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Research Article

Adaptive Path Selection for Efficient Data Collection in Wireless Sensor Networks

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ABSTRACT

With the rise of interest in the Internet of Things (IoT), Wireless Sensors Network (WSN) has drawn a lot of attention as they are seen as the foundation of IoT-based systems and can be deployed in a wide range of delay-intolerant applications. However, energy remains one of the major concerns for Wireless Sensors Network (WSN). Data collection was proposed as one of the methods that can help preserve energy. And, the use of Mobile Sink (MS) has been widely employed in WSN as a preferred approach for data collection. This approach can significantly prolong the network lifetime by reducing radio communication between nodes, thus, reserving the overall energy. Employing MS can also enhance the Quality of Service (QoS) by increasing throughput and reducing End-to-End (E2E) delay if the MS trajectory is chosen wisely. However, this can also pose many unique challenges that must be solved.

In this paper, we propose an adaptive algorithm that chooses the optimal MS trajectory regardless of the network topology. The MS will choose the shortest path to collect critical data, ensuring minimal delay and maximum throughput. We present different scenarios and analyze the performance of the suggested scheme in a simulated environment. The findings show that our algorithm outperforms other existing approaches.

Keywords: Wireless sensor networks, Mobile sink, End-to-End delay, Throughput.

I. INTRODUCTION

Wireless sensor networks are widely used in many facets of industry, agriculture, and health care. They can replace people in potentially hazardous environments like laboratories and the oil and gas sector [1, 2].

Employing mobile sink nodes to gather information from the distributed sensor nodes helps cover a wider area. This approach improves the reachability and reduces the number of transmitted packets, thus, prolonging the network lifetime [3].

Moving the sink node down the shortest path leads to less energy consumption in the sink itself. In addition to reducing the packet reception latency, both of which are critical for network efficiency.

In wireless sensor networks, the key parameters vary depending on the application being used. However, in most cases, delay and throughput—the rate at which packets are received—are crucial parameters since they influence other parameters, such as energy consumption and overall network lifetime.

This research investigates the scenario of WSN with a single sink node and some CN that behold crucial data that should be reported reliably with minimum latency and without disturbing the usual data exchange and node communication in the system, because mobile sink will gather the usual data, while moving in predetermined path in case there is no crucial data. otherwise usual data can be stored in sensor node, until gathering crucial data.

We develop an algorithm that minimizes delay by guiding the sink node along the shortest path. This reduces the energy consumed in the sink and the *Cardinal Node* (CN) since communication occurs via a single hop from the sink to the CN.

This paper is structured as follows: in section II, we review recent reference studies, highlighting their advantages and disadvantages. Section III is dedicated to presenting the proposed algorithm in detail. The experimental setup and results obtained are presented in IV. Finally, we conclude our research in section V.

