Utilizing minimum spanning trees for effective mobile sink routing in wireless sensor networks

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ABSTRACT

With many practical applications, wireless sensor networks (WSNs) represent an important field of study. Real-world applications of WSNs include smart home automation, healthcare, agriculture, industrial automation, and environmental monitoring. WSNs present countless chances for creative solutions across various industries as they develop and become more sophisticated. But because they are unattended, we must devise ways to make them work better without using the sensor nodes' most important resource—battery power. A unique sink mobility model from a deployed WSN is proposed in this paper, based on constructing a minimal Spanning tree. The proposed approach derives a controlled movement model for the mobile sink based on minimal spanning tree (MST) features. Consequently, fixed nodes will be scheduled and visited to save routing overhead and improve network efficiency. Using the properties of the minimal spanning tree, the moving sink node can visit immobile sensor nodes, which is the most effective approach to gather data and send it to the base station. The effectiveness of WSNs was examined when implementing this mobility model, and we used the NS-2 simulator to run simulations to assess how efficiently the suggested strategy performed. Our findings demonstrate that WSN performance can be significantly enhanced by implementing the proposed method.

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1. INTRODUCTION

Wireless sensor networks (WSNs) come across challenges in their employment. To support mobility-dependent applications, like emergency and seismic recovery, field surveillance in combat, animal monitoring, and applications for law enforcement. One use case for WSNs that uses 5G internet of things (IoT) technology is psychoacoustic monitoring. Therefore, a dynamic and adaptive WSN supporting mobility is needed to enable dependable communication, consistent network connectivity, energy savings, and a longer network lifespan for these applications [1], [2]. Therefore, self-organizing and fault-tolerance capabilities must be preserved for these networks to operate properly [3]-[6]. Because stack mobility variations significantly impact WSNs' capacity to scale and save energy, energy-efficient devices must be made available. Performance deterioration and erratic broken links must thus be examined to deliver a trustworthy mobility model [1], [7], [8].

Numerous models have been presented and are considered good choices for ad-hoc networks. But in WSNs, they behave differently, leading to lower quality of service (QoS) ratings and higher energy usage. Stated differently, sensor networks can transmit multiple data types, including video. As a result, bitstream and other QoS criteria must be fulfilled. Interestingly, QoS in WSNs is distinguished into two groups: node reading, coverage, deployment, and number of alive nodes; the former is reliant on the network, while the latter is dependent on the application.

The second group focuses on efficiently using energy, bandwidth, throughput, and packet delivery ratio. Stated differently, the random waypoint mobility model (RW) performs well in ad hoc networks. Nevertheless, it is not a good alternative in WSNs due to its uniform distribution and poor velocity selection [9]-[13].

As an alternative, the nomadic community mobility model was developed to solve the limitations of the RW model. The random roaming of nodes between sites makes this architecture appropriate for mobile communications in conferences and applications supporting military operations. Based on the group's collective motion, a reference point is also established for each moment. This method requires Large amounts of energy to locate or find a single node [14], [15].

A circular mobility model based on geographical information was thus introduced to manage the mobility of sink nodes. Data is collected by this model using a fixed, circular point-based track. The nodes must stay idle for eight or sixteen cycles, a significant constraint. Premi and Shaji [14], a model of wind movement using eight directions was published to prolong the network's lifespan. Hence, to determine one node's location, a group of nodes must move and expend energy [15]. High network performance is required from the wind mobility model attributable to the additional pause time, node speed, and interdependencies [16].

Moreover, three subsystems are also present in sensor nodes: communication, processing, and sensing. Because the amount of energy required to convey a message depends on the distance between the source and destination nodes, the communications subsystem is also the main energy-consuming source [17], [18]. Therefore, compared to single-hop communication, multi-hop communication can shorten transmission distances, but at the cost of longer delays [17], [19]. Additionally, IEEE 802.15.4 governs communication between sensor nodes, with the premise that each sensor node's energy determines the communication range. Typically, it is under 100 meters [20].

The solution to this problem has been suggested using a mobile device rich in energy sink nodes or nodes. With this strategy, data is collected from fixed sensor nodes and sent to the base station (BS) via a mobile sink that follows a specified mobility model or moves randomly. Using a movable sink further improves the performances of WSNs by reducing the distance at which a fixed node must broadcast data, minimizing the overall number of nodes that act as intermediaries, improving network throughput, and providing coverage for distant locations [3].

Besides utilizing a mobile sink or sinks, researchers have proposed different ways to improve WSN performance. For example, a clustered routing protocol was defined in the work proposed in [21]. A cluster head is chosen according to the centroid position, and the gateway is selected from within the cluster. The study that this paper suggests depends on deriving an MST from a randomly deployed network. Then, the mobile sink (MS) will adopt the order according to which nodes were added to the MST as the path to be adopted to visit fixed nodes and collect data. This article proposes combining multi-hop and single-hop routing to achieve high network performance and minimize latency.

To summarize, not using a mobile sink will increase the use of multi-hop routing; thus, messages will suffer from high delays in being delivered to the BS. On the other hand, relying on single-hop routing enhances the performance regarding one-way delay. However, stationery nodes might need to wait long for the MS to visit them and send them data. As a result, station nodes might suffer from buffer overflow, and the data reported to the mobile sink might be outdated.

To resolve these issues, this paper suggests using a single energy-rich MS that will move within the WSN based on a particular mobility model to gather information from stationary sensor nodes. The mobility paradigm this study suggests is predicated on deriving a minimum spanning tree to build the precise route the MS will take to visit stationary sensor nodes to collect information from them. Also, the proposed model relies on having a stationary node that uses multi-hop routing to send messages to the MS when it is impossible to use single-hop routing because the MS is not in communication range. Utilizing the NS-2 simulator, one may imitate the suggested mobility model, and its performance is examined across various MS speeds and network sizes. The mobility model described in this work is studied using three parameters: packet delivery ratio, average one-way delay, and network throughput.

