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Using Minimum Connected Dominating Set for Mobile Sink Path Planning in Wireless Sensor Networks

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Abstract

Wireless sensor networks are a motivating area of research and have a variety of applications. Given that these networks are anticipated to function without supervision for extended periods, there is a need to propose techniques to enhance the performance of these networks without consuming the essential resource sensor nodes have, which is their battery energy. In this paper, we propose a new sink node mobility model based on calculating the minimum connected dominating set of a network. As a result, instead of visiting all of the static sensor nodes in the network, the mobile sink will visit a small number or fraction of static sensor nodes to gather data and report it to the base station. The proposed model's performance was examined through simulation using the NS-2 simulator with various network sizes and mobile sink speeds. Finally, the proposed model's performance was evaluated using a variety of performance metrics, including End-To-End delay, packet delivery ratio, throughput, and overall energy consumption as a percentage.

Keywords: Wireless Sensor Networks (WSNs), Mobility Model, Mobile Sink, Connected Dominating Set (CDS), Path Planning

1. Introduction

Wireless sensor networks (WSN) are a significant example of pervasive and ubiquitous computing since they are deployed to study a particular phenomenon and are supposed to work in an unsupervised mode for extended periods in hostile situations. As a result, WSNs may be deployed randomly and are designed to function continuously for a very long time without any human help. Additionally, sensor nodes are manufactured with restricted functionality to be tiny, light, and battery-operated, so they may be deployed quickly. Due to their limited energy source, these nodes must use their energy efficiency to prolong the WSN lifespan. Therefore, these networks must maintain fault tolerance and self-organizing capacities [1]-[4].

According to [5] and [6], sensor nodes are composed of three subsystems; processing, communication, and sensing. The primary source of energy consumption is the communication subsystem because the amount of energy consumed is distant dependent. For instance, the energy the processing subsystem needs to carry out thousands of instructions in a single sensor node is equivalent to the energy needed to send a single bit.

As a result, it is preferred that a sensor node seek the help of other sensor nodes and adopt multi-hop routing to convey messages to the base station rather than sending messages directly to the base station via single-hop routing. Thus, the amount of energy consumed will be smaller for a sensor node in multi-hop because the distance used in multi-hop is less than that needed for single-hop routing. In contrast, adopting multi-hop rather than single-hop routing comes at the cost of increasing the delay and causing unbalanced energy consumption between sensor nodes, particularly for sensor nodes located near the base station because most of the traffic generated by distant sensor nodes will pass through these nodes. Therefore, these sensor nodes will spend most of their energy passing messages generated by other sensor nodes dispersed far from the base station [5], [7].

To solve this problem, deploying a mobile and energy-rich sink node or nodes has been introduced. In this approach, the mobile sink might move randomly or based on a specific mobility model to gather sensed data generated by stationary sensor nodes and report it to the base station. Moreover, deploying a mobile or un-stationary sink helps to improve the performance of WSNs in various aspects, such as reducing the distance required for data transmission by a static sensor node, reducing the number of intermediate nodes, improving network throughput and providing coverage for disconnected areas [1].

This paper introduces the use of a single and rich-in-energy mobile or un-stationary sink node for data gathering from stationary sensor nodes. Moreover, the mobile sink will follow a predetermined path calculated using the connected dominant set. (CDS). Conversely, a network's CDS is computed, and the mobile sink will traverse the subgraph consisting of the sensor nodes that are members of the CDS in a pre-order fashion to collect information. Other sensor nodes that are not members of the CDS are required to report data to the nearest CDS member or directly to the mobile or un-stationary sink if the mobile sink is visiting a nearby CDS member sensor node. Consequently, the number of intermediate nodes will decrease, and the energy needed for data transmission will be reduced.

The remaining sections are structured as follows: A description of connected dominant sets is given in section 2. Section 3 follows with a review of previous sink mobility models in the literature. In section 4, the proposed mobility mechanism is then discussed. Section 5 presents the adopted energy model, simulation scenarios, and performance indicators. Additionally, the simulation results are presented and discussed in section 6. In section 7, findings and recommendations for future work are addressed.

1.1 *Connected Dominating Set Overview*

Nowadays, WSNs are playing a significant role in a diverse range of applications, including military applications, applications for monitoring the environment, and applications for monitoring disasters, to name a few [8]. Consequently, identifying the minimum number of relevant sensor nodes, minimum connected dominating set (MCDS), and providing full connectivity and coverage of the deployment area is vital to control better the phenomenon being studied. As a result, the MCDS will form a backbone for the WSNs [9]. According to [9], determining the MCDS of a sensor network's nodes aids in optimizing the network's performance by optimizing the allocation of the sensor network's limited resources. The challenge of locating the most miniature dominating set is NP-hard, nevertheless. Several approximation techniques were subsequently proposed [10]. So, to be comprehensive, a summary of MCDS is provided in this section. A CDS can be defined as a subset of nodes of an undirected graph forming a connected subgraph that is derived from the original one where each of the original graph's nodes is either a member of the derived CDS or a neighbour to a CDS member. Furthermore, constructing a CDS with minimum cardinality results in forming an MCDS, which can be used to exchange information in any type of network because an MCDS act as a virtual backbone [11], [12].

