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Effective Routing of Mobile Sink in Wireless Sensor Networks Using Steiner Trees

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Abstract

Wireless sensor networks, or W.S.N.s, are an important field of study with a wide range of real-world uses. Real-world applications for W.S.N.s include smart homes, industrial automation, healthcare, agriculture, and environmental monitoring. As W.S.N.s develop and grow more complex, they provide many chances for creative solutions across a range of industries. Because they are unattended, it is necessary to devise ways to enhance their functionality without depleting the sensor nodes' battery life, which is their most precious asset. The unique sink mobility model presented in this study is established on building a minimal Steiner tree from a wireless sensor network that has been installed. The suggested approach derives a movable sink with controlled movement based on the features of Steiner trees. Consequently, fixed nodes will be scheduled and visited in order to save routing overhead and improve network efficiency. Fixed nodes are visited via the mobile sink in the most efficient manner to gather data and send it to the base station by utilizing the features of the Steiner tree. The efficiency of the network was examined while implementing this mobility model, and using the NS-2 simulator, we ran simulations to assess the proposed approach. According to our findings, the suggested method may greatly improve wireless sensor network performance.

Keywords: Steiner Tree, Mobility Model, Mobile Sink, Path Planning, Wireless Sensor Networks.

1 Introduction

When used to assist mobility-dependent applications, such as emergency and seismic recovery, combat area observation and animal monitoring, wireless sensor networks (W.S.N.s) face challenges. Psychoacoustic monitoring is one of the applications of W.S.N.s that utilizes 5G internet of things technologies (Sudhakar et al., 2019). Hence, an adaptable and dynamic WSN with mobility assistance is needed ensure trustworthy communication, dependable network connectivity, low energy consumption, and prolong the network operational time for these applications (Al-Rahayfeh et al., 2018; Segura-Garcia et al., 2021; Sreenivasu et al., 2022). Hence, for these networks to function correctly, fault tolerance and self-organizing capacities must be maintained (Srinivasan & Wu, 2008; Sun et al., 2019; Sikora & Niewiadomska-Szynkiewicz, 2011; Sardouk et al., 2009; Mleh et al., 2023).

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Consequently, energy-efficient devices must be provided across the entirety of the protocol, because stack differences in mobility have a significant impact on the scalability and energy-saving measures of W.S.N.s (Santhosh et al., 2023). Therefore, the requirement of offering a reliable mobility model leads to the need of taking performance degradation and unpredictable broken links into account (Al-Rahayfeh et al., 2018; Razaque & Elleithy, 2014; Wang & Akyildiz, 2010).

There are several mobility models that have been suggested in the literature and are seen to be appropriate choices for usage in ad-hoc networks. They do, however, act differently in W.S.N.s., resulting in low QoS values and increased energy usage (Rosa et al., 2023). To put it another way, sensor networks can deliver a variety of data formats, including videos. Consequently, some QoS requirements need to be upheld, like bitstream (Praveenchandar et al., 2024). Notably, QoS in W.S.N.s is separated into two categories: network-dependent and application-dependent, encompassing node reading, coverage, deployment, and number of live nodes (Camgözlü et al., 2023).

Effective use of bandwidth, energy usage, throughput, and the ratio of packet delivery, on the other hand, is the main focus of the second group. In ad hoc networks, to put it another way, the random waypoint mobility model functions well. But due of its poor velocity selection and uniform distribution, it is not a good option in W.S.Ns (Yoon et al., 2003; Salvatore, 2007; Navidi & Camp, 2004; Garcia-Pineda et al., 2018; Mbowe & Oreku, 2014; Giji et al., 2023).

Conversely, the random waypoint mobility model's shortcomings were addressed with the introduction of the nomadic community mobility model (Kang et al., 2019). This architecture fits the needs of applications supporting military operations and mobile communications in conferences because nodes roam randomly between sites. Furthermore, a reference point is established for every point based on the group's collective motion. Finding or locating a single node using this method uses considerable amounts of energy (Premi & Shaji, 2011; Jabour et al., 2008; Akila et al., 2023; Basic et al., 2018).

Thus, sink node mobility was handled by introducing a circular mobility concept based on geography. Through the use of a static, circular point-based track, this model gathers data. An important limitation of this architecture is that nodes have to stay fixed for eight or sixteen times in a cycle. Thus, to increase the network lifespan, a wind movement model that is based on eight directions was presented in (Premi & Shaji, 2011). Despite the fact that this model's nodes only allow group mobility, this concept is illustrated for sink nodes. Therefore, a group of nodes travels and uses energy to identify the position of one node (Jabour et al., 2008). The added pause time, node speed, and interdependencies mean that the wind mobility model needs to offer excellent network performance (Camp et al., 2002).