To further explain, this paper's primary contribution can be summed up as follows:

a) Introducing a new strategy to sink mobility that can be utilized to gather information from stationary sensor nodes.
b) Combining the usage of multi-hop and single-hop routing techniques to improve performance by reducing delay and ensuring timely delivery of information from static nodes to the mobile sink.

c) Simulating the suggested work and examining the network's performance in light of several performance measures. Consequently, an analysis of the impact of the movement model being proposed will be conducted. Additionally, the ideal circumstances can be identified, such as the size of the sensor network and the speed of the mobile sink mode.

This paper will be organized into the following sections. A brief explanation of MST is given in subsection 2.1. A survey of previous models' literature is included in subsection 2.2. The method and the suggested mobility model are explained in section 2, along with the performance metrics and simulated scenarios, to examine the efficacy of the proposed work. The simulation's results are described in section 3, along with a comparison with the other three models. In section 4, the last observations are covered.

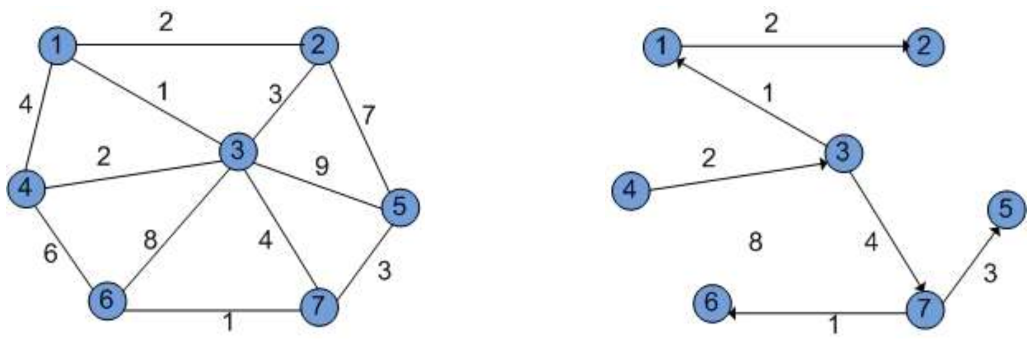
2. METHOD

2.1. Overview of prim's minimum spanning tree

As stated in [22], Prim's algorithm is greedy for determining an undirected, weighted graph's minimal spanning tree (MST). The subset of edges in a graph that joins all vertices to minimize the edges' overall weight without creating a cycle is known as a MST. Remember that there must not be a cycle if you use Prim's approach to determine the MST of a graph. As stated otherwise, if node one links to node two and node two to node 3, node three cannot link to node one again since that would create a loop.

Another term for cost that is frequently used is the total weight of the edges. Prim's approach also aims to find the smallest cost tree that covers all of the graph's vertices without omitting any of them. Thus, another consideration is that all vertices must be involved to obtain the MST.

Prim's algorithm, also referred to as Jarník's algorithm, it was initially developed in 1930 by Czech mathematician Vojtěch Jarník. Prim's algorithm got its name after Robert C. Prim rediscovered it and published it in 1957 [22]. Prim's algorithm operates by starting at any vertex, adding the edge with the smallest weight between it and the next vertex in the tree, and continuing until all vertices are included as shown in Figure 1. To clarify, consider the random graph presented in Figure 1(a). The MST that results from starting at node four is shown in Figure 1(b). In other words, the MST generated starting from node four will add node 3. After that, node one is added. Then, node two is added-consequently, the algorithm adds nodes 7, 6, and 5, respectively.



(a) (b)

Figure 1. Constructing MST from a random graph (a) random graph representing a network and (b) the derived minimum spanning tree

2.2. Mobility models

Several academic articles have proposed models or methods that facilitate mobility in WSNs. Node mobility in WSNs describes a node's capacity to move itself after deployment, according to [23]. Therefore, the mobility algorithms or sensor node models can be classified into two main types. Whereas the second approach is predicated on allowing every sensor node to move, the first involves using MSs that can accept data from fixed sensor nodes while in motion. Since this directly pertains to the proposed model, our review will focus on studies involving only one MS that travels to get data from fixed nodes.

To reduce both the range of communication and the MS's travel distance, a path planning-based data collection technique was implemented in the study suggested in [24]. An inner center path planning algorithm was employed to minimize the distance an MS has to cover. A back-routing technique was also introduced to solve the movement route back propagation issue. For the MS to move appropriately, the suggested design must allow it to make adaptive decisions.

Furthermore, to lower energy usage and increase the longevity of WSNs, the research in [25] recommended addressing the relay selection problem. As such, the suggested study splits the network into clusters utilizing the k-means algorithm. A cluster head selection technique based on movable sinks was proposed to improve energy consumption inside the cluster. To collect data and save energy dissipation for both the cluster head and static sensor nodes, the MS node will act as a cluster head near immobile sensors.

Kohonen's self-organization map (SOM) provided the basis for the mobility model the research authors reported in [26]. Their research uses Kohonen SOM to determine the route taken by the MS. Thus, the MS moves while it is moving and stops when it is pausing. During the halt periods, the movable sink will endure where it is for a particular period before starting to migrate to a new site selected by the Kohonen SOM, and so forth, until changes in topology arise from the exhaustion of energy. This will lead to a fresh Kohonen SOM computation of the mobility route.

Moreover, a cooperative strategy was introduced in [27] to monitor the environment further and detect abnormality in WSNs. The suggested approach consists mostly of two parts. First and foremost, a weighted Gaussian coverage technique will be used to deploy the fixed sensor nodes collaboratively. In contrast, the second portion deals with route planning for the MS. It relies on altering an anomaly search and active surveillance mechanism that uses a Markov decision process model. The main goal is to detect abnormalities in the environment quickly so that the mobile mode can react properly using a cumulative reward function.

To improve WSNs performance and increase their lifespan, another study is suggested in [28] that splits the network into zones. The MS will pass close to the highly laden area. Remembering that a fuzzy logic system is employed to choose the zone undergoing substantial load to account for any potential uncertainties is crucial.

