The Use of Multiple Mobile Sinks in Wireless Sensor Networks for Large Scale Areas

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Abstract: Sensing coverage and network connectivity are two of the most fundamental issues to ensure that there are effective environmental sensing and robust data communication in a WSN application. Random positioning of nodes in a WSN may result in random connectivity, which can cause a large variety of key parameters within the WSN. For example, data latency and battery lifetime can lead to the isolation of nodes, which causes a disconnection between nodes within the network. These problems can be avoided by using mobile data sinks, which travel between nodes that have connection problems. This research aims to design, test and optimise a data collection system that addresses the isolated node problem, as well as to improve the connectivity between sensor nodes and base station, and to reduce the energy consumption simultaneously. In addition, this system will help to solve several problems such as the imbalance of delay and hotspot problems. The effort in this paper is focussed on the feasibility of using the proposed methodology in different applications. More ongoing experimental work will aim to provide a detailed study for advanced applications e.g. transport systems for civil purposes.

1. Introduction

A Wireless Sensor Network (WSN) is a group of autonomous static devices called sensor nodes that are spatially distributed. These nodes are configured to work cooperatively to collect physical or environmental information from the monitored area, such as temperature, sound, motion, and pollutants, and then send it wirelessly to a receiver point called the data sink. The radio signal is interpreted by the receiver which then converts the wireless radio signal into a specific output [1]. Wireless sensors can be used in locations that are difficult to access due to extreme conditions such as high temperature, humidity, and pressure [2]. Also, they can be used to form a wireless sensor network that would allow technicians to monitor a large number of different locations far from their position, such as tracking targets in a battlefield and monitoring the physical environment for the benefit of agriculture and plants [3]. Every sensor node is capable of communicating with other sensor nodes wirelessly and monitoring an environment. This is accomplished by sensing and collecting data such as temperature, humidity, light or motion from the region of interest (ROI) and sending it to the end-user who can then make an informed decision. Parts of the data, which have been collected by different types of sensors, may be different in importance level. Tiny sensor nodes with multi functionalities make it possible to deploy wireless sensor networks (WSNs), which represent a significant improvement over traditional wired sensor networks (Bellazreg 2014). Figure 1 shows a typical Wireless Sensor Network. A WSN can differ from traditional networks, as it has different design and resource constraints; these constraints can include limited processing and storage at each node, a limited amount of energy to power the node, short communication ranges and low bandwidth [5]. Wireless

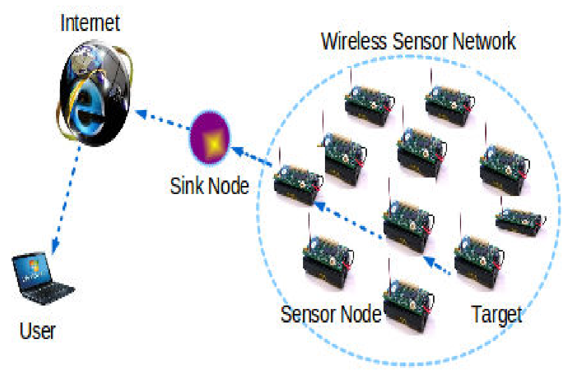

Fig. 1. *Wireless Sensor Network (After [4])*

sensor networks have a large number of nodes when they are compared with traditional *ad hoc* networks. As well as this the sensor nodes have a limited lifetime and the topology of the network may change continuously [5]. The key parts of a wireless sensor network are mainly the sensors, the power units, the processors and the communication receiving components. Depending on the application of WSN the node may also be integrated with additional components. For instance, in some applications of WSN, the sensor node is dynamic and may change its position; in this case, the sensor node will be equipped with an additional device called a mobilizer to permit relocation of the node [6]. For location finding it can be equipped with GPS. Figure 2 illustrates the architecture of a sensor node with a mobiliser. There are several basic concepts that have a significant effect on any network design, including WSN. Network topology (the arrangement of a network, including its nodes and connecting lines) has several different types, such as star, mesh and hybrid. Researchers have made efforts to develop the design standards for WSN to be reliable and robust to address many potential network problems. The IEEE 802.15.4, 802.15.4 PAN and IEEE802.15.4 standards are common examples that are used, depending on the application.