Furthermore, sensor nodes have the following subsystems namely; processing, sensing, and communication. The key energy consumer is also the communication subsystem since the distance across the source and destination nodes governs the amount of energy needed to deliver a message (Taleb, 2018; Aslam et al., 2009). Therefore, compared to single-hop communication, multi-hop communication can shorten the transmission distance, but at the cost of longer delays (Taleb, 2018; Al-Razgan & Alfakih, 2022). In addition, the IEEE 802.15.4 standard is followed for communication between sensor nodes, with the understanding that the communication range is contingent upon the energy of each sensor node. However, it is typically less than 100 meters (Navarro-Camba et al., 2018).

To address this problem, a movable, rich in energy sink nodes or node have been proposed. So as to gather data from fixed nodes, this technique uses a mobile sink (MS) that either travels at random or according to a predefined mobility model. The performance of W.S.N.s is also improved by employing a MS in a number of ways, such as reducing the distance at which a fixed node must broadcast data, reducing the number of intermediary nodes, enhancing the throughput of the whole network, and offering coverage for distant locations (Srinivasan & Wu, 2008).

In addition to employing MS's, other researchers have suggested alternative methods for improving the effectiveness of W.S.Ns. In the study suggested in (Qureshi et al., 2020), for instance, a clustering routing protocol was described. The gateway is chosen within the cluster, and a cluster head is chosen according to a centroid's location. This research work proposes a sink mobility model that gathers data from stationary sensor nodes using a single MS node that is rich in energy. Constructing a Steiner tree of the W.S.N. is the foundation of the suggested model. Next, using the Steiner tree attributes, a sink node mobility path is obtained. Additionally, this paper suggests mixing multi-hop and single-hop routing to attain high levels of network efficiency and reduce delay.

The following order will be used to show the upcoming sections of this article. Section 2 offers a succinct description of the Steiner tree. An overview of the literature on current models is included in Section 3. Section 4 provides an explanation of the suggested mobility paradigm. Section 5 delves into the performance metrics and simulated scenarios aimed at examining the efficacy of the planned effort. The simulation's results are described in section 6. In Section 7, the performance of the suggested model is examined in comparison with three different models. Lastly, Section 8 discusses concluding ideas and recommendations for further study.

2 Steiner Tree

The minimal weight tree that joins a predetermined group of vertices known as terminals in an undirected, weighted graph or points in a space is known as a Steiner tree. It is a challenge to identify the tree that covers a collection of destinations with the smallest cost over all links. The tree may include non-terminals known as Steiner points or Steiner vertices. The Steiner tree problem aims to minimize the amount of resources required in order to discover the lowest cost Steiner tree that connects the group members via a specified graph (Babu et al., 2013).

Finding a tree of G that spanning S with the minimum total distance along its edges is the goal of the Steiner tree problem, which requires an undirected distance graph G = (V, E, d) and a set S. S⊆V is a subset of V's vertices, V's set of vertices is V, and the distance function d maps E into the set of non-negative numbers (Kou et al., 1981).

A path in G will be represented by the series of vertices u1, u2, …, up, such that for every k, $1 \leq k < p; \{u_k, u_{k+1} \in E$ and $u_k \in V$. The path from u1 to uk is denoted by the notation $\sum_{k=1}^{p-1} d(\{u_k, u_{k+1}\})$. Of all the possible pathways from u1 to up, the path with the smallest distance is called the shortest path from u1 to up (Kou et al., 1981).

Consider the graph shown in figure 1 representing an undirected weighted graph that contains Steiner vertices and a number of required vertices that is adapted from (Dolagh & Moazzami, 2011). As can be seen a graph with minimum weight can be derived from the original graph when calculating the Steiner tree. In other words, figure 1 shows a minimum Steiner tree that can be derived from an undirected weighted graph that is generated randomly.