Yalcin and Erdem [29] suggests an adaptable mobile routing methodology for burst traffic identification. In addition, the network architecture that is being suggested is predicated on deploying two movable sinks, and the method relies on splitting the clusters in the network into two groups. Subsequently, every sensor node will oversee a single group and interact with the cluster masters. Furthermore, the MS will pay particular visits to the cluster heads in the group. Conversely, when a traffic burst is observed, the movable sink will move near the heavily loaded cluster head and ignore the sequence of visits to the cluster heads.

Wu *et al.* [30], an end-to-end data-gathering method strategy based on optimizing ant colonies was also introduced. The suggested approach is predicated on constructing a data forwarding tree and selecting data collection locations randomly. Consequently, a predicted and detailed itinerary of the MS is provided.

Taleb [31], a model based on a genetic algorithms model is introduced. The MS's optimal direction of movement is determined by the mobility model with the application of genetic algorithms. Subsequently, the MS will employ single-hop forwarding to reach the nodes in the constructed path and acquire data from them. However, nodes not included in the MS travel path use multi-hop routing to convey packets to the MS. Additionally, to improve data transfer and minimize routing path modifications, the movement of the MS is split between movement and pause intervals. In other words, during the movement phase, the MS migrates to new places determined by the suggested algorithm while remaining in its present position during the pause interval.

In addition, a model centered on establishing mobile channels for the MS to reduce energy dissipation and delay was proposed by [32]. The algorithm operates in four stages: selecting a meeting place, creating a trajectory, gathering data, and sending data. A geographic routing strategy based on MSs was created in [33]. This investigation utilized two mobile sinks to acquire data from sensors located in cells or geographical areas. Thus, data is gathered by each cell's nodes and transmitted to the MS. It is important to remember that sensor nodes can connect to the MS via single-hop and multi-hop routing.

Furthermore, a mobility model based on bipartite graphs was presented by the authors of [34]. The suggested model determines the movement path of the MS by utilizing the features of a bipartite graph. In addition, the proposed approach is predicated on building a bipartite graph from a randomly distributed network. The network's nodes will consequently be split into two distinct groups. The MS will then proceed to visit the first group's nodes in a breadth-first manner. The MS will visit each node in the group before moving on to the nodes in the second group similarly.

Consequently, a variety of models are discussed in the research literature. Some use the movable sink's current location to choose a new site, while others rely on random mobility. The work presented in this study takes an alternative approach to tackling the MS path planning problem. By building an MST of the network, the suggested method seeks to leverage the network topology and the node neighborhood to generate a logical topology. Subsequently, the movable sink will visit all nodes in the series of orders that the MST is built.

2.3. The proposed mobility models

The work presented in this study is based on randomly dispersed WSNs consisting of one MS node (M) and several fixed sensor nodes (N). After the network is deployed, the MS and fixed sensor nodes' locations are sent to the BS. As a result, the BS computes the MST, taking the nearest fixed sensor node to the MS as the root of the MST. After that, the BS sends the order according to which the MST is constructed to the MS. Consequently, this sequence will serve as the movement path for the MS when it visits nodes and gathers data. Noteworthy is that the portable sink is not factored into this computation because its purpose is to see fixed sensor nodes and collect data.

To clarify, from Figure 1 part (A), assume that the closest node to the MS is node 4. Thus, node four will be considered as the root of the MST. After that, the next node to be added to the MST is node three, and so forth. As a result, using Prim's algorithm to construct the MST will result in adding nodes to the MST in the following order: 4, 3, 1, 2, 7, 6, 5. Consequently, the sequence or order according to which nodes were added to the MST is sent to the MS to be adopted as the movement path. Therefore, the MS will proceed by visiting node 4, node three, and so on until the last node in the sequence, node 5, is visited.

It is crucial to remember that while the MS visits fixed nodes in the built MST, it will be in the communication range of other fixed nodes that it will visit later. As a result, these neighboring nodes can communicate with the MS and provide data to it. As a result, it can be guaranteed that nodes will not experience buffer overflow and that the MS will receive the sensed data quickly.

Additionally, there are two phases to the mobile sink's movement: sojourn and movement. During the sojourn phase, the MS stops in its present location for a specified time. It will then start traveling at a predetermined speed toward a new site. The sojourn period starts over when the MS gets to the next area and continues there for the same amount of time. Below is an algorithm that explains the mobility model that this study proposes. In other words, the nearest node to the MS is selected to be the root of the MST. Thus, the MS starts its journey by initiating the sojourn period and remaining in its current position for a predetermined amount of time to visit the root of the MST, node 4 in our previous example, and collect information from it. Once the sojourn period ends, the movement interval is initiated, and the MS will move at a specific speed to visit the next node in the sequence of the MST constructions, node 3. After reaching its new location, the MS initiates the sojourn interval to gather information. The same process is repeated until every node in the network gets visited according to the sequence in which the MST is constructed.

To elaborate, after constructing the MST, the MS will traverse it according to which it was built. When visiting the first node, the MS enters a pause or sojourn period in order to collect information from the node being visited via single-hop routing. Also, the MS can collect information from the neighbors of the visited node via multi-hop routing. At the expiry of the sojourn time, the MS will start moving, at a specific speed, towards the next node to be visited according to the MST construction order. Upon arrival at the new location, the movement period expires, and the sojourn period is initiated again to collect information in the same manner mentioned before. Thus, it can be concluded that the movement of the MS is split into sojourn intervals where the MS must stay in its present location for a specific period. Meanwhile, in the movement intervals, the MS moves to a predetermined location at a predetermined speed. The mobility model to be adopted by the MS is illustrated in Algorithm 1.

Algorithm 1. Proposed mobility model

```
1.  Start
2.  Initialize a set of nodes: N = {n_0, n_1, n_2, … n_(n-1)}
3.  Initialize mobile sink: MS = {n_n}
4.  Initialize MST = {}
5.  From N, select the node closest to MS to be the root of MST.
6.  Add n to MST.
7.  While MST is not Empty
    7.1. Find all edges connecting the current node to any node in N.
    7.2. Select the edge with minimum weight.
    7.3. if the selected edge does not form a cycle
         7.3.1 Add the edge with minimum weight to MST, connecting the current node to the
         new node n.
         7.3.2.  Remove node n from N.
     7.4. End if
8.   End While
9.   Generate a mobility path to MS based on MST
Stop
```

In the following subsections, the scenarios used to conduct the simulation and the performance metrics adopted to assess the performance of the proposed work are presented.