Consider an undirected graph G = (V, E), where G denotes a connected graph that contains no loops or multiple edges, V denotes the vertices, and E denotes the edges. Be aware the size and order of G are indicated by the n and m, respectively. For a specific vertex u in G, the number of edges that are incident to u is used to define the degree of u and is denoted by d(u). $\delta(G)$ indicates the minimum degree of G, and $\Delta(G)$ denotes the maximum degree of G. Any two vertices w and v in G are considered neighbours if a direct edge between them can be found. In addition, if there is a path connecting any two nodes in a network, it is said to be connected [13], [14]. A subset S where $S \subseteq V$ is referred to as a dominating set if every vertex in $V-S$ is a neighbour to at least one vertex belonging to S. $\gamma(G)$ denotes the minimum number of the cardinality of the dominating set. If a connected subgraph of G can be constructed for the vertices in S, then S is called a connected dominating set [13]. To further explain, consider the following scenario: Suppose we have a randomly constructed graph consisting of 15 nodes that are numbered from 0 to 14, as shown in Figure 1 below, where the labelled circles denote the vertices and the lines denote the edges. When calculating the MCDS of the graph, the result will be a subgraph consisting of 6 connected nodes, namely nodes 0, 1, 4, 7, 8 and 9, as shown in Figure 2. As a result, it can be observed that the nodes that are not part of the MCDS are neighbours to at least one node that is a member of the MCDS. Also, the MCDS nodes can act as a virtual backbone of the network or the graph.

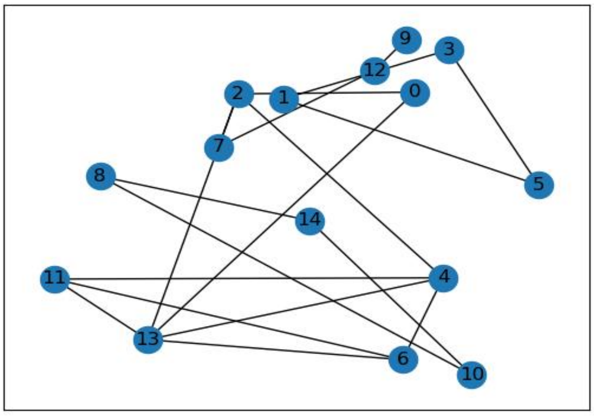

Figure 1. A Randomly Deployed Network or Graph

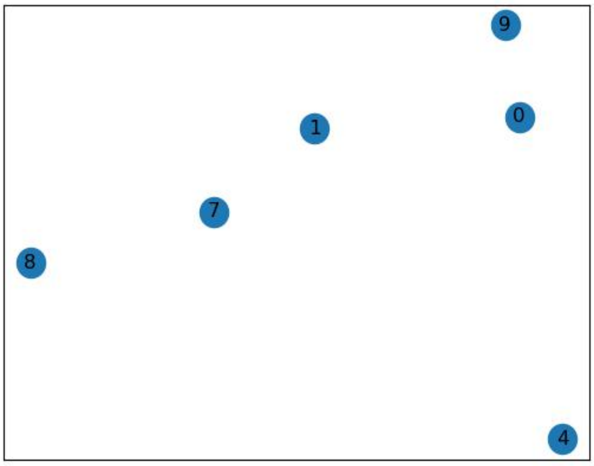

Figure 2. The Computed Minimum Connected Dominating Set

2. Mobility Models

Various researchers have proposed algorithms or techniques that support mobility in WSNs. According to [15], the capacity of nodes in WSNs to relocate themselves upon deployment is referred to as mobility. Thus, there are two primary types of sensor node mobility algorithms; first, mobile sinks or sinks can receive data from static sensor nodes while moving. Second, provide all sensor nodes with movement capability to perform the task of static sensor nodes and move from one location to another to report data. In this paper, we will concentrate our review on research that provided one node to act as a mobile sink that moves and collects data from stationary sensors and forward them to the base station because it is more related to the proposed mobility model.

The research in [16] presented a method to gather data based on the path planning of the mobile sink in an effort to shorten the mobile sink's travel distances and communication range. Using an inner centre path planning method decreased the distance travelled by a mobile sink. A back-routing algorithm was also presented to address the movement path back propagation problem. As a result, the recommended method can make adaptive decisions and may thus create a pathway for the mobile sink to follow.

In addition, the authors of [17] suggested addressing the relay selection problem to reduce the consumed energy and lengthen the lifetime of WSNs. As a result, the k-means method was used in the proposed study to partition the network into clusters. A movable sink-based cluster head selection technique was then suggested to increase energy usage within the cluster. Since the mobile or un-stationary sink node will function as a head of the cluster when it is close to stationary sensor nodes to gather information and decrease the energy being consumed by stationary nodes and the cluster head, the proposed work has also introduced the use of a virtual cluster head to achieve energy optimization.