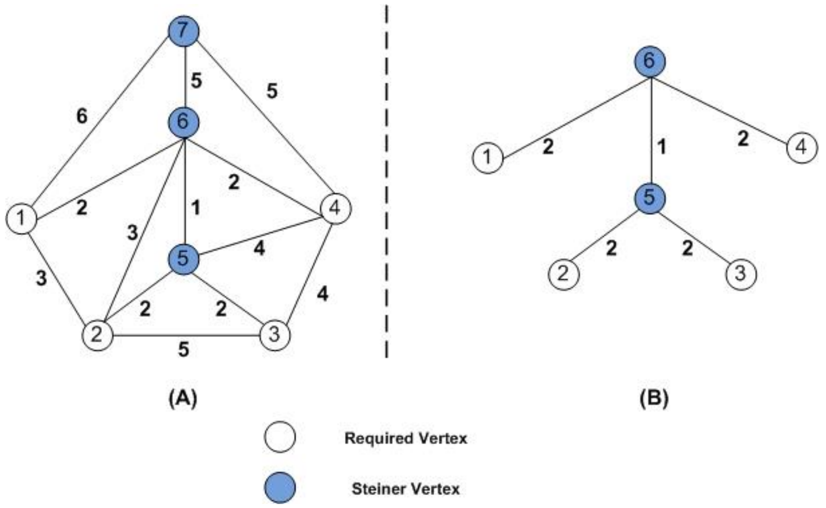

Figure 1: Part (A) Graph with Three Steiner Vertices and Four Required Vertices. Part (B) The Derived Minimum Steiner Tree of the Graph

3 Mobility Models

Several studies have proposed models or methods to facilitate mobility in WSNs. Node mobility, as defined by (Jwair & Abdlhusein, 2022; Bašić et al., 2018), is the ability of nodes within WSNs to migrate after being deployed. Consequently, there are two main classes of methods or models for sensor node mobility. In the first, all sensor nodes must have the ability to move; in the second, MS or sinks that are employed to receive data from immobile sensors while moving are adopted. In this study, we will concentrate our review on works that provide only one MS that travels to gather information from immobile nodes and transmits them to the base station.

In order to shorten the communication range and decrease the distance traveled via the MS, a path planning-based data collection technique was implemented in the study suggested in (Temene et al., 2022). In order to reduce the distance a MS needed to travel; an inner center path planning method was employed. To solve the motion pathway back propagation issue, a back-routing technique was also introduced. In order for MS to move appropriately, the suggested design must allow it to make adaptive decisions.

Furthermore, in an effort to lower energy usage and extend the life expectancy of W.S.N.s, the research provided in (Chang et al., 2020) recommended addressing the relay selection problem. Consequently, the network was divided into clusters in the proposed study using the k-means algorithm. For the purpose of improving energy consumption inside the cluster, MS based cluster head selection method was proposed. To gather information and reduce energy usage for both the cluster head and stationary sensor nodes, the MS will act as a cluster head in close proximity to fixed sensor nodes.

A model for sink mobility which is predicated on Kohonen's self-organization map (S.O.M.) was developed by the research authors of (Taleb, 2021). Using Kohonen S.O.M., their investigation determines the MS's path of motion. For this reason, the MS moves when in moving period and stops when in stopping period. For the duration of the halt periods, the MS will stay at its current location. After that, it will start to migrate to a different location selected by the Kohonen S.O.M., and so forth, up until topology changes resulting from energy exhaustion occur. Therefore, the mobility path will be recalculated using the Kohonen S.O.M. method.

A collaborative strategy was provided in (Guo et al., 2021) to improve the way that anomaly searches and environmental monitoring are conducted. There are two main components to the suggested method. Installing the static sensor nodes cooperatively is the primary goal, founded on a weighted Gaussian coverage technique. Conversely, the second part, which focuses on the MS's route planning, is built on altering an anomaly search and active monitoring system that makes use a Markov decision process model. Rapidly detecting abnormalities in the surroundings is the main goal, allowing the mobile node to react suitably by using a cumulative reward function.

To better improve the performance of wireless sensor networks and increase their lifespan, another study is suggested in (Prasanth & Pavalarajan, 2019) that splits the network into zones. The highly laden zone is where the MS will pass. It is critical to emphasize that a fuzzy logic approach is employed to determine which zone is highly loaded to resolve any potential uncertainties during this decision-making process.

In a similar manner, (Yalc & Erdem, 2022) suggests an adaptive mobile routing technique that addresses burst traffic identification. In addition, the suggested network architecture is predicated on having two MS nodes, and the method depends on splitting the clusters within the network into two groups. Subsequently, every node will belong to a single group and will interact with the cluster leaders. Furthermore, the MS will pay particular visits to the cluster heads in the group. However, if a traffic burst emerges, the MS will move close to the heavily loaded cluster head and ignore the sequence in which visits to the cluster heads take place.

In (Wu et al., 2022), an end-to-end data-gathering method based on ant colony optimization was also introduced. The suggested approach is predicated on constructing a tree for data forwarding and selecting data collection locations at random. Consequently, a predicted and detailed plans of the MS are provided.