2.4. Experiments

2.4.1. Scenarios

The suggested mobility model's efficacy was thoroughly evaluated through a series of simulations using the NS-2 simulator. This discrete event simulation tool is specifically designed for communication network research and supports a diverse range of both wireless and wired network protocols [35], [36]. In the simulation, the ad hoc on-demand distance vector (AODV) routing protocol was employed to manage message delivery to the appropriate recipients. Fixed sensor nodes were configured to generate traffic at a constant bit rate (CBR), allowing for a steady flow of data. The AODV protocol was chosen for its reactive nature, which limits the amount of routing information stored in the routing table and thereby reduces memory usage and processing time. The protocol only acquires routing information on-demand, enhancing efficiency [17].

To assess the proposed model under conditions of heavy traffic, the CBR was utilized to simulate continuous data flow from static sensor nodes. The simulation covered networks with 26, 51, 76, and 101 randomly distributed nodes within a 1000 × 1000 grid. In each network, there were N static sensor nodes, numbered sequentially from 0 to n−2, with one additional node, numbered n−1, serving as the mobility sink. For example, in the network with 26 nodes, the stationary sensor nodes were numbered from 0 to 24, while node 25 acted as an energy-rich mobility sink that moved among the static nodes.

The proposed model was tested across different mobility sink speeds-specifically 5, 10, 15, and 20 m/s-to evaluate its performance in various scenarios. This testing aimed to determine how changes in the mobility sink's speed affected the overall efficiency and effectiveness of the proposed model in managing network traffic and maintaining connectivity. Through these simulations, insights were gained into the model's ability to handle dynamic network conditions and its potential benefits in real-world applications.

For example, after randomly deploying the 26-node network, the mobility model's performance will be studied while the MS moves according to 5 m/s speed. After that, the speed according to which the MS moves will be increased to 10 m/s for the same network size and so on for 15 and 20 m/s speeds. After studying the performance of the 26 nodes network under all the previously mentioned speeds, the network size is changed to 51 nodes network that will be randomly deployed, and the performance of the proposed model is studied by varying the MS speed in the same approach adopted for the previous network size. It is important to note that each case was run ten times, and the results obtained from all the trials were averaged to get more accurate results. The parameters with which the simulation was conducted are shown in Table 1.

Table 1. Parameters for simulation

Parameter name	Used value
Period of simulation	500 seconds
Network size	26, 51, 76, 101
Sink stop time	5 Seconds
Deployment area size	1000*1000
Generated traffic type	CBR
Movement speed	5, 10, 15, 20 m/s
Size of packet (bytes)	512

2.4.2. Experiment metrics

The average one-way delay, packet delivery ratio, and throughput metrics are used to examine the network's performance under the suggested mobility paradigm. The average one-way delay is the amount of time a packet takes to go from one place to another. The average one-way delay for the network is determined by taking the average time required to send each packet between each source and each destination inside the network [37]-[39]. In (1) is used to determine the average one-way delay:

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

in (1), H^i_r and H^i_t represent the received transmitted copy of a packet, respectively, and N is the total number of delivered packets.

The packet delivery rate is determined by dividing the total number of packets transmitted by the ratio of successfully received packets, as stated in (2) [37]-[40]:

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

P_{rs} is the total number of successfully received packets, and p_{sent} is the overall number of sent packets.

The third measure of performance considered is throughput, which is defined as the total number of packets that were correctly received during a given period. Consequently, throughput is calculated in our simulation using (3), which states that throughput is computed by dividing the total number of packets successfully received by the whole simulation duration [37]-[40].

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

3. RESULTS AND DISCUSSION

The results obtained from using the simulated scenarios are displayed and discussed in this section. Ten trials for every scenario were conducted to obtain more thorough results. For each case, the results of the ten runs were averaged to get the simulation results.

The average one-way delay findings for different network sizes and MS movement speeds are shown in Figure 2. The best overall one-way delay results were obtained by networks with 51 and 76 nodes, particularly when the MS speed was ten m/s. This kind of behavior can be attributed to the fact that the MS is operating at a pace that is deemed moderate, merging the utilization of single-hop and multi-hop transmission to achieve low one-way delay values.

Moreover, Figure 2 demonstrates that networks with 26 and 101 nodes had the worst performance compared to all other networks. This can be explained by the fact that multi-hop routing is often used to get packets to their destination. Stated differently, the MS has a relatively short road to adoption. Consequently, most of the immobile sensor nodes' routing paths will be impacted by the MS's motion. As a result, packets delivered from fixed sensor nodes will make several hops, some of which are caused by routing path alterations or modifications. As a result, it's possible that those packets were routed multiple times from the same node to accommodate routing path modifications before reaching the MS. On the other hand, for a 101-node network, the path to be followed by the MS is long, and the routing paths adopted to convey messages to the MS using multi-hop routing are long, too. As a result, messages will suffer from a high one-way delay in getting to the MS. Also, changes in the routing paths that result from MS relocation cause even longer routing paths to be constructed and followed to deliver messages.

Because not every node in the network was impacted by the routing path adjustments, better results were obtained for other networks. As a result, packets did not have to travel over the network or pass through any duplicated intermediate nodes. As a result, fewer hops were required for packets to reach the MS. Smaller one-way delay results were therefore attained.

Figure 3 displays the packet delivery ratio observations obtained. It is clear from this data that the suggested mobility model achieved unswerving performance across various network sizes. Consistent with the findings from Figure 2, the networks of 51 and 76 nodes demonstrated the best performance in terms of packet delivery ratio across all MS speeds.