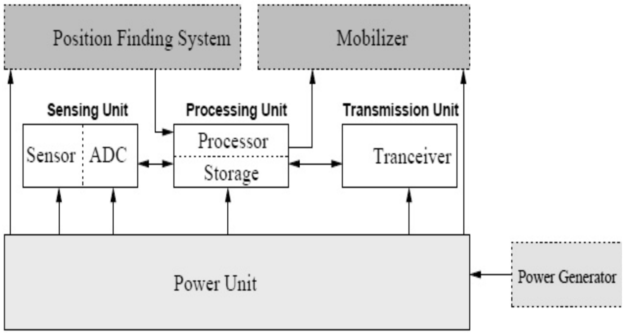

Fig. 2. *The sensor node architecture [6].*

Various challenges exist currently in this field. These include power reduction, routing optimisation and congestion management; sensing coverage and network connectivity are two of the most fundamental issues to ensure effective environmental sensing and robust data communication in a WSN application. The aim of this study is to design, test and optimise a data collection system that addresses the isolated node problem, as well as to improve the connectivity between sensor nodes and the base station, and to reduce the energy consumption simultaneously. In addition, this system will help to solve some problems such as the imbalance of delay and hotspot problems.

2. Previous studies

Studies in [7] and [8] give the reader a good survey about different issues in coverage and connectivity in wireless sensor networks. Coverage and connectivity (CC) are two of the most fundamental issues to ensure effective environmental sensing and robust data communication in a WSN application [9]. If these are attained then the information centre can extract data from any location in the whole ROI. Applications with such CC requirements include battlefield monitoring, intrusion detection and many others (see [10]).

Using mobile sinks in WSNs is a prospective area of technology that has been studied by many researchers. They have shown that the use of mobile elements can enhance connectivity and the lifespan of a network. The mobile nodes can communicate with other nodes in the network. They can address the connectivity problem by carrying information between isolated parts of WSNs (parts that have become disconnected, as can occur due to damage of some nodes or mistakes of deployment [11]). Utilizing the mobile parts in a network is another way to reduce the communication distance between sensors and sinks. This means that the network lifetime can be improved with mobile devices by reducing multi-hop communication. Another important problem of static deployments is the bottleneck problem, which shows up in the nodes close to the sink. As all of the data is forwarded towards the sink, the average load on a sensor node increases with a decreasing distance between the node and the sink [12].

The three papers most relevant to the work in this paper are [13], [14] and [15]. The authors in [13] proposed an Adaptive Moving Strategy (AMS). These researchers had the objective of balancing the trade-off between energy efficiency, total path length, and buffer overflow deadlines. The authors present a solution to the problem of planning a moving path for a mobile sink in hierarchically structured sensor networks. The mobile sink starts at a stationary position and follows a well-planned route, which ends with the sink returning to the starting position. Sensor nodes are randomly deployed in the area. Sensors are organized into clusters, and cluster heads are selected. A cluster head has the role of gathering information from the nodes in its cluster, saving data in a buffer, and then transferring data to the mobile sink when it gets within the communication range. The sink moves along the path through each cluster, which means that it will pass (at most) one hop away from each cluster head, therefore each cluster head will send data directly to the sink which saves energy. Path optimization is accomplished by employing the Bees algorithm with an appropriate fitness function that incorporates the optimality criterion.

In [14], the authors proposed a method to employ one static sink and one mobile sink to gather data from the network. The mobile sink moves along the outer circle and the fixed sink is deployed at the centre of the annular area, and they collect data from the network. The main goal was to enhance the network performance including delivery delay and energy consumption. However, the trajectory of the mobile sink is long, which can result in making the data collection latency too large.

In [15], the authors propose an efficient data collection algorithm using a ferry node. To minimize the overall roundtrip travel time, they divided the sensing field area into virtual grids based on the assumed sensing range and assigned a checkpoint in each one. A Genetic Algorithm with weight metrics is used to solve the Travelling Sales Man Problem (TSP) to find an optimum path for the ferry to collect data. They used a ranking clustering algorithm (NRCA) in each virtual grid to choose the locations to place the ferry's checkpoints. In NRCA the decision of selecting cluster heads is based on their residual energy and their distance from their associated checkpoint, which acts as a temporary sink.