In (Taleb, 2021), genetic algorithms were used to introduce a sink mobility model. The MS's optimal direction of travel is determined by the mobility model with the application of genetic algorithms. Subsequently, Single-hop routing will be used by the MS to reach the nodes included in the generated path and get information from them. However, nodes not included in the MS traveling path use multi-hop routing to convey packets to the MS. Additionally, in order to improve data transfer and minimize routing path modifications, intervals of movement and pause make up the MS's movement. Stated differently, instead of staying in the present place during the pause time, the MS relocates to other locations that are determined using the suggested method during the movement stage.

Moreover, a model centered on establishing mobile channels for the MS to reduce energy usage and delay was proposed in (Alsaafin et al., 2018; Rajesh et al., 2023). 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 devised in (Naghibi & Barati, 2020). To get data from sensors in cells or geographical areas, two mobile sinks were employed in this study. Consequently, data is gathered by each cell's sensor nodes and transmitted to the MS. It is noteworthy that sensor nodes can be connected to the MS using both single-hop and multi-hop routing.

Additionally, the authors of (Abu Taleb et al., 2023) presented a bipartite graph-based mobility model. The proposed model utilizes the characteristics of a bipartite graph to determine the movement path of the MS. Furthermore, the proposed work depends on building a bipartite graph from a randomly distributed network. Thus, nodes will be split into two disjoint groups. After that, the MS will visit the nodes of the first group in a breadth first fashion. After visiting all the nodes in the group, the MS will visit the nodes of the second group in the same manner.

As a result, the literature presents a number of mobility models. While some of the reviewed models rely on random mobility, others attempt to determine a new site by utilizing the movable sink's present location. The work presented in this study takes a different approach for tackling the MS path planning problem. The suggested method seeks to build a logical topology based on calculating Steiner tree based on the current network topology and the node neighborhood. After that, we derive a sink mobility model based on Steiner tree features.

4 Proposed Mobility Model

The strategy suggested in this study is predicated on randomly distributed W.S.N.s consisting of many fixed sensor nodes, N, and one MS node that may move. The MS and stationary sensor nodes' positions are sent to the base station when the network is deployed. To prevent having redundant nodes, the base station chooses a subset of nodes that provide complete coverage and connection throughout the research area. According to section 2's explanation of how Steiner trees are built, the terminal nodes that must be visited are the selected nodes. It is important to note that although the MS is intended to visit fixed sensor nodes and gather data, it is not included into this computation.

To clarify, a subset of stationary sensor nodes will be selected as terminal nodes based on nodes' positions and neighborhood in order to avoid having redundant nodes and to provide full connectivity and coverage accross the deployment area. After selecting the subset of terminal nodes, the based station will derive or calculate the Steiner tree containing all terminal nodes in addition to some other nodes that are not part of the selected subset that are called Steiner nodes or vertices where these nodes are used to connect Steiner vertices in the selected subset.

Worth noting, the construction of the Steiner tree starts from the nearest node to the MS. After constructing the Steiner tree, it will be traversed in a pre-order fashion by the MS with the intention of collecting data from all the nodes that are members of the calculated Steiner tree. Also, sensor nodes that are neither terminal nodes nor Steiner nodes will be functional and will report their data to the nearest neighbor that is part of the constructed Steiner tree. As a result, it can be concluded that the constructed Steiner tree forms a backbone to the whole network and stationary sensor nodes will be reporting data to other neighboring nodes that are part of the constructed Steiner tree. In this way, the trip or the trajectory to be followed by the MS will be minimized as the MS is not obliged to visit every node in the network. The MS will be visiting a subset of nodes, terminal and Steiner nodes, and collect data from them.

It is important to note that while the MS makes visits to static sensor nodes in the Steiner tree, it will be in the communication range of other fixed sensor nodes that do not belong in the tree but are the node's neighbors; as a result, these neighbor nodes can communicate with the MS and send data to it. As a result, we can guarantee that nodes will not experience buffer overflow and that the MS will get the sensed data quickly.