II. RELATED WORKS

Many studies have been conducted on sink node mobility, most of which were concerned with collecting regular data via multi-hop communication from Cluster Nodes (CNs) to a mobile sink node with a pre-determined path [4, 5, 6]. The research [7] employs a technique to identify CNs' locations and creates an algorithm to ascertain a mobile sink node's journey when random data must be collected from the network. However, it shows no concern for gathering critical data ahead of routine data. The study [8] carried out a dynamic design of the path, where meeting points are chosen periodically, and mobile sink nodes move through these points to gather corresponding data. This research helped the network save energy overall but ignored the potential existence of critical data and was not concerned with delays in the system. In [9], an artificial bee colony algorithm is utilized to identify the places the mobile node would visit. This study succeeded in reducing energy consumption but failed to reduce network delays. In [10], the mobile sink node trajectory is determined to resolve the issue of hot spots and unbalanced energy depletion in the network. The sink node goes towards rendezvous points that have a greater load in the network and collects data from other ordinary sensor nodes. The algorithm shortens the data forwarding paths between the sensor nodes and the sink. Although such an approach helps reduce energy consumption and avoid the death of sensor nodes, it does not consider the presence of high-priority data that needs to be transmitted immediately. Similarly, the authors of [11] designed an algorithm that chooses an energy-efficient delay-aware path for the mobile sink. The suggested algorithm chooses rendezvous points based on the energy density of the sensor nodes as a way to distribute energy consumption evenly among the sensor nodes. The study in [12] follows a different approach by dividing the network into clusters with a header assigned as the nodes with the highest energy level in the cluster. Then, the sink node trajectory is selected based on an artificial bee colony algorithm, which directs the moving sink towards locations where there is a high likelihood of data present. The study achieves better energy saving and more efficient data collection. The algorithm proposed in [13] tries to find the shortest path between the sink node and the sensor node based on their corresponding coordinates by subtracting the coordinates. The study, however, does not investigate the angle at which the sink node should move and does not discuss the presence of high-priority data in the network. Despite the variety of methods used in the previous studies to design the movement of the sink node, directing it to follow the shortest path or to save energy, most of these studies ignore the presence of critical data in the network, which is usually the main purpose of deploying the WSN network in the first place in applications such as intrusion detection and fire alarm. Conversely, the research presented in [14] addressed the existence of critical data within the network. To address this problem, the network is split up into squares, and each cluster is given a cluster head, which is the node with the highest energy. When regular data is gathered, the sink node follows a predefined route. Upon receiving a request message to deliver critical data, the sink node will proceed in the direction of the square where the node that initiated the request is located. It will follow the pre-planned path, passing through nodes en route to reach the requested square. This algorithm is an improvement of a previous study [15]. In this research, we try to find the shortest path for the sink to follow to collect the critical data when present. We determine both the trajectory and the angle the sink should follow, saving time and energy by bypassing intermediate squares where no data must be gathered and heading straight forward to the node associated with the request message. We discuss the case of a relatively large network and derive a law that can scale to any network size.

III. PROPOSED ALGORITHM

In this study, we consider a wireless sensor network with a single mobile sink node. We divide the network into subnetworks shaped as squares. For simplifications, we consider dividing the network into two columns in the case of a relatively small network and more than two in the case of a medium or large network. The algorithm determines the shortest trajectory a mobile sink node should follow to reach the CN which has critical data. For routine data collection, a pre-determined path is followed. Figure 1 illustrates the network division plan. Typically, when routine data is collected, the sink node will pass through squares (1) and (2) till the end of the first row. Then, it shifts its route to the second row, and so on. When a sensor node detects data of significant relevance, the sink

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node will go immediately to the block that houses the cluster head from whom the request to deliver critical data originated, following the shortest way possible. If the CN that has critical data is within the same row as the sink and ahead of it, the sink will move a distance of D and at an angle of 0 degrees. $D=S\times X$, where S is the length of the square division and X denotes the number of squares lying between the sink and the CN as in Figure 2 (a). If the CN is in the same row as the sink but in a square behind, the sink should move a distance of $d=X\times S$ with an angle of 180 degrees since it should change direction. When the CN is not in the same row as the sink node, we distinguish two scenarios:

A. **First Scenario: CN is directly below the MS**

In this scenario, the CN is in the next row but in the same column as the MS. In this case, the sink node will move a distance of S and at an angle of 90 degrees. We can write the distance needed to be crossed as $Y\times S$, where Y denotes the number of lines or rows lying between CN and MS as in Figure 2 (B).

A. Second Scenario: CN is in different column and row from the MS

The length of the hypotenuse ($L = D$) is the shortest path to the square where the CN is situated if it is positioned in a

different row and column than the MS. $L = \sqrt{2}S$ can be used to compute this distance, and $\theta = 45$ (a right isosceles triangle) is the angle the sink should be at. As shown in Figure 3 (a).