Recent studies, such as [16], have been conducted to survey the different methods for node deployment, given in research literature, for coverage and connectivity purposes. In [17] evolutionary algorithms that deal with the problems of coverage and connectivity are assessed.

In view of this research, a connectivity process will be investigated to address the isolated nodes problem, which uses WSN with mobile sinks that move along fixed paths with constant speed. A concurrent aim is to cover the whole network area as much as possible by applying a path determination algorithm to plan the path of the sinks in the network. Energy consumption and hot spot problems can be reduced by using mobile sinks. All of these issues are studied experimentally using a Waspmote sensor node, towards the long-term objectives of this research.

3. Proposed method

Connectivity is one of the primary issues of Wireless Sensor Networks (WSN). Two sensor nodes are connected if they can communicate either directly (single-hop connectivity), or indirectly (multi-hop connectivity). In WSN, the network is considered to be fully connected if there is at least one path between the sink and each sensor node in the sensing area [17]. For traditional WSN, which has static nodes and a static sink, several problems may occur, such as sink node isolation. This makes the sink node unable to communicate with sensor nodes that have plentiful energy reserves. Another problem is an imbalance of energy consumption that occurs because some sensor nodes act as relays for other sensor nodes. Furthermore, the closer the sensor node is to the sink the higher its energy consumption due to the larger amount of data it relays. The third problem is the imbalance of sensor node life; this occurs due to two factors, namely the limited energy reserves of a battery and the imbalance of energy consumption. This will lead to the situation that sensor nodes closer to the sink node will deplete their energy reserves earlier than nodes further from the sink node. The imbalance occurs because data that originates far from the sink needs to travel through more hops, referred to as hop count, as compared with nodes that are closer to the sink node [19].

To overcome these problems, it is necessary to use energy-efficient data collection techniques. One of these techniques is to use a mobile sink that moves within the sensor field, collects the sensed data from source nodes and sends these data to an information centre, or network administrators [20].

Utilizing mobile sinks in WSNs is a comparatively new field of research that has caught the attention of many researchers. Sink mobility can significantly increase network lifetime, reduce traffic and decrease the communication latency, as well as helping in eliminating the need for multi-hop forwarding of data [21]. In our research mobile sinks are proposed to ensure continuous monitoring of the connected coverage in the region of interest (ROI).

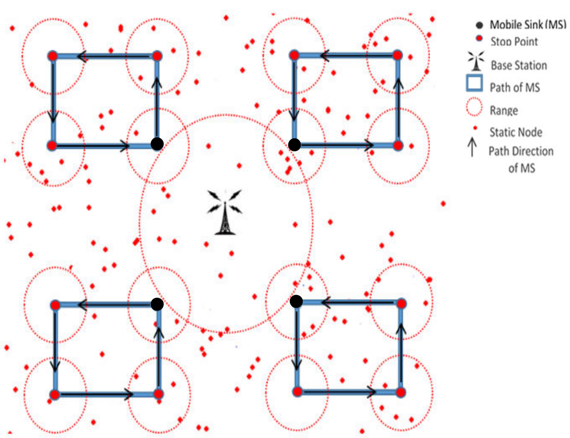

Fig. 3. *The proposed approach*

In order to deal with connectivity problems in large-scale wireless sensor networks, mobile sinks that move along fixed paths (in all directions) with a constant speed can be used to address isolated node problems. Thus the data collection scheme improves the connectivity between the sensor nodes and base station, as well as reducing the energy consumption of fixed nodes.

The proposed work is a large-scale sensor network such as used in forest fire detection and in agriculture. In smart agriculture, WSN has been applied to monitor the development of crops in remote places. The monitored data might include temperature, humidity and soil moisture. This area is divided into four regions; each region has several clusters and a mobile sink that moves inside the region along a planned path, and uploads sensed data from the cluster heads and send it to another base station (BS). Figure 3 illustrates the proposed approach.