Moreover, the movement of the MS will be split into sojourn and movement phases and will correspond to the pre-order traversal of the Steiner tree. The movable sink will stop in its present place for a certain amount of time throughout the sojourn period. It will then start traveling at a predetermined speed in the direction of 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 a pseudocode for the mobility model that this study suggests.

```
Algorithm 1: MOBILITY MODEL
1.  Start
2.  Initialize nodes: $N = \{n_0, n_1, n_2, \ldots n_{n-1}\}$
3.  Initialize mobile sink node: $SN = \{n_n\}$
4.  Select a subset of terminal nodes $S = \{s1, \ldots, s_k\} \subseteq V$
5.  From S select terminal node X that is closest to SN
6.  Start with subtree T containing one terminal node X from S.
7.  While S in not Empty
    7.1.  Select terminal node Y that is not a member of T and closest to a node in T
    7.2.  Add the shortest path connecting Y with T.
8.  End While
9.  Generate a mobility path to SN based on Pre-order traversal of T
10. Stop
```

Consider the network shown in part (A) of Figure 1 that was processed to deduce a minimum Steiner tree presented in part (B) of Figure 1. The MS will select the closest node to it to begin its journey according to the Euclidian distance. Accordingly, the MS must visit all the nodes in the calculated minimum Steiner tree according to the pre-order traversal algorithm. Upon visiting every node in tree, the node representing the end point of the current round will be considered as the starting point by the MS. As a result, the minimum Steiner tree is calculated taking into consideration the new starting point and the pre-order traversal technique will be used to navigate the constructed tree.

Also, from Figure 1 it can be seen that the nodes included in the minimum Steiner tree form a backbone of the network and the MS is not obligated to visit all the nodes in the network but, it must visit all the nodes that are members of the tree. It is noteworthy that when the MS travels to a tree node, it will be within the transmission range of some nodes that are not part of the tree. Thus, information may be gathered from the nodes that are being visited, their non-tree neighboring nodes, and so forth. After pausing for a specified period at certain node in the minimum Steiner tree, the MS will move towards another node in the tree according to the pre-order traversal. Therefore, information from will be available for the MS to gather from the node being visited and its neighbors which might not be members of the tree. Upon visiting all the nodes in the tree, the MS will consider the last node visited as the starting point of the new round. As a result, a new minimum Steiner tree will be generated and the pre-order traversal will be applied when traversing it. Worth mentioning, when the MS arrives at the new location, the MS can collect information from the node being visited and its neighbors using single-hop communication.

As a result, by using this strategy, the MS will have the ability to make visits to nodes that are not next to one another and get information from those nodes' neighbors. Additionally, it is evident that static sensor nodes—especially those with several neighbors—will have several opportunities to communicate their data to the MS. As a result, sensor nodes will quickly provide current data. Fixed sensor nodes are not obliged to store and maintain the information they collect for a long time while they wait to be visited by the MS, which lowers the likelihood of buffer overflow on those nodes.

5 Simulation

5.1. Scenarios for Simulation

To analyze the efficiency of the suggested sink mobility model, a number of scenarios were performed using the NS-2 simulator. A discrete event-driven simulator called NS-2 was created to aid in communication network research. It offers several protocols and supports both wired and wireless networks (NS-2, 2023). Messages are delivered to their appropriate receivers via the Ad-Hoc On-Demand Distance Vector (AODV) routing mechanism. Traffic arrives at a constant bit rate by static sensor nodes (C.B.R.). Because AODV is a reactive routing protocol, it was employed. Thus, the routing table created by AODV only contains routing information for a subset of nodes.

Conversely, in order to minimize the size of the routing table that sensor nodes maintain, routing information will be obtained when needed. As a result, less processing time and memory are used (Taleb, 2018). Moreover, C.B.R. was employed to provide continuous bit-rate traffic from immobile nodes in order to analyze the suggested model's effectiveness. under a heavy workload.

Furthermore, the efficacy of the suggested model was examined within the 26, 51, 76, and 101 nodes networks randomly dispersed and organized in a 1000 × 1000 grid. Moreover, for every network size, there are N nodes representing static sensor nodes, numbered 0 to n−2. In the network, one more energy-rich node, denoted by n−1, acts as a mobility sink. To elaborate, in the 26 node network, stationary sensor nodes are numbered 0 through 24. According to the mobility model put forth in this work, a separate node bearing the number 25 symbolizes an energy-rich MS node that will travel between the static sensor nodes. Also, the performance of the proposed model was investigated at MS speeds of 5, 10, 15, and 20 m/s for each network size. Table 1 presents the parameters adopted for the simulation.

Table 1: Simulation Parameters

Parameter	Value
Simulation Time	500 seconds
Number of Nodes	26, 51, 76, 101
Pause Time	5 Seconds
Area Size	1000*1000
Traffic Type	CBR
MS Speed	5, 10, 15, 20 m/s
Packet size (bytes)	512

5.2. Evaluation Metrics

The metrics average end-to-end delay or latency, packet delivery ratio, and throughput are used to examine the network's performance under the suggested mobility model. The amount of time a packet takes to go from one node to another is known as the average end-to-end delay. The end-to-end latency can be found by averaging the time required to send each packet between each source and each destination inside the network (Taneja & Kush, 2010; Amnai et al., 2011). Equation (1) is used to determine the average end-to-end delay:

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

The received and transmitted copies of a packet are denoted by H^i_r and H^i_t, respectively, in Equation (1), where N is the total number of packets received.