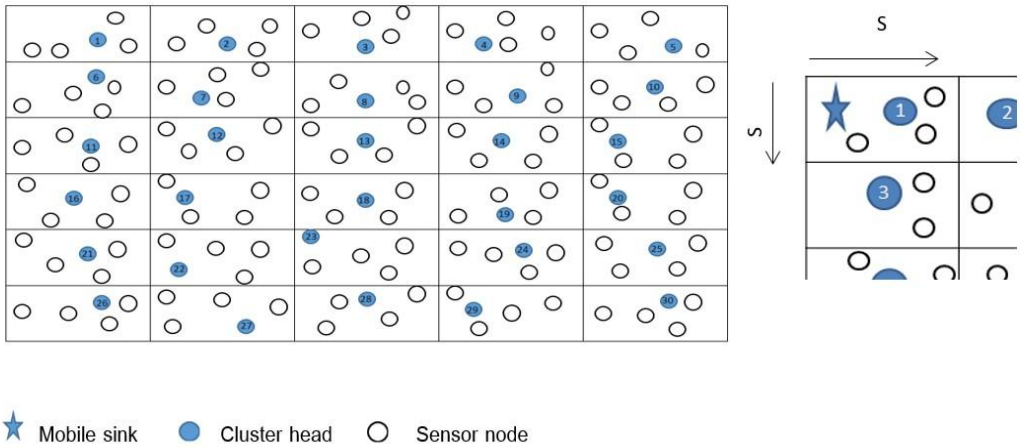
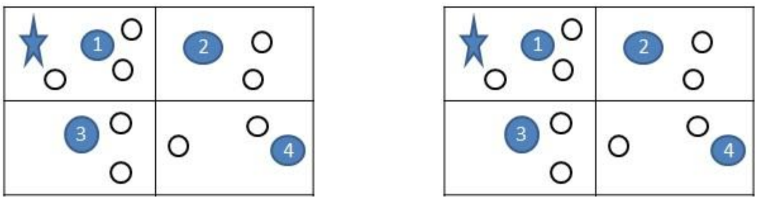


Fig. 1: Network division and dimensions.



(a) (b)

Fig. 2: The different scenarios of cardinal node and sink node positioning

If the CN is located in the third row and the adjoining column to the sink node. Then, the shortest distance for the sink to

follow is $L = \sqrt{5}S$ with a trajectory angle as $\theta = \sin^{-1}(1/\sqrt{5})$

If there is a three-row gap between the location of the sink and the CN, which is in the fourth row. The shortest route is thus: $L = \sqrt{10}S$ (1)

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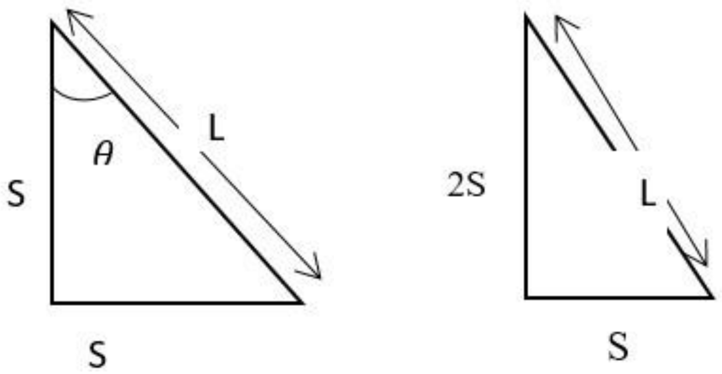

(a) The triangle formed if the difference is (b) The triangle formed if the difference is one line between MS and CN two lines between MS and CN

Fig. 3: MS chosen trajectory

$$\theta = \sin^{-1}(\frac{1}{\sqrt{10}}) \tag{2}$$

If four rows separate the CN from the sink node, meaning it is on the fifth row. Then, the shortest route is as follows: The shortest path is:

$$L = \sqrt{17}S \tag{3}$$

$$\theta = \sin^{-1}(\frac{1}{\sqrt{17}}) \tag{4}$$

Likewise, if the sink node is five lines away from the CN, which is located on the sixth line. Then, the shortest path is:

$$L = \sqrt{26}S \tag{5}$$

$$\theta = \sin^{-1}(\frac{1}{\sqrt{26}}) \tag{6}$$

By mathematical extrapolation, we can generalize the shortest path length equation as follows:

$$L = \sqrt{2+n}S \tag{7}$$

$$\theta = \sin^{-1}(\frac{1}{\sqrt{2+n}}) \tag{8}$$

Where n is an integer number that can be calculated according to the network division. For instance, when the network is divided into two columns. Two groups are formed. Group A refers to the row number and Group B is the group of odd numbers starting from 3. Table I shows the groups (A,B).