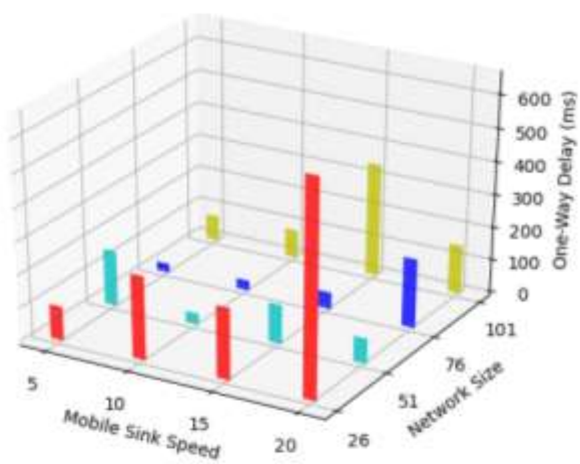


Figure 2. Average one-way delay

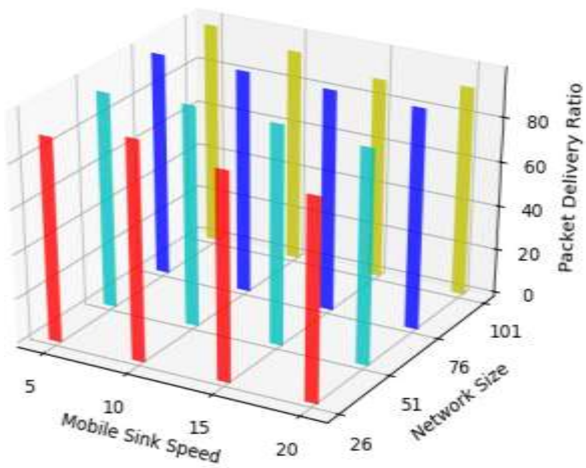


Figure 3. Packet delivery ratio

To further explain, this network will achieve the best results for the packet delivery ratio since it obtained the best results for one-way delay for the same reason stated when presenting the results of Figure 2. Furthermore, Figure 3 shows how the MS's velocity increased to 20 m/s, which impacted and somewhat decreased the performance of all networks. Accordingly, rapid and frequent modifications to the routing pathways will occur for small networks when the MS travels at high speeds, resulting in a drop in performance. Also, it won't be easy to complete data transfer between the MS and the fixed sensor nodes since the MS will also be traveling quickly.

However, compared to medium- and large-sized networks, the expected mobility path of the MS is shorter for smaller network sizes. This means that the static sensor nodes and their neighbors will be impacted if the MS's speed is increased to 20 m/s. As a result, packets must be routed via multi-hop routing to reach their destination because these nodes will not have enough time to send them to the MS. To accommodate the frequent modifications in the routing path, packets will also make extra and needless hops before reaching the MS. The network throughput results are displayed in Figure 4 for different network sizes and speeds when the MS traveled by the recommended mobility model.

Because the length of the routing path is consistent with the speeds at which the MS is moving, Figure 4 shows that the suggested mobility achieved high and stable performance for the network comprising 51 nodes under all of the movable sink's speeds. Consequently, decreasing the frequency of updates and potential modifications to the routing pathways. Fixed sensor nodes will also have enough time to transmit data and connect with the MS properly. Due to the fair length of the routing paths, the packet did not have to pass through many hops to be delivered, making the 51-node network the most performant and stable in all scenarios. Because the MS used a somewhat long movement path, fixed sensor nodes were not required to update their routing tables regularly, leading to superior performance outcomes. On the other hand, for small-size networks, changes in the routing path resulting from relocating the MS cause frequent updates that may result in messages circulating through the network by passing through many unnecessary hops. As a result, the network gets congested easily, which affects the network performance in terms of throughput. Moreover, the routing paths are long for large network sizes, and messages suffer from high one-way delays due to multi-hop routing. This situation is made even worse when relocating the MS. Consequently, most traffic will be redirected and concentrated on a specific path in the network, causing bottlenecks and congestion. Thus, packets get dropped, and network performance is affected.

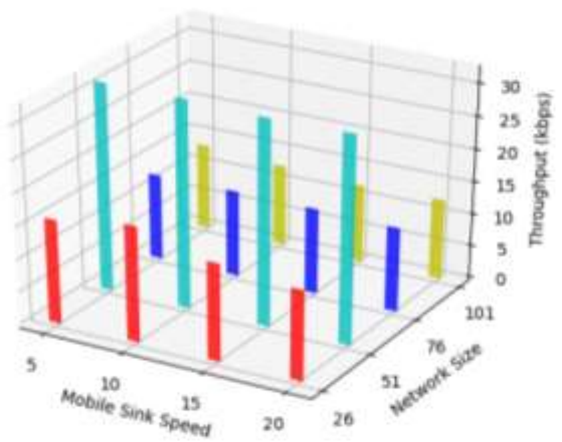


Figure 4. Network throughput

In conclusion, it can be observed that the effectiveness of various network sizes remained nearly constant for all other scenarios of MS speeds, but it was not as good as the networks with 51 nodes. Either of two reasons applied to this. First, the speed of the MS might not be appropriate for the size of the network. To put it another way, because of packet loss and network congestion, low and high speeds might not be suitable for larger or smaller networks, respectively. Second, the routing paths might be extremely long for large network routing at low speeds. This could lead to congestion in some areas of the network and packet dropping. Conversely, in small networks with high MS speeds, packet loss may occur from frequent topology and routing path changes. Updating the paths requires a significant amount of bandwidth, degrading network performance and raising the number of dropped packets.

Furthermore, many packets could make extra hops to be delivered; as a result, the packet's counter or time to live timer may expire, causing the packets to be discarded. Additionally, it can be observed that medium-size networks, 51 nodes, achieve acceptable results in all cases under different parameters. In other words, the network that has achieved good performance results in terms of one-way delay managed to achieve high performance in terms of PDR and throughput because the one-way delay directly impacts the other two parameters, especially when taking sink mobility into account.

Using the same performance measures, the suggested model's performance was also contrasted with that of three other mobility models, namely, the Depth First-based mobility model (DF), the Gauss Markov mobility model (GM), and the random waypoint mobility model (RW). All models were run through the simulation scenarios outlined in subsection 2.2.1 to gather data and compare the models in the same conditions. The four models' performances are contrasted in Tables 2-4. It is worth briefly describing the mobility models adopted for performance comparison with the mobility model proposed in this paper. Thus, subsections 3.1–3.3 discuss the mobility models utilized in the comparison. It is worth noting that these models were selected for comparison because they have a similar behavior for the MS as the proposed model, where the movement of the MS is divided into movement periods and sojourn periods. They differ in the way or mechanism according to which the new location for the MS is selected or calculated.