The research provided in [18] was written by writers who developed a sink mobility model based on computing the Kohonen self-organization map (SOM). In their study, the mobile sink's movement path is computed using Kohonen SOM. The mobile sink thus moves during movement times and stops during pause periods. The mobile sink will remain in its present location during the stop periods for a set amount of time, after which it will begin migrating to a new location determined using the Kohonen SOM, and so on, till topology changes. Imposed by energy depletion take place. As a result, a complete Kohonen SOM re-calculation of the mobility path will be performed.

Furthermore, a collaborative method was proposed in [19] to optimize environmental monitoring and anomaly search tasks in WSNs. The proposed scheme is composed mainly of two components. The first concerns deploying the static sensor nodes collaboratively based on a weighted Gaussian coverage method. The second section, on the other hand, focuses on planning a path for the mobile sink and is built around implementing an active monitoring and anomaly search system that uses a Markov decision process model. This system's primary objective is to quickly identify environmental anomalies so that the mobile node can respond appropriately based on a cumulative reward function.

Another research aiming to improve the efficacy of WSNs and prolong their lifetime is proposed in [20], where the network is portioned into zones. Based on a load of every formulated zone, the mobile sink will move near the strongly loaded zone. It is worth noting that the selection of the strongly loaded zone is based on a fuzzy logic system to solve uncertainties that might occur when deciding on the heavily loaded zone.

Likewise, the research in [21] proposed an adaptive mobile routing algorithm to detect burst traffic. Also, the adopted network model is based on having two mobile sinks, and the algorithm is based on dividing the network clusters into two groups. After that, each sensor node will be responsible for one group and will inform the cluster heads. Furthermore, within the group, the mobile sink will visit the cluster heads in a specific manner to collect information. However, if a traffic burst is detected, the mobile sink will break the order in which cluster heads are visited and move near the heavily loaded cluster head.

Additionally, an end-to-end technique for data collection based on ant colony optimization was proposed in [22]. The presented technique relies on building a data forwarding tree and heuristically choosing data gathering points. Thus, the route to be taken by the mobile sink is calculated and specified.

A sink mobility model built on genetic algorithms is presented in [23]. The mobility model uses genetic algorithms to calculate the motion path to be utilized by the mobile sink. After that, Visits from the mobile or un-stationary sink will occur at the nodes on the computed path to collect data from them via single-hop routing. For other nodes not part of the movement path, multi-hop routing is used to route data to one of the node members of the sink movement path. Also, the mobile sink motion is split into pause durations and movement durations. To elaborate, the mobile sink should stay still for a predetermined amount of time before beginning to move to a new position determined by genetic algorithms.

The research proposed in [24] is based on creating mobile pathways for the mobile sink to reduce the energy consumed and latency. The algorithm's operation is divided into four stages: detecting data, selecting a meeting point, designing the trajectory and transmitting data.

A geographic routing plane using a mobile sink was proposed in [25]. In this research, sensor nodes were set in geographic zones called cells and adopted using two mobile sink nodes for data gathering. Consequently, sensor nodes in each cell sense data and report this information to the mobile sink. It is important to note that sensor nodes and the mobile sink can use single-hop routing or multi-hop routing to communicate.

2.1 Proposed Mobility Model

In this section, the proposed mobility model will be discussed. The work proposed in this paper is based on randomly deployed WSNs consisting of N static sensor nodes and an extra node with movement capabilities to act as a mobile sink node. After the network deployment, the base station gets the locations of stationary sensor nodes and the mobile sink. Consequently, the base station will calculate the MCDS, explained in section 2, of the network consisting of static sensor nodes only.

To elaborate, to calculate the MCDS, the base station will take the position of the mobile sink as a reference point. It will calculate the MCDS of the network based on a network consisting of stationary sensor nodes only. As a result, the starting point of the MCDS will be one of the stationary sensor nodes near the current mobile sink location. Thus, it can be inferred that the MCDS is calculated without considering the mobile or un-stationary sink as a part of the network but considering its position to find a starting point from which the MCDS calculation will start.

After identifying the static sensor nodes that form the MCDS, the subgraph will be traversed according to the pre-order traversal algorithm of a graph starting from the closest node to the un-stationary sink. Accordingly, the mobile sink would start visiting the stationary sensor nodes that are members of the MCDS in a pre-order fashion. In other words, consider the graph or network shown in Figure 1 and assume that the mobile or un-stationary sink is located near node 0. When calculating the MCDS of that network, the result will be a sub-graph or network consisting of 6 connected nodes, namely nodes 0, 1, 4, 7, 8 and 9, as shown in Figure 2.