TABLE I: Groups (A, B)

A	B
3	3
4	5
5	7
6	9
7	11

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To demonstrate how to compute n using the table I, we assume the following scenario. A node is situated in the fourth row while the sink node is in the first row, that is, the row gap between the two is 3 rows. From the table, we find that What corresponds to the fourth row in group B is the number 5. We add this number to the former number in the table, which in this case is 3. Hence, the result is 8, which is the value of n. By substituting, we observe the same result that we reached by Pythagorean arithmetic.

Using the same method used to compute n, we can determine the angle at which the sink node should go through by using the following generalized equation:

$$\theta = \sin^{-1}(\frac{1}{\sqrt{2+n}}) \tag{9}$$

To ensure a single-hop connection, we must choose the dimension S based on the communication radius, denoted as R, which is the communication range between each pair of nodes. Thus S must oblige to the following constraint:

$$S^2 + S^2 \leq R^2 \rightarrow 2S^2 \leq R^2 \rightarrow S \leq (\frac{R}{\sqrt{2}}) \tag{10}$$

When the cardinal node is not in the same column the equation we derived remains correct. However, the angle is added to the calculation as follows:

$$90 + \sin^{-1}(\frac{1}{\sqrt{2+n}}) \tag{11}$$

The equations still hold true when the network is divided into more columns. But, more columns should be added to the table used to compute n as shown in Table II.

From the third line on, it is evident that the numbers are repeated; regardless of the number of columns added, only the first number in each column varies. For example, we can see that the first number in column 2 is equal to the sum of the first TABLE II: n calculation in large network

Row	Column 1	Column 2	Column 3	Column 4
2	0	3	8	15
3	3	3	3	3
4	5	5	5	5
5	7	7	7	7
6	9	9	9	9

two numbers in column 1. In the same way, the first number in column 3 is equal to the total of the first three numbers in column 1, and so forth. Thus, regardless of the size of the network, we can construct this table. In a unique instance, if the cardinal node is in a different row and the preceding column, L remains the same and the angle is calculated as follows

$$90 + \sin^{-1}(\frac{1}{\sqrt{2+n}}) \tag{12}$$

Figure 4: shows the flow chart of the algorithm employed.

IV. SIMULATION SCENARIO AND RESULTS:

To evaluate the performance of the proposed algorithm, we compare it against two different related works, namely [14, 15]. We used the open-source NS2 network simulator, version 2.35, running on the Linux environment. We chose this simulator as it has been used extensively in published research worldwide.

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TABLE III: Simulation parameters

Area Size	100*100 m^2
Number of nodes	250
Protocol	IEEE802.15.4
Simulation time	100 s
Mobile sink speed	10 m/s
Initial node energy	1 j
Contact area radius	25 m
Distribute nodes	Random

As a simulation scenario, We consider a widely distributed WSN, with static sensor nodes and mobile sink. The network is split up into square-shaped subnetworks. The node with the highest energy in each network square is designated as the cluster head. The cluster head is then re-elected after the data collection cycle, which comes to a close after the sink node has visited every network square.

Table IV displays the simulation parameters, which were taken from prior research to facilitate results comparison between the different algorithms.

TABLE IV: Simulation parameters

Area Size	100*100 m^2
Number of nodes	250
Protocol	IEEE802.15.4
Simulation time	100 s
Mobile sink speed	10 m/s
Initial node energy	1 j
Contact area radius	25 m
Distribute nodes	Random

To compare the three algorithms, we take into account two metrics. These are the experienced end-to-end delay and the packet arrival rate.

A. Packet received ratio (Throughput):

Throughput is defined as the percentage of intact packets reaching the target (receiver). Figure 5 shows the throughput achieved when employing the suggested approach and the other previously described algorithms.

As shown in the figure, the proposed algorithm yields better results compared to the other two reference approaches. This is essentially because, as was previously mentioned, the sensitive node in the study [15] wakes up the nodes neighboring the sensitive node and then sends the request message to the sink node.