The mobile sinks are equipped with powerful transceiver. These move within a region to gather the data periodically from cluster heads (CH). The member nodes in the region can send their data to a mobile sub-sink via cluster heads, the mobile sub-sink then transmits the data to Base Station (BS). During their tour the mobile sinks have stop points at chosen locations, for certain durations, to collect the sensing data from all head clusters

The long-term objectives of this research are to:

a- Develop a mechanism to address the problem of isolated nodes and to investigate the connectivity. Isolation occurs by isolation of several sensor nodes from the Base Station (BS) due to damage of some sensor nodes, or due to mistakes of deployment where the BS does not receive the data from these sensor nodes.

b- Address the hotspot problem, which can occur because the sensor nodes closest to the base station are critical for the lifetime of the sensor network. These nodes need to relay more packets of data than nodes further away from the base station. The mobile sinks can approach each cluster head to avoid multi-hop forwarding. An energy-efficient process can be realized by searching for a path that traverses all network head nodes, within a transmission range.

c- Cover the whole network area as much as possible by using sinks that move in a defined path in the network to collect data from static cluster heads.

A Libelium Waspmote testbed will be used to implement the proposed work on a real testbed. This will give accurate measurements for the parameters that are affected such as throughput, packet delay, data error rate, and end-to-end delay. The mobilizer is a 4WD Mobile Platform that works with the Arduino Mobile Platform.

4. Initial experiments

In order to be familiar with the experimental work and environment, several initial experiments were performed on Waspmote with XBee 802.15.4, and are described below.

4.1. *Scenario* 1

In this experiment, the behaviour of a multi-hop path from source to sink was investigated. Two Waspmote nodes were used with a gateway connected to a laptop, as shown in Figure 4. The Waspmote nodes were programmed using Waspmote IDE software from the Libelium company. Codes were written in C++ to achieve the required behaviour. The output data was first displayed (this could be any kind of records such as temperature and signal strength) and then stored in a file for later analysis using a number of available software products. The software that was used includes Serial Monitor, HyperTerminal and XCTU. The most important issue is to save the data to a text file, which was achieved by using the XCTU Save instruction. After this, the data file was analysed using Matlab, and the network performance can be assessed. The established path of two hops (2 nodes and 1 gateway) is done by employing the Mac addresses of the nodes; the source can send any sensing data using the 1st hop and the 2nd hop and thus to the gateway. It is possible to display the received and sent packets through the serial monitor software of Waspmote IDE software or XCTU software. The fraction of successfully received packets can be calculated from the ratio of the number of received packets to the total of the packets sent. This ratio is an important metric of the performance of the network since it reflects the error rate of packets.

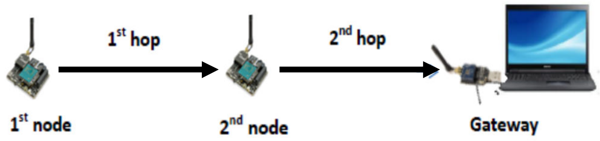

Fig. 4. *Scenario 1*

Additionally, this metric is necessary for event applications, where each packet should be received by the sink. Obviously, a higher value of this ratio gives an indication that the network can provide reliable communication.
Sink throughput is another metric; it is the measure of how fast the data can be sent through a network and can be estimated by measuring the average of the number of packets that are transmitted through the network in a unit of time:

$$\text{Average Throughput} = \frac{\text{Total received size}}{\text{Elapsed time between send and receive}} \quad (1)$$

It is desirable to have a network with a high throughput [22].

The Packet delivery ratio (PDR) is another metric that must be considered. It is the ratio of the number of packets received at the destination to the number of packets generated at the source. A network should work to attain high PDR to have a better performance. The PDR shows the amount of reliability offered by the network [22].

$$\text{Packet Delivery Ratio} = \frac{\text{Number of packets received successfully}}{\text{Number of packets sent}} \quad (2)$$

Average end–to–end delay is the average time delay consumed by data packets to propagate from source to destination. This delay includes the total time of transmission i.e. propagation time, queuing time and route establishment time [22].

$$\text{Average end-to-end delay} = \frac{\text{Receive time} - \text{send time}}{\text{Total time}} \quad (3)$$

At the sink, the number of received packets every second can be determined. Then, the received packet rate can be used to compare the network in both situations: with congestion control and without it. Moreover, the battery level may also be observed at any node in the network, so at the congested node, packet loss is more likely to be seen. Therefore a useful metric comes from measuring battery level, and this factor can be considered when comparing the designed network with another network.