As a result, when calculating the pre-order traversal on the subgraph, the result will be node 0, 9, 8, 7, 1 and 4, which is the pre-order traversal of the sub-network, and this will be the route to be adopted by the mobile sink. Therefore, it is evident that the mobile sink will only visit a small subset of nodes rather than the entire network's stationary sensor nodes. In addition, the un-stationary sink will gather the sensed data from stationary nodes that are members of the MCDS via single-hop routing when it visits every node in the MCDS. In contrast, stationary sensor nodes that are not members of the MCDS will employ multi-hop routing in order to forward information to the nearest node that is a member of the MCDS. As a result, MCDS nodes will be responsible for delivering information about other sensor nodes to the mobile sink node once it comes to their communication range.

Furthermore, the motion of the mobile sink will be according to the pre-order traversal of the MCDS and is divided into two periods, namely, sojourn periods and movement periods. The mobile sink will remain at its location for a predetermined time throughout the sojourn phase. After that, it will begin to move towards a new location with a specific speed. Upon arrival at the new location, the sojourn period starts again, and the mobile sink will remain in this position for the same amount of time used before. For example, based on the pre-order traversal calculated from Figure 1 and Figure 2, the mobile or un-stationary sink will be near node 0 and be in the sojourn period. When the pause period is over, it will start moving towards node 9 because it will be visited based on the pre-order traversal. A new sojourn period is initiated in the mobile sink when arriving at the new location. Consequently, when the sojourn period expires, the mobile or un-stationary sink will start moving toward node 8, representing the new location to be visited according to the pre-order traversal of the sub-graph.