The packet delivery rate is determined by dividing the total number of packets transmitted by the ratio of successfully received packets, as indicated in Equation (2) (Taneja & Kush, 2010; Amnai et al., 2011; Karyakarte & Tavildar, 2013):

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

where the total number of packets sent is represented by p_{sent}, and the total number of successfully received packets is P_{rs}. The third metric for performance evaluation is throughput, which is the total number of packets successfully received in a specified amount of time. Thus, throughput is calculated in our simulation by dividing the total number of packets successfully received by the whole simulation time, as indicated in Equation (3) (Taneja & Kush, 2010; Amnai et al., 2011).

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

6 Results

The outcomes of using the simulated scenarios in Section 5.1 are displayed and discussed in this section. Ten trials of each scenario were conducted in order to obtain more comprehensive findings. The average of the outcomes from the ten iterations of each scenario was used to generate the simulation results.

The average end-to-end latency findings for different network sizes and MS movement speeds are shown in Figure 2. The best overall end-to-end delay values were obtained by networks with 51 and 76 nodes, particularly when the MS speed was 5, 10, and 20 m/s for networks with 51 nodes and 5, 10, and 15 for networks with 76 nodes. The main aspect influencing the end-to-end latency results reported for this scenario is the extensive utilizing a single-hop method of communication, which might be considered the reason for this behavior.

The suggested mobility model resulted in high end-to-end latency findings for different network sizes, particularly when the MS's speed increased. This could be related to the MS's frequent use of multi-hop communication as it travels at a moderate speed and frequently visits immobile sensor nodes. Because of the limited size of the network and the MS speed is quite high, which may cause the routing paths to be updated and changed frequently, the performance of the 26-node network grew considerably when the MS speed was increased. As a result, more multi-hop communication occurs, requiring packets to go through extraneous hops in order to reach the MS.

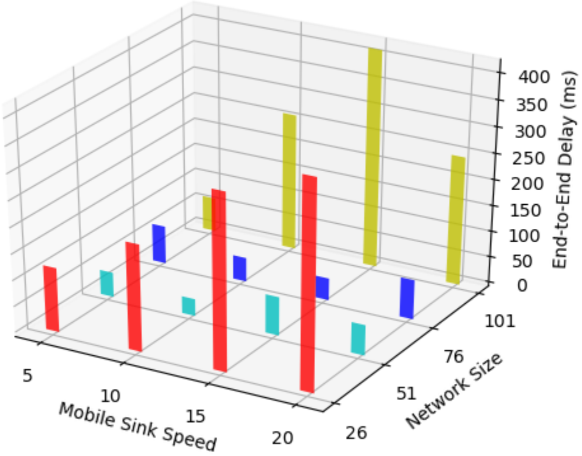

Figure 2: Average End-to-End Delay

Because not every node in the network was impacted by the routing path adjustments, better results were obtained for various network sizes. As a result, packets didn't have to travel over the network or pass through any unnecessary, duplicated intermediate nodes. As a result, there were fewer hops required for packets to reach the MS. Smaller end-to-end delay results were therefore attained.

Moreover, Figure 2 demonstrates that, in comparison to all other networks, networks with 26 and 101 nodes had the worst performance. This can be explained by the fact that multi-hop routing is used a lot to get packets to their destination. Stated differently, the MS has a relatively short route to be adopted. Consequently, most of the routing paths of the immobile sensor nodes will be impacted by the MS's motion. Accordingly, packets delivered from fixed sensor nodes will make several hops, some of which are caused by routing path alterations or modifications. Thus, to accommodate for variations in the routing path before reaching the MS, the same node may have routed such packets more than once.

Figure 3 displays the results acquired for the ratio of packet delivery and demonstrates that the suggested mobility model achieved extremely steady performance across all network sizes. In terms of packet delivery ratio, the networks with 51 and 76 nodes performed the best across all MS speeds, which is in line with Figure 2's findings. Also, the 51 and 76 node networks' outcomes were comparable to those of the 101 networks.