Available space memory at any node can be measured to give an indication of node overflow. Measuring the memory can be achieved through programming the node to include the free space memory in the output data. This is useful in that possible congestion at any node can be detected. A received packet from experiment 1 can be displayed on the XCTU window.

4.2. Scenario 2

This scenario was created by connecting two source nodes to a sink node, then from the sink to the gateway which is connected to a laptop. In this scenario, three Waspmote nodes and one gateway were employed (Figure 5). In this experiment memory space in the receiver is measured (out of 8 kilobytes of RAM in total) to see how overflow occurs in the receiving node. The measurement may be monitored using the Waspmote IDE window.

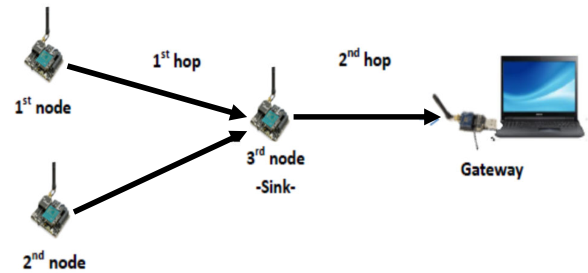

Fig. 5. *Scenario 2*

However, the main goal from doing the above experiments was to ensure that different work scenarios (e.g. single and multi) can be performed through utilizing the work tools. The following are some brief points, which can be deduced from these experiments:

a-It is possible to build a route (path) from source to sink by using the built-in Mac address of the XBee transceiver on Waspmote.

b- It is possible to make some analyses when the packet number is displayed on the packet. For example, the lost packet can be detected at the sink by finding the missing number. The sink can send these missing packets numbers back to the source, for retransmission.

c- The available memory space can be measured to deduce the probable congestion in the node. Information is available to maintain power consumption in the network by reading the battery level.

d- Many statistics can be deduced from the data such as the numbers of sent and received packets, the types of the data frames, and the node IDs using XCTU software, in which the packet header and the payload of sent and received packets can be displayed.

e- The XCTU software gives the possibility of displaying the network and its data, which is evidence that the intended experiments are feasible.

5. Deployment scenarios

In this ongoing work (ongoing according to research proposals), Waspmotes were deployed as shown in Figure 6, and several scenarios have been developed, which will be discussed. Firstly, a feasibility study has been performed using a Matlab based environment, and the outcomes of experimental results are left for future work within the same overall project.
The intended plan for this research is to test existing methods for gathering data and to design and test new methods to address the isolated node problem, and to cover the whole network area as much as possible. Several experiments will be performed to achieve this purpose.
The proposed location for the implementation of these experiments is an open space, with dimensions of 40m × 20m. All scenarios in this section have been implemented using MATLAB and are within the same environment.

Fig. 6. Sensor nodes deployment

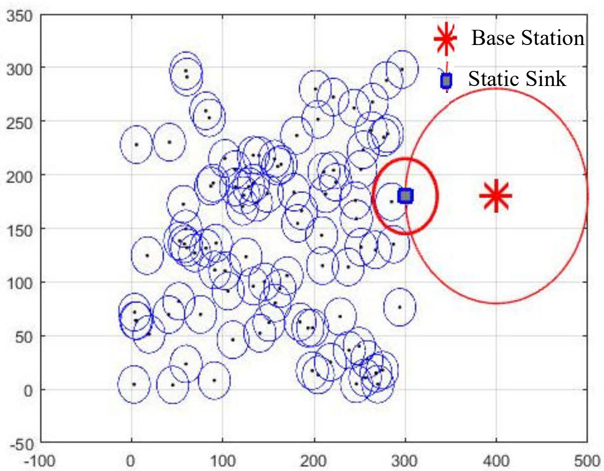

Fig. 7. Static Sink of WSN

- **Static Sink**

The first experiment aims to implement a WSN with only static nodes and static sink node by using real sensor nodes. 25 Waspmote sensor nodes are used in this experiment. The sensor nodes that were randomly deployed are connected in clusters. The data from each cluster goes through the cluster head (CH) node. Each cluster has two members (normal nodes) and one cluster head. The CH is selected based on residual