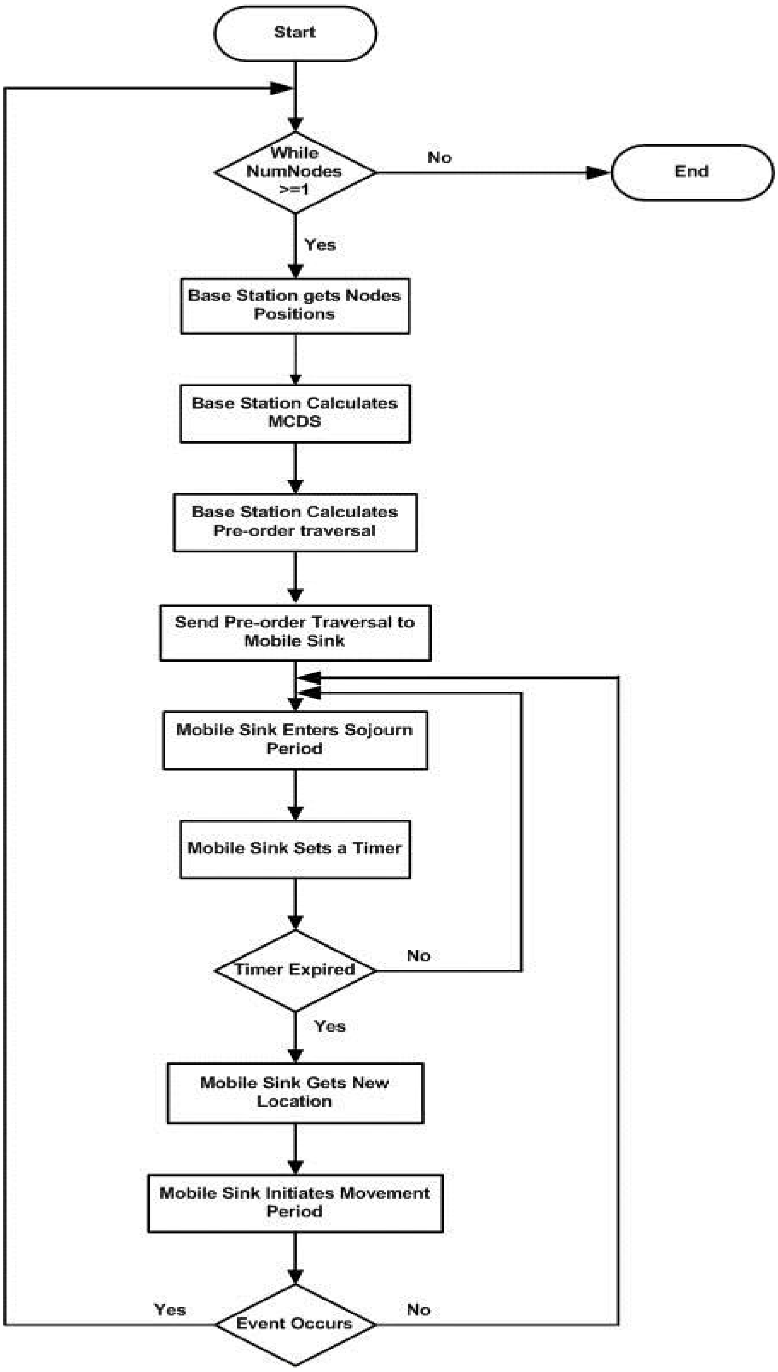

Figure 3. A Flowchart of the Proposed Model

When the last node in the MCDS is visited, node 4 in our example, the mobile sink will move towards the starting node, node 0, and follow the same path. This process continues until an event occurs, such as MCDS member node death, because of energy depletion. When such an event occurs, it will be used as a trigger to recalculate the MCDS and the base station's pre-order traversal of the MCDS. In other words, a message will be sent from one of the neighbours, an MCDS member, of the dead node to the mobile sink, which will report it to the base station to recalculate the MCDS and the pre-order traversal of the MCDS. Figure 3 shows a flowchart of the proposed model. It's important to note that there are two categories of static sensor nodes; the first group consists of stationary sensor nodes that are members of the motion route or path.

Consequently, when the mobile sink reaches its communication range, these nodes will be visited by it and can employ single-hop routing to transfer packets straight to the sink node. The second group consists of stationary sensors that are not part of the motion route of the un-stationary sink. These nodes must employ multi-hop routing to forward their packets to the nearest node that is a part of the mobile sink's movement path.

3. Simulation

3.1 Energy Model

The first radio-order radio model is used in this study to calculate the energy required by a node to transmit and receive data packets [26]. This model calculates the energy expended while sending and receiving data packets using equations 1, 2 and 3 [27], [28].

$$E_{Trans}(k) = k(E_{elec} + \epsilon_{amp}E * d^2) \quad (1)$$

$$E_{Rcv}(k) = k * E_{elec} \quad (2)$$

where k is the packet length in bits and d is the distance between sending and receiving nodes. Also, Eelec represents the amount of consumed energy by the sending and receiving circuitries to transmit a single bit. Ɛamp is the energy the amplifier requires to obtain the acceptable signal-to-noise ratio for a single bit [28]. As a result, the total energy consumed in transmission and reception is shown in equation 3 as follows [27], [28]:

$$E_{total}(k) = E_{Trans} + E_{Rcv} = k * (2 * E_{elec} + \epsilon_{amp} * d^2) \quad (3)$$

Consequently, from equation 1, it can be observed that the amount of energy used to transmit bits or packets depends greatly on the distance d between source and destination nodes.

3.2 Simulation Scenarios

The NS-2 simulator was used to evaluate the performance of the proposed sink mobility model, and various simulation scenarios were conducted. Also, Ad hoc On-Demand Distance Vector (AODV) is the routing protocol used to deliver messages to their destination, and stationary sensor nodes produce traffic at a constant bit rate (CBR). In addition, the performance of the proposed mobility model was investigated under 26, 51, 76 and 101 nodes network sizes arranged in a flat grid of 1000 ∗ 1000 at random. Furthermore, for each network size, the network consists of N nodes numbered from 0 to n − 2 representing stationary sensor nodes and one additional and energy-rich node to act as a mobile sink in the network denoted by n − 1, for the network of 26 nodes, static sensor nodes are numbered from 0 to 24. An additional node, numbered 25, represents an energy-rich mobile sink node that will move between static sensor nodes according to the mobility model this paper proposes. The performance of the suggested mobility model was also examined for each network size at various mobile sink speeds, including 5, 10, 15, and 20 m/s. The simulation parameters are presented in Table 1.

Simulation experiments were conducted to investigate the performance of the mobility model suggested in this paper using the NS-2 simulator. Messages are also sent to the mobile or un-stationary sink via the AODV routing protocol, as explained in section 3.

Table 1. Used Parameters for Simulation

Name of Parameter	Value of Parameter
Sim. time	500 seconds
Network Size	26, 51, 76, 101
Sojourn period	5 Seconds
Grid Dimensions	1000*1000
Type of Traffic	CBR
Speeds of Mobile Sink	5, 10, 15, 20 m/s
Packet size (bytes)	512
Initial energy for sensor nodes	5j
Initial energy for mobile sink	10j
$\mathbf{E_{elec}}$	5nj/bit
$\mathbf{\varepsilon_{amp}}$	100pj/bit/m2

3.3 Performance Metrics

The performance indicators used to analyze the network's performance while utilizing the proposed mobility model include average End-to-End delay, packet delivery ratio, throughput, and energy consumption. The average End-to-End delay is when a packet travels from its origin to its final destination. The average End-To-End delay for the entire network is computed by averaging the time taken for each packet to be transmitted between each source and each destination within the network [29]. Equation 4 demonstrates how to calculate the average End-To-End delay.

$$T_{AVG} = \sum_{i=1}^{N} \frac{(H_r^i - H_t^i)}{N} \quad (4)$$

H_r^i and H_t^i represent a packet's received and transmitted copies, and N represents the overall number of received packets.

The packet delivery ratio is calculated by [30], [31] by dividing the overall number of packets successfully received by the overall number of sent packets, as indicated in Equation 5.

$$\text{Packet Delivery Ratio} = \frac{P_{rs}}{\sum_{i=1}^{n} P_{sent_i}} \quad (5)$$

where Prs is the overall number of packets that were received successfully. And P_{sent_i} is the overall number of packets that were sent.