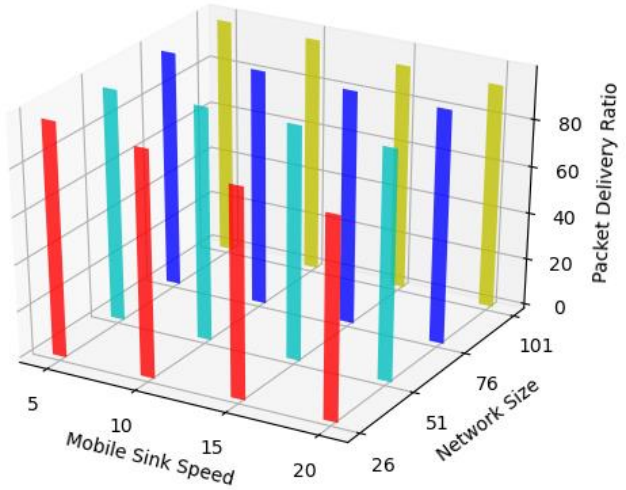

Figure 3: Packet Delivery Ratio

To clarify, for the same rationale that was mentioned when discussing the findings of Figure 2, this network, having obtained the greatest results for end-to-end latency, would also obtain the best packet delivery ratio results. Furthermore, Figure 3 illustrates how the MS's velocity was increased to 20 m/s, which had an impact on and somewhat decreased the performance of every network. Consequently, frequent and quick modifications to the routing pathways will result in a loss in performance for small networks when the MS is moved at a fast pace. In addition, the MS will be traveling quickly and it will be difficult to complete the transmission of data between the MS and the fixed sensor nodes.

Additionally, it is evident that the network's performance, which was initially based on 101 nodes, increased as the MS's speed increased. This is because the more frequently the MS visits the immobile sensor nodes, the faster it can transmit data to the MS via a single hop, and the immobile nodes are spared from buffer overflow, which arises from maintaining sensed data for extended durations of time whilst they await the MS's arrival.

In contrast, the expected mobility route of the MS is smaller for small networks than it is for medium- and large-sized networks. The impact on fixed sensor nodes and their neighbors will thus arise from raising the MS's speed to 20 m/s. Owing to this, packets cannot be delivered to the MS by these nodes in time; instead, they must be routed via many hops in order to reach their destination. In order to adjust to the routing path's frequent changes and reach the MS, packets will also make extra and needless hops.

When the MS moved at different speeds and with different network sizes, according to the recommended mobility model, Figure 4 displays the findings for network throughput.

Figure 4 shows that, for all network sizes, the proposed mobility achieved high and stable results under the MS's 10 and 15 m/s speed limits. This is because the MS moves at moderate speeds, minimizing the number of updates and potential changes to the routing paths. Fixed sensor nodes will also have enough time to correctly transmit data and connect with the MS. Because the length of the routing pathways was reasonable, the packet did not have to pass through many hops in order to be delivered, making the 51-node network the most performant and reliable in all scenarios. Due to the moderate movement path's length. used by the MS, better performance outcomes were attained since immobile nodes were not required to update their routing tables as frequently.

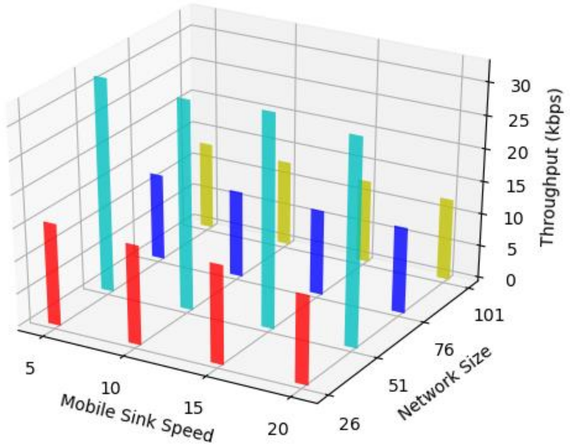

Figure 4: Network Throughput

The performance of various network sizes remained nearly constant for all other scenarios of MS speeds, although it was not as good as the networks with 51 nodes. Either of two explanations applied to this. First, the speed of the MS could not be appropriate for the scale of the network. To put it another way, because of packet loss and network congestion, low and high speeds may not be appropriate for larger or smaller networks, respectively. Second, the routing pathways may be quite long for big network routing at low speeds. This might lead to congestion in some areas of the network and packet loss. 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, which degrades network performance and raises the number of packets dropped.

Furthermore, a lot of packets could make extra hops in order to be delivered; as a result, the packet's counter or time to live timer may expire, causing the packets to be discarded.

7 Comparison with the Performance of Other Mobility Models

Using the same performance criteria, the suggested model's performance was compared with those of three other mobility models: the Depth First-based mobility model, the Gauss Markov mobility model, and the Random Waypoint mobility model. All models were run through the simulation scenarios outlined in Section 5.1 in order to gather data and compare the models in the same conditions. The four models' performances are evaluated in Tables 2-4. Sections 7.1–7.3 provide a discussion of the three mobility models that were used in the comparison.

Table 2: End-To-End Delay Performance Comparison

Model Name	Speed	Network Size			
		26 Nodes	51 Nodes	76 Nodes	101 Nodes
Proposed Model	5	123.56	47.50	73.00	65.47
	10	204.54	32.85	46.51	262.20
	15	336.02	74.38	42.66	415.68
	20	395.68	58.75	76.43	247.35
Random Waypoint 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
Gauss Markov 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
Depth First Based 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			
		26 Nodes	51 Nodes	76 Nodes	101 Nodes
Proposed Model	5	99.38	98.27	99.94	99.94
	10	96.13	98.73	99.69	98.38
	15	89.10	99.00	98.94	95.76
	20	85.98	97.55	98.95	95.17
Random Waypoint 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
Gauss Markov 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
Depth First Based 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			
		26 Nodes	51 Nodes	76 Nodes	101 Nodes
Proposed Model	5	15.67	32.50	13.21	13.28
	10	15.25	31.83	13.26	13.03
	15	15.21	32.52	13.09	12.72
	20	13.67	31.63	13.26	12.55
Random Waypoint 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
Gauss Markov 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
Depth First Based 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

7.1. Random Waypoint Mobility Model

The movable sink's motion in this model is split into rounds of pause and movement. The MS will first pause for a certain amount of time. The movement round begins after the pause round ends, and the movable sink will choose a new spot at random. It will begin traveling there at a predetermined pace. A new pause cycle begins when the MS arrives at its target, and it remains there for a certain amount of time, and so on (Taneja & Kush, 2010; Amnai et al., 2011; Karyakarte & Tavildar, 2013; Guezouli et al., 2017). Since this model's behavior is comparable to the model suggested in this paper, it was selected for comparison. Stated differently, in both models, there are phases of halt and movement for the movable sink.

7.2. Gauss Markov Mobility Model

This model was presented to take into account various amounts of unpredictability and to make the model more realistic. A movable node in this architecture may adjust its direction and speed as needed. The mobile node is initially given a movement speed and direction, and it moves for a certain amount of time in accordance with these parameters. Following then, a new direction and speed are determined using the values from the previous round when the timer ends (Taleb, 2018; Naghibi & Barati, 2020). Since this model begins with set values for both speed and direction, it was included in the comparison. In line with the suggested paradigm, the new values are computed from the earlier rounds. Beginning with a single subset, the new locations are chosen by taking into account both the closest neighbor and the present location.

7.3. Depth First-Based Mobility Model

In this approach, the Depth First Traversal algorithm of a graph will determine how the MS moves across the network. Consequently, the MS's movement is split between halt and motion phases, with the beginning node chosen at random. The MS will travel at a predetermined pace to the new place after choosing the beginning point. When it gets to the new place, it will remain there for a predetermined amount of time. Subsequently, the MS moves toward the next site, which is determined using the Depth-First Traversal method (Anas & Tareq, 2014). This model was chosen because it behaves similarly to the model that is suggested in this work: the MS moves in rounds and its new position is determined using a predetermined procedure. Along with the attributes on the topology or graph, it also makes use of the nodes' locations.

According to Tables 2-4, the movement paradigm proposed in this study performs better than the other three models when sink speeds and network sizes vary.

8 Conclusion and Future Work

This research developed a sink mobility model developed through building a minimal Steiner tree of the existing network. After introducing the idea of a Steiner tree, the suggested mobility model was discussed. Furthermore, a number of scenarios were conducted using the NS-2 simulator in order to assess the efficacy of the mobility model that was introduced in this study. Moreover, throughput, packet delivery ratio, and end-to-end latency were employed to evaluate the mobility model's performance. The obtained results show that the suggested mobility model worked better and is suitable for use in medium sized networks with modest MS speeds since the network with 51 nodes gave consistent and acceptable performance. Future research directions can proceed by assessing more performance metrics, such as energy efficiency, routing overhead, and jitters, future study can expand on the findings given in this publication. Furthermore, alternative routing protocols other than AODV may be employed to examine the performance of the suggested mobility model. Through the examination of these domains, scholars may get a more all-encompassing comprehension of the system's functionality and possible constraints, hence facilitating subsequent advancements and discoveries within this discipline. Additionally, thorough mathematical modeling and analysis may be carried out for additional research topics within the same field of study, which will help to enhance our comprehension of the fundamental mechanics and possible uses of the suggested methodologies.

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