3.1. RW model

The movable sink's motion in this model is split into rounds of pause and movement. The MS will first pause for a predetermined amount of time. The movement round begins when the pause round ends and the movable sink will randomly choose another location. It will start traveling there at a predetermined speed. A new pause round begins when the MS reaches its destination, remains there for a predetermined time, and so on [37], [41]. Given this model's behavior is comparable to the model suggested in this work, it was selected for comparison. Stated differently, the MS's movement in both models is split between movement and pause intervals.

3.2. GM model

This model was proposed to consider various amounts of unpredictability and make the model more realistic. A movable node in this framework can adjust its direction and speed as needed. The mobile node is initially given the direction and speed of motion and moves for a certain amount of time by these parameters. Afterward, a new course and velocity are determined using the values from the previous iteration when the timer ends [17], [33], [35]. Since this model starts with designated speed and direction values, it was included in the comparison. Starting with a single subset, the new locations are chosen by considering both the closest and present neighbors.

3.3. DF model

In such a case, a graph's depth first traversal algorithm will determine how the MS moves through the network. Consequently, the movement of the MS is divided as halt and motion phases, with the starting node chosen at random. After selecting the beginning point, the MS will travel at a predetermined speed to the new place. It will remain there for a predetermined time when it gets to the new place. Subsequently, the MS moves toward the next location, which is determined using the depth-first traversal algorithm [42]. DF model was chosen because it behaves similarly to the model suggested in this work: the MS moves in rounds, and its new location is determined using a predetermined procedure. It also uses the nodes ‘ locations along with the properties on the topology or graph.

3.4. Performance comparison results

After simulating the four mobility models, it can be observed that the suggested mobility model in this research performed better than all three mobility models under various MS velocities and network sizes, according to Tables 2-4.

Tables 2-4 show the results obtained for one-way delay. The acquired results are consistent with the findings obtained in Figure 2, where networks made up of 51 and 76 nodes for the proposed model in this work received the best results when the MS speed was equal to 10 m/s. Also, the suggested model's overall performance with various network sizes and MS speeds was better than the other three models because the MS movement path is calculated and predetermined. In contrast, in the RW model, the new location and speed of the mobile sink are selected randomly. Also, the selection of the parameters for a specific round in the GM model depends on previous rounds, which may cause problems for new rounds. Compared to the DF Model, the proposed model performed better under all network sizes and speeds for the MS. The reason behind such observation can be regarded as the mechanism for generating the MS movement. In other words, the proposed model is based on building an MST that aims to reduce the cost and time of visiting static sensor nodes, which results in a proper way of visiting nodes. On the other hand, the DF model is based on constructing the routing path based on the locations of the nodes, i.e., neighborhood, which might affect other parts or nodes in the network and cause performance problems.

Table 2. One-way delay performance comparison

Model name	Speed	Network size (Nodes)			
		26-Node	51-Node	76-Node	101-Node
Proposed model	5	104.99	169.78	27.22	77.61
	10	256.36	34.60	30.87	87.13
	15	220.48	120.40	51.75	346.04
	20	655.19	77.59	212.51	150.58
RW model	5	1070.78	3590.09	5344.26	7348.23
	10	1069.12	4247.96	4665.35	6904.05
	15	811.182	3507.06	5812.7	4860.76
	20	993.193	3535.66	6268.34	6077.27
GM model	5	578.377	4642.27	6166.82	6084.23
	10	231.716	3631.09	4142.33	7122.23
	15	461.982	2907.25	3492.46	4196.06
	20	579.801	3803.8	5322.32	6334.38
DF model	5	153.439	2790.29	7334.31	12043.8
	10	116.511	3152.62	5937.32	11173
	15	145.011	3335.92	6229.31	11422.9
	20	392.171	3718.6	5352.08	11506.4

Table 3. Packet delivery ratio performance comparison

Model name	Speed	Network size (Nodes)			
		26-Node	51-Node	76-Node	101-Node
Proposed model	5	91.70	96.64	99.88	99.57
	10	98.55	98.71	99.75	95.12
	15	93.45	98.42	99.07	90.07
	20	90.78	96.21	98.93	94.08
RW model	5	59.76	34.80	20.76	14.84
	10	53.55	31.82	19.16	13.32
	15	38.51	19.91	15.17	5.70
	20	39.72	26.49	13.85	9.47
GM model	5	51.27	29.19	20.92	14.29
	10	49.71	22.36	18.24	15.53
	15	35.44	22.18	15.42	11.47
	20	29.95	19.94	15.11	10.75
DF model	5	55.91	37.62	19.38	9.06
	10	56.92	34.54	19.93	10.64
	15	55.33	35.48	17.62	7.39
	20	53.08	33.62	18.34	7.19

Table 4. Network throughput performance comparison

Model name	Speed	Network size (Nodes)			
		26-Node	51-Node	76-Node	101-Node
Proposed model	5	16.06	31.91	13.28	13.32
	10	17.83	31.90	13.35	12.59
	15	15.07	31.58	13.28	12.09
	20	13.96	31.83	13.06	12.49
RW model	5	2.44	2.85	2.55	2.43
	10	2.19	2.60	2.35	2.18
	15	1.57	1.62	1.86	1.18
	20	1.62	2.12	1.70	1.55
GM model	5	2.09	2.39	2.56	2.34
	10	2.03	1.83	2.24	2.54
	15	1.51	1.81	1.89	1.87
	20	1.22	1.63	1.85	1.76
DF model	5	2.28	3.07	2.37	1.48
	10	2.32	2.82	2.45	1.74
	15	2.27	2.90	2.16	1.21
	20	2.18	2.75	2.25	1.18

4. CONCLUSION

This research developed a sink mobility model based on building a MST of the current network. After introducing the concept of MST, the suggested mobility model was discussed. Furthermore, a number of scenarios were conducted using NS-2 simulator in order to assess the efficacy and performance of the mobility model that was introduced in this study. Moreover, throughput, packet delivery ratio, and one-way delay were employed to evaluate the mobility model's performance. After studying the proposed model's performance, it can be concluded that the network with 51 nodes produced stable and respectable performance, the mobility model that was recommended worked better and is suitable for usage in networks of moderate size with modest MS speeds. Also, the proposed model's performance was compared to that of the other three mobility models, and the results show that the proposed model outperformed the other three models for all network sizes and all speeds of the mobile sink.