The third performance metric considered is throughput, which is the overall number of packets that are successfully received over a given period of time. Therefore, as indicated in equation 6, the throughput in our simulation is determined by dividing the overall number of successfully received packets by the whole time of the simulation [29], [30].

$$\text{Throughput} = \frac{\text{Number of Packets Delivered} * \text{Packet Size} * 8}{\text{Total Simulation Time}} \quad (6)$$

The last performance metric considered is the power consumption, calculated according to equations 1, 2 and 3, as discussed in section 5.1.

3.4 Simulation Results

The simulation scenarios presented in section 5.2 are applied, and the results are reported and analyzed in this section. Each scenario was run ten times to acquire more detailed findings. The simulation results were thus produced by computing the average of the results of the 10 runs for each case.

Figure 4 illustrates the average end-to-end delay results for various network sizes and mobile sink movement velocities. When the mobile sink node moved at speeds of 5, 10, and 15 m/s, the suggested mobility model produced End-To-End delay results that were low and steady for networks with 76 nodes. On the other hand, when the mobile sink speed was increased to 20 m/s, there was an increase in the End-To-End delay since stationary sensor nodes will not have enough time to deliver data to the mobile sink when the mobile or un-stationary sink moves according to this speed. In other words, the routing path from the source to the mobile or un-stationary sink will change quickly and frequently. As a result, packets destined for the mobile sink will go through multiple hops until they reach their destination, which plays a crucial role in increasing the results obtained for the End-To-End delay.

Furthermore, from Figure 4, it can be said that the network consisting of 26 nodes obtained the lowest performance when compared to all other networks. This can be attributed to the frequent utilization of multi-hop routing for the packets to be delivered to their destination. Say it in another way: the mobile sink's path is relatively short. Consequently, the motion of the mobile or un-stationary sink will affect the routing paths for the majority of the static sensor nodes. Thus, packets sent from static sensor nodes will go through multiple hops, and some of these hops result from the changes or updates to the routing path. Therefore, it can be concluded that those packets might have been routed more than one time from the same node to be capable of adapting to changes in the routing path until they are delivered to the mobile sink.

For other network sizes, better results were obtained because the changes in the routing path did not affect all the nodes in the network. Hence, packets did not need to wander around or circulate through the network and go through some unnecessary and replicated intermediate nodes. Consequently, packets go through smaller hops until they get delivered to the mobile sink. As a result, better values of End-To-End delay were attained.

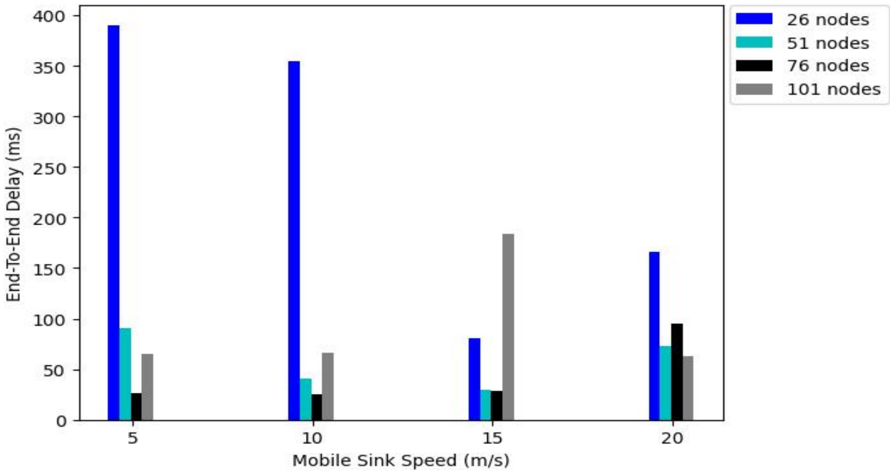

Figure 4. Results for Average End-to-end Delay

The results for the packet delivery ratio are illustrated in Figure 5. As can be seen, the proposed mobility model produced high and consistent performance results across all network sizes. Again, the network consisting of 76 nodes obtained the highest performance results regarding packet delivery ratio, consistent with the results obtained from Figure 4.