In [14], there was no intermediary between the cardinal node and the sink node, so it gave better results. However, the path of the sink node to the sensitive node was not the shortest. Consequently, when a request is received from the sensitive node and its corresponding subnet, the sink node must visit all of the intermediate squares between its location and the CN location

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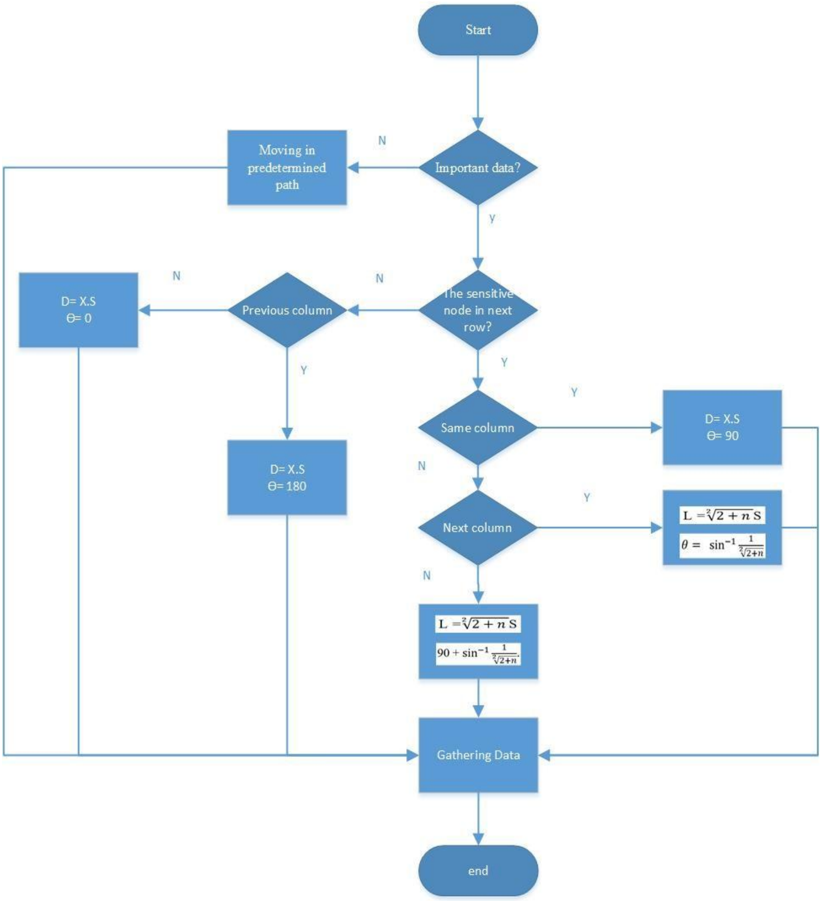

Fig. 4: The proposed algorithm flow chart

(without stopping). The longer it takes the sink node to reach the sensitive node, the more likely it is that critical data will be lost. The shortest path to the CN was determined in our algorithm, This lead to it having better results in terms of throughput and delay. It must be noted that the worst simulation result was obtained when the sink node was moving randomly (without change).

B. End-end delay comparison:

The second parameter we suggested for comparison is the delay, which is defined as the difference between the expected arrival time of packets and the actual arrival time of these packets.