REFERENCES

[1] A. Al-Rahayfeh, A. Razaque, Y. Jararweh, and M. Almiani, "Location-based lattice mobility model for wireless sensor networks," *Sensors,* vol. 18, p. 4096, 2018, doi: 10.3390/s18124096.

[2] J. Segura-Garcia, J. M. A. Calero, A. Pastor-Aparicio, R. Marco-Alaez, S. Felici-Castell, and Q. Wang, "5G IoT system for real-time psycho-acoustic soundscape monitoring in smart cities with dynamic computational offloading to the edge," *IEEE Internet of Things Journal,* vol. 8, pp. 12467-12475, 2021, doi: 10.1109/JIOT.2021.3063520.

[3] A. Srinivasan and J. Wu, "TRACK: A novel connected dominating set based sink mobility model for WSNs," in *2008 Proceedings of 17th International Conference on Computer Communications and Networks,* 2008, pp. 1-8, doi: 10.1109/ICCCN.2008.ECP.127.

[4] X. Sun, Y. Yang, and M. Ma, "Minimum connected dominating set algorithms for ad hoc sensor networks," *Sensors,* vol. 19, p. 1919, 2019, doi: 10.3390/s19081919.

[5] A. Sikora and E. Niewiadomska-Szynkiewicz, "Mobility model for self-configuring mobile sensor network," in *Proceedings of the Fifth International Conference on Sensor Technologies and Applications, SENSORCOMM, French Riviera, France*, 2011, pp. 21-27.

[6] A. Sardouk, R. Rahim-Amoud, L. Merghem-Boulahia, and D. Gaïti, "Data aggregation scheme for a multi-application WSN," in *Wired-Wireless Multimedia Networks and Services Management: 12th IFIP/IEEE International Conference on Management of Multimedia and Mobile Networks and Services, MMNS 2009, Venice, Italy, October 26-27, 2009. Proceedings 12*, 2009, pp. 183-188, doi: 10.1007/978-3-642-04994-1_16.

[7] A. Razaque and K. M. Elleithy, "Energy-efficient border node medium access control protocol for wireless sensor networks," *Sensors,* vol. 14, pp. 5074-5117, 2014, doi: 10.3390/s140305074.

[8] P. Wang and I. F. Akyildiz, "Effects of different mobility models on traffic patterns in wireless sensor networks," in *2010 IEEE Global Telecommunications Conference GLOBECOM 2010*, 2010, pp. 1-5, doi: 10.1109/GLOCOM.2010.5684190.

[9] J. Yoon, M. Liu, and B. Noble, "Random waypoint considered harmful," in *IEEE INFOCOM 2003. Twenty-second Annual Joint Conference of the IEEE Computer and Communications Societies (IEEE Cat. No. 03CH37428)*, 2003, pp. 1312-1321, doi: 10.1109/INFCOM.2003.1208967.

[10] J. Salvatore, "Bipartite graphs and problem-solving," *University of Chicago,* p. 8, 2007.

[11] W. Navidi and T. Camp, "Stationary distributions for the random waypoint mobility model," *IEEE transactions on Mobile Computing,* vol. 3, pp. 99-108, 2004, doi: 10.1109/TMC.2004.1261820.

[12] M. Garcia-Pineda, J. Segura-Garcia, and S. Felici-Castell, "A holistic modeling for QoE estimation in live video streaming applications over LTE Advanced technologies with Full and Non Reference approaches," *Computer Communications,* vol. 117, pp. 13-23, 2018, doi: 10.1016/j.comcom.2017.12.010.

[13] J. E. Mbowe and G. S. Oreku, "Quality of service in wireless sensor networks," *Wireless Sensor Network,* vol. 2014, 2014, doi: 10.4236/wsn.2014.62003.

[14] M. G. Premi and K. Shaji, "Impact of mobility models on MMS routing in wireless sensor networks," *International Journal of Computer Applications,* vol. 22, pp. 47-51, 2011, doi: 10.5120/2608-3638.

[15] F. C. Jabour, E. Giancoli, and A. C. Pedroza, "Mobility support for wireless sensor networks," in *2008 International Conference on Computer and Electrical Engineering*, 2008, pp. 630-634, doi: 10.1109/ICCEE.2008.79.

[16] T. Camp, J. Boleng, and V. Davies, "A survey of mobility models for ad hoc network research," *Wireless communications and mobile computing,* vol. 2, pp. 483-502, 2002, doi: 10.1002/wcm.72.

[17] A. A. Taleb, "A comparative study of mobility models for wireless sensor networks," *Journal of Computer Science,* vol. 14, pp. 1279-1292, 2018, doi: 10.3844/jcssp.2018.1279.1292.

[18] S. Aslam, F. Farooq, and S. Sarwar, "Power consumption in wireless sensor networks," in *Proceedings of the 7th International Conference on Frontiers of Information Technology*, 2009, pp. 1-9, doi: 10.1145/1838002.1838017.

[19] M. Al-Razgan and T. Alfakih, "Wireless sensor network architecture based on mobile edge computing," *Security and Communication Networks,* vol. 2022, p. 9073220, 2022, doi: 10.1155/2022/9073220.

[20] E. A. Navarro-Camba, S. Felici-Castell, J. Segura-García, M. García-Pineda, and J. J. Pérez-Solano, "Feasibility of a stochastic collaborative beamforming for long range communications in wireless sensor networks," *Electronics,* vol. 7, p. 417, 2018, doi: 10.3390/electronics7120417.