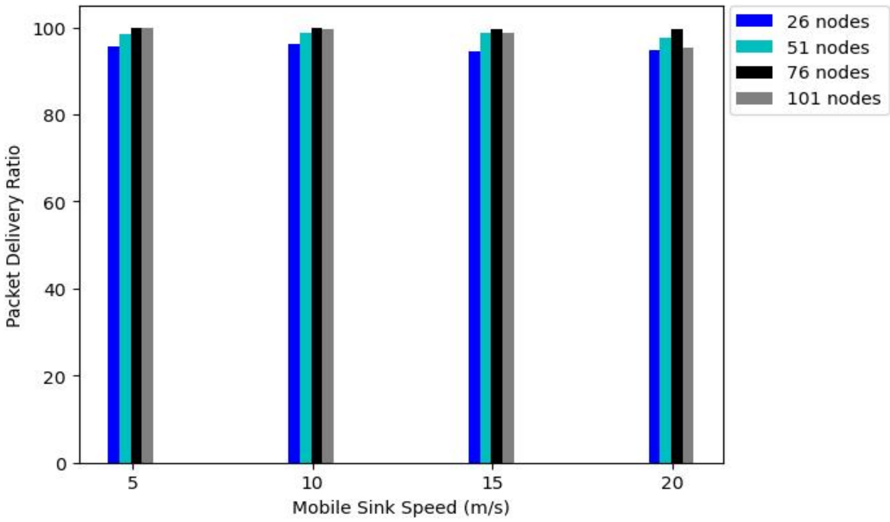

Figure 5. The result for the packet delivery ratio

To elaborate, since this network obtained the best results in terms of End-To-End delay, this will obtain the highest results for packet delivery ratio due to the same reason discussed when explaining the results of Figure 4. Additionally, from Figure 5, it can be observed that the increase in the speed of the mobile or un-stationary sink to 20 m/s has affected the performance of all networks and caused a slight decrease in the performance of all networks. Thus, for small network sizes, when the mobile sink is moving at high speed, frequent and rapid changes in the routing paths will take place and will cause a decrease in performance. On the other hand, for large network sizes, the mobile sink's calculated mobility route is longer than that in small networks. As a result, increasing the velocity of the mobile sink to 20 m/s will affect static sensor nodes and their neighbours. Thus, these nodes will not have enough time to deliver packets to the mobile sink, and packets must be routed via multi-hop routing to be delivered to the destination.

Figure 6 illustrates the results obtained for network throughput under different network sizes while the mobile sink travelled at various speeds following the suggested mobility model. In terms of throughput, it can be concluded that the 76-node network performed best when the mobile sink speed was equivalent to 5 m/s. However, the performance of the 76 nodes network declined when the mobile or un-stationary sink's speed was increased, and in every instance, this network's performance remained stable. The decrease in the performance can be regarded as the quick change in the routing path when increasing the mobile sink speed. Figure 6 shows that when the mobile or un-stationary sink was travelling at a low speed, networks with 51, 76, and 101 nodes performed better, and as the speed of the mobile or un-stationary sink was increased, their performance declined.

On the other hand, from Figure 6, it can be concluded that the network consisting of 26 nodes obtained very high results when the mobile or un-stationary sink was moving according to 10 and 15 m/s speed. The cause of such behaviour can be attributed to how the mobility model is calculated and the network size. In other words, at these speeds, the mobile sink was visiting the static sensor nodes at the right time so that packets were sent to the mobile or un-stationary sink via single-hop routing for nodes that are members of the mobility pathway. On the contrary, stationary sensor nodes, not members of the mobility route, are neighbours to at least one node in the mobility path. As a result, packets can be delivered from these nodes to stationary sensor nodes that are part of the mobility route in one hop. These nodes will deliver the packets to the un-stationary sink regarding their communication range via single-hop routing. Therefore, when the mobile sink speed is 10 or 15 m/s, the mobile or un-stationary sink will visit the stationary sensor nodes that are members of the mobility route more frequently. Thus packets originating from these nodes and their neighbours will be delivered to the mobile sink at the right time before these nodes suffer from buffer overflow and start dropping packets.

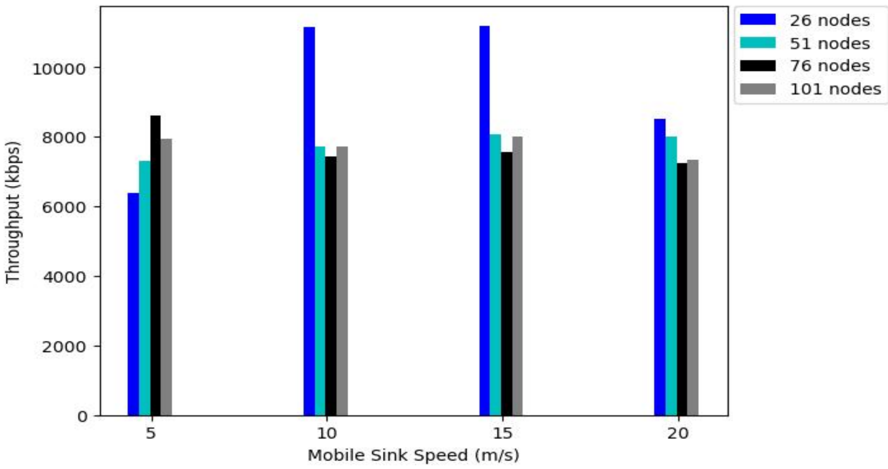

Figure 6. Results for Network Throughput

From Figure 7, the network of 76 nodes has consumed the lowest amount of energy and has obtained a stable performance for all cases. As a result, it can be observed that this network has the best performance in terms of energy consumption because the energy being consumed by this network under different speeds of the mobile sink was the lowest among all other networks. Also, it can be concluded that the length of the mobility path in this network was suitable for the mobility model so that the un-stationary sink will visit all stationary nodes that are members of the movement pathway and collect data from them via single-hop. Moreover, since the mobile sink is visiting such nodes, the distance required to transmit packets is small. Thus, the amount of wasted energy is negligible. Therefore, it can be concluded that single-hop routing was used most of the time under small transmission distances. As a result, a smaller amount of energy was consumed.