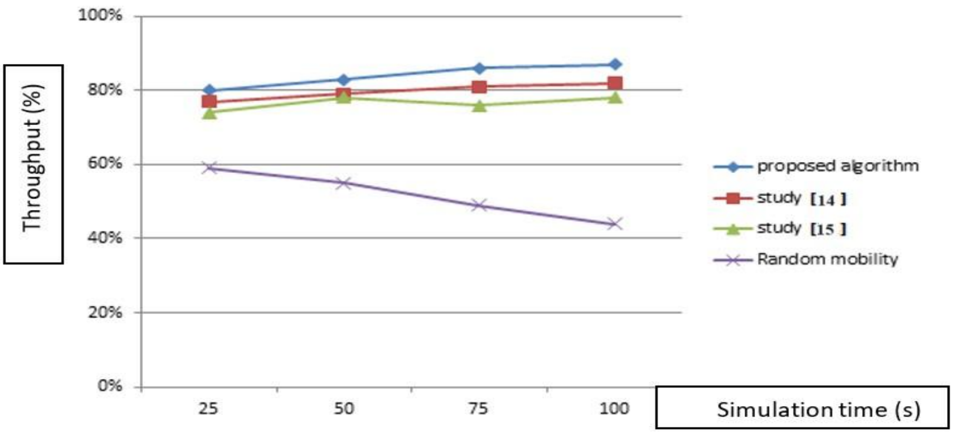

Fig. 5: Throughput comparison between the different algorithms

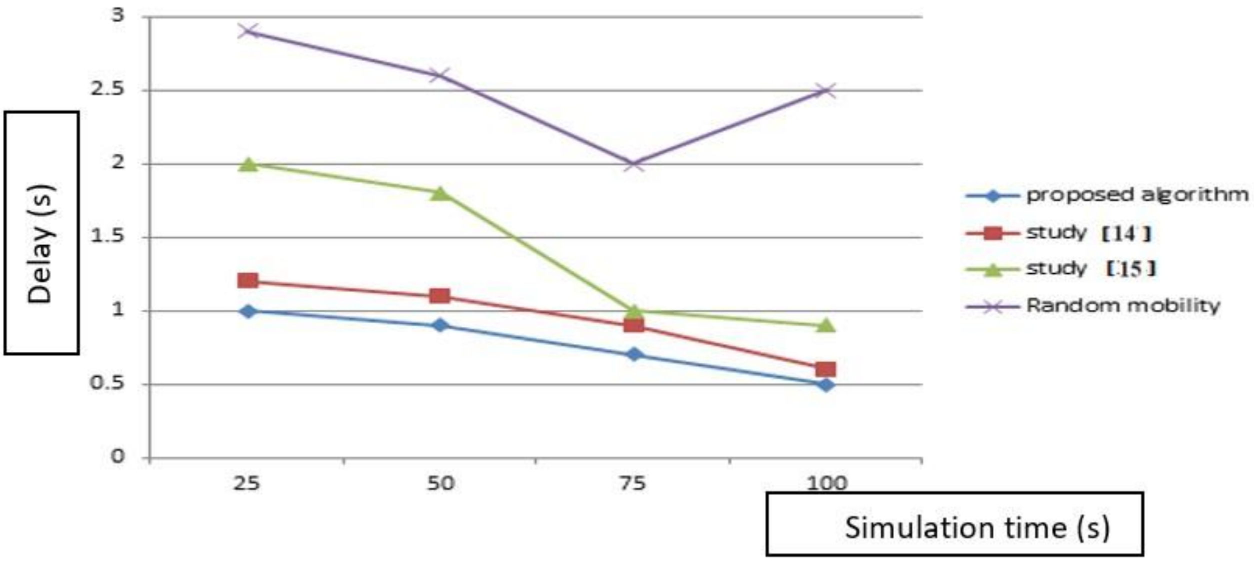

Fig. 6: End-to-end delay comparison

Figure 6 illustrates less delay when applying the proposed algorithm compared to the other two approaches [14, 15]. This is due to the sink node following the shortest path when a request comes in to receive data of utmost importance. On the other hand, [14, 15] require the sink node to take a long path or that nearby nodes keep data until the sink node reaches the target box, resulting into more delay.

V. CONCLUSIONS

In this research, we suggested an algorithm that, in response to a request for delivering data of the highest priority, alters the sink node's route to ensure that vital information is collected without influencing the collection of routine data. The sink node is instructed to choose the shortest route to the CN to save energy and reduce potential delay.

The method performed better than earlier algorithms in terms of latency and throughput, according to the simulation results. We advise using our technique for wireless sensor networks working in areas where data collection must be quick and may involve critical data.

The significance of this issue is evident in critical applications that use sensor networks, such as gathering data for medical facilities, oil fields, or industrial areas using a sink node mounted on a drone or robot. For this reason, it will be crucial to get critical data immediately passing through the shortest path with the least delay.

In the future, we plan to expand our study to three-dimensional networks, where nodes' altitude may influence the choice of MS trajectories. We will also examine other use cases in which nodes can be given varying weights according to the significance of their locations, the data they collect, and other factors.

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