density parts higher number of nodes can be visited. Also, when the mobile sink is in the vicinity of a static sensor node the number of static sensor nodes that are neighbors to the one being visited is high which results in more packets to be delivered to the mobile sink using very shorts multi-hop routing path.

Results regarding packet delivery ratio are presented in figure 3. It can be observed that better ratios can be obtained for small network sizes under low movement speeds of the mobile sink. The reason behind this observation can be regarded to shorter routing paths required to deliver messages to the mobile sink. Additionally, because the network size is small and the mobile sink is moving at low speed static sensor node are capable of using single hop communication. Also, a short multi-hop path can be used to deliver messages because the time spent by the mobile sink in the vicinity of a static sensor nodes or one of its neighbors is long enough to receive packets destined to it. Furthermore, the mobile sink will visit static sensor nodes more frequently for small network sizes because its movement path is shorter and less time is need to visit all the nodes in the network.

Figure 3 shows that the network consisting of 26 and 51 nodes performed better than other networks while larger networks obtained stable results regarding packet delivery ratio. This can be regarded to the multi-hop paths length that can be used to deliver packets to the mobile sink. In other words, for small size networks, e.g. 26 node, it was possible to use single hop communication more frequently. Additionally, when there was a need to use multi hop routing, the routing paths used were short. On the other hand, for larger network sizes, e. g. 101 nodes, the multi-hop routing paths were not long enough to deliver packets to the mobile sink. Say it in another way, packets might enter a loop in order to be routed to the mobile sink as they keep following the mobile sink from one node to another because the mobile sink is visiting smaller number of nodes and there will be smaller number of sojourn periods.

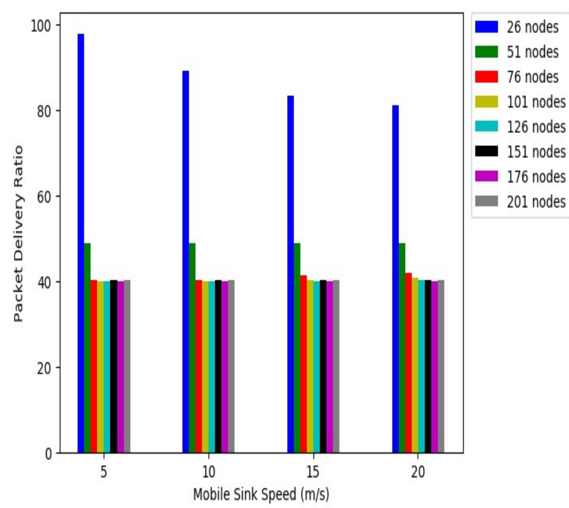

Figure 3: Packet Delivery Ratio for Different Network Sizes

The performance of different network sizes according to network throughput is shown in figure 4. It can be observed the networks with small sizes especially 26 nodes network obtained higher throughput than all other network sizes. This complies with our observations from figures 2 and 3. Since small network sizes obtained better performance results regarding end-to-end-delay and packet delivery ratio, they will obtain higher performance results regarding throughput since these parameters are linked to each other. Thus, lower end-to-end delay results in higher values and results in terms of packet delivery ratio and throughput. This kind of performance can be regarded to the same reason that justified the behavior and performance in the previous two cases. In other words, the length of the routing paths and the increase of the movement speed has direct impact of the use of single hop and multi-hop communication which in term affect the end-to-end delay, packet delivery ratio and throughput.

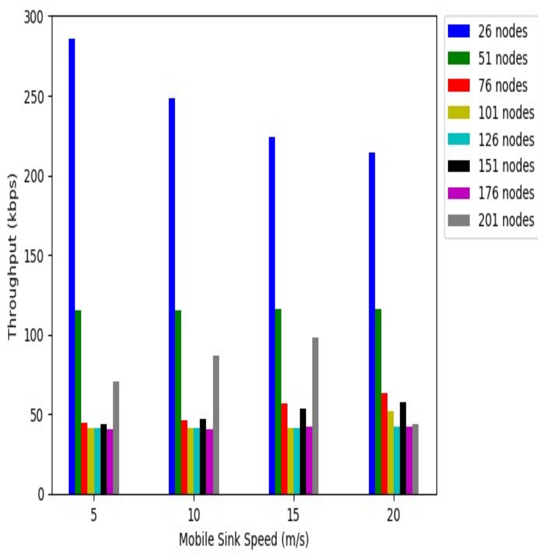

Figure 4: Throughput for Different Networks Sizes

Worth noting the fluctuations in the performance of some networks can be regarded to the random deployment of the nodes in the generated scenarios. As a result, node density in some parts of the simulation area might change from one case to another because the scenarios are based on randomly deployed WSNs.

Therefore, it can be concluded that the mobility model proposed in this paper is more suitable to be used for small network sizes. Additionally, better performance can be achieved by the proposed model when the mobile sink is moving at low speed. As a result table II shows the results obtained for 26 nodes network sizes in terms of end-to-end delay, packet delivery ratio and throughput.

Table II Performance of 26 Nodes Network

Mobile Sink Speed m/s	End-to-End Delay (ms)	Packet Delivery Ratio	Throughput (kbps)
5	223.46	97.81	285.93
10	324.14	89.09	248.59
15	366.14	83.27	224.09
20	311.69	80.95	214.16

6 CONCLUSIONS AND FUTURE WORK

A breadth first based sink mobility model was proposed in this paper. After that, the performance of the proposed model was studied under different network sizes and different speeds of the mobile sink node. Our results show that this model is suitable to be used for small network sizes and low speeds of the mobile sink. In other words, the proposed mobility model achieved the highest packet delivery ratio, around 98%, for a network consisting of 26 nodes with a mobile sink movement speed equal to 5 m/s. Also, the results obtained for end-to-end delay and throughput were the highest for the same network size and the same speed of the mobile sink.

The work presented in this paper can be extended in future to study the performance of the proposed mobility model under different routing protocol along with AODV. Furthermore, the performance the breadth first mobility model can be compared to that of other mobility models using the same simulation parameters. Finally, other performance metrics such as energy consumption can be investigated to study the performance of the proposed mobility model on the network lifetime.

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