[21] K. N. Qureshi, M. U. Bashir, J. Lloret, and A. Leon, "Optimized cluster-based dynamic energy-aware routing protocol for wireless sensor networks in agriculture precision," *Journal of sensors,* vol. 2020, p. 9040395, 2020, doi: 10.1155/2020/9040395.

[22] R. C. Prim, "Shortest connection networks and some generalizations," *The Bell System Technical Journal,* vol. 36, pp. 1389-1401, 1957, doi: 10.1002/j.1538-7305.1957.tb01515.x.

[23] Z. N. Jwair and M. A. Abdlhusein, "Some dominating results of the topological graph," *International Journal of Nonlinear Analysis and Applications,* vol. 14, pp. 133-140, 2023.

[24] N. Temene, C. Sergiou, C. Georgiou, and V. Vassiliou, "A survey on mobility in wireless sensor networks," *Ad Hoc Networks,* vol. 125, p. 102726, 2022, doi: 10.1016/j.adhoc.2021.102726.

[25] J.-Y. Chang, J.-T. Jeng, Y.-H. Sheu, Z.-J. Jian, and W.-Y. Chang, "An efficient data collection path planning scheme for wireless sensor networks with mobile sinks," *EURASIP Journal on Wireless Communications and Networking,* vol. 2020, p. 257, 2020, doi: 10.1186/s13638-020-01873-4.

[26] A. A. Taleb, "Sink mobility model for wireless sensor networks using Kohonen self-organizing map," *International Journal of Communication Networks and Information Security,* vol. 13, pp. 62-67, 2021, doi: 10.17762/ijcnis.v13i1.4813.

[27] Y. Guo, Z. Xu, and J. Saleh, "Collaborative allocation and optimization of path planning for static and mobile sensors in hybrid sensor networks for environment monitoring and anomaly search," *Sensors,* vol. 21, p. 7867, 2021, doi: 10.3390/s21237867.
[28] A. Prasanth and S. Pavalarajan, "Zone-based sink mobility in wireless sensor networks," *Sensor Review,* vol. 39, pp. 874-880, 2019, doi: 10.1108/SR-11-2018-0310.
[29] S. Yalçın and E. Erdem, "Performance analysis of burst traffic awareness based mobile sink routing technique for wireless sensor networks," *Gazi University Journal of Science,* vol. 35, pp. 506-522, 2022, doi: 10.35378/gujs.863598.
[30] X. Wu, Z. Chen, Y. Zhong, H. Zhu, and P. Zhang, "End-to-end data collection strategy using mobile sink in wireless sensor networks," *International Journal of Distributed Sensor Networks,* vol. 18, p. 15501329221077932, 2022, doi: 10.1177/15501329221077932.
[31] A. A. Taleb, "Sink mobility model for wireless sensor networks using genetic algorithm," *Journal of Theoretical and Applied Information Technology,* vol. 99, pp. 540-551, 2021.
[32] A. Alsaafin, A. M. Khedr, and Z. A. Aghbari, "Distributed trajectory design for data gathering using mobile sink in wireless sensor networks," *AEU-International Journal of Electronics and Communications,* vol. 96, pp. 1-12, 2018, doi: 10.1016/j.aeue.2018.09.005.
[33] M. Naghibi and H. Barati, "EGRPM: Energy efficient geographic routing protocol based on mobile sink in wireless sensor networks," *Sustainable Computing: Informatics and Systems,* vol. 25, p. 100377, 2020, doi: 10.1016/j.suscom.2020.100377.
[34] A. Abu Taleb, Q. Abu Al-Haija, and A. Odeh, "Efficient mobile sink routing in wireless sensor networks using bipartite graphs," *Future Internet,* vol. 15, p. 182, 2023, doi: 10.3390/fi15050182.
[35] R. A. Gbadebo, M. L. Sanni, B. O. Akinyemi, T. O. Ajayi, and G. A. Aderounmu, "An enhanced cluster-based routing model for energy-efficient wireless sensor networks," *Indonesian Journal of Electrical Engineering and Informatics (IJEEI),* vol. 11, pp. 586-609, 2023, doi: 10.52549/ijeei.v11i2.4566.
[36] S. Khera, N. Turk, and R. Rakheja, "Analysis of DSR protocol in varying network configurations," in *Recent Developments in Electrical and Electronics Engineering: Select Proceedings of ICRDEEE 2022*, ed: Springer, 2023, pp. 179-189, doi: 10.1007/978-981-19-7993-4_15.
[37] S. Taneja and A. Kush, "A survey of routing protocols in mobile ad hoc networks," *International Journal of Innovation, Management and Technology,* vol. 1, p. 279, 2010.
[38] M. Amnai, Y. Fakhri, and J. Abouchabaka, "Impact of mobility on delay-throughput performance in multi-service mobile ad-hoc networks," *International Journal of Communications, Network and System Sciences,* vol. 4, p. 395, 2011, doi: 10.4236/ijcns.2011.46047.
[39] S. Jabbar, R. Iram, A. A. Minhas, I. Shafi, S. Khalid, and M. Ahmad, "Intelligent optimization of wireless sensor networks through bio-inspired computing: survey and future directions," *International Journal of Distributed Sensor Networks,* vol. 9, p. 421084, 2013, doi: 10.1155/2013/421084.
[40] A. A. A. Asmael and B. Al-Nedawe, "Energy efficient WSN using hybrid modification PEGASIS with ant lion optimization," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS),* vol. 23, pp. 273-284, 2021, doi: 10.11591/ijeecs.v23.i1.pp273-284.
[41] L. Guezouli, K. Barka, S. Bouam, and A. Zidani, "Implementation and optimization of RWP mobility model in WSNs under TOSSIM simulator," *International Journal of Communication Networks and Information Security,* vol. 9, p. 1, 2017, doi: 10.17762/ijcnis.v9i1.2116.
[42] A. A. Taleb and T. Alhmiedat, "Depth first based sink mobility model for wireless sensor networks," *International Journal of Electrical and Electronics Computer Systems*, vol. 19, pp. 9-14, 2014.

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