In contrast, Figure 7 shows that the performance of the network consisting of 51 nodes was the worst as it consumed the highest amount of energy, especially when the mobile or un-stationary sink was moving at 5 m/s speed. This can be attributed to the length of the movement path and the changes in the routing path. In other words, since the mobile sink is visiting a small fraction of nodes because they are members of the calculated movement path at a low speed, all stationary sensor nodes will employ multi-hop routing to deliver packets to the mobile sink. These nodes cannot wait for the mobile sink to visit them and use single-hop routing to avoid buffer overflow. As a result, packets will go through several intermediate nodes. Thus, these intermediate nodes will consume higher energy sending and forwarding packets originating from other stationary sensor nodes.

Additionally, when the velocity of the mobile or un-stationary sink was increased, the amount of energy consumed was decreased. However, still, it was higher than in other cases because moving the mobile sink at higher speeds caused frequent and quick changes or updates to the routing paths.

Consequently, packets needed to go through many hops to reach the mobile sink and higher energy was consumed to route and forward these packets. Worth noting that the same applies to the case of the network consisting of 26 nodes.

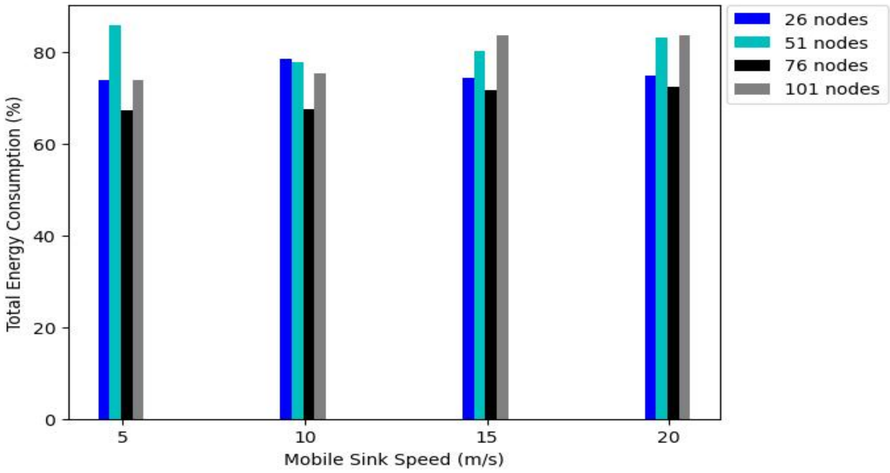

Figure 7. Results for the Percentage of Consumed Energy

The movement path was the longest for the network consisting of 101 nodes. As a result, when the speed of the un-stationary sink was 5 and 10 m/s, stationary sensor nodes that are members of the movement route had to employ multi-hop routing to forward packets to the mobile or un-stationary sink to evade buffer overflow because the mobile sink is not visiting them frequently considering the length of the movement route. However, when the mobile sink speed was increased to 15 and 20 m/s, the frequency of the mobile or un-stationary sink visits was increased at the expense of causing multiple changes to the routing path. As a result, packets will go through many hops to adapt to routing path changes to reach their destination. Thus, multi-hop routing is used more frequently, and more energy is consumed.

4. Conclusion

The calculation of a network's minimum connected dominant set served as the foundation for the sink mobility model that was put forth in this research. The proposed mobility model was introduced and explored after introducing a minimum connected dominating set. Additionally, using the NS-2 simulator, numerous scenarios were simulated to examine the effectiveness of the proposed mobility model. Furthermore, the End-To-End delay, packet delivery ratio, throughput, and the percentage of total energy spent were employed to analyze the performance of the mobility model. According to the results, the proposed mobility model proved to be more efficient for networks with 76 nodes when the mobile or un-stationary sink travelled at speeds of 10 and 15 m/s. Thus, it can be said that the mobility model proposed in this research is appropriate for usage in medium-sized networks with moderate mobile sink speeds.

The research presented in this paper can be extended in further work to assess additional performance measures like routing overhead and jitters. The effectiveness of the suggested mobility model can also be investigated while utilizing routing protocols other than AODV. Furthermore, multiple graph traversal techniques, such as in-order and post-order traversal, can be used to examine the performance of the model presented in this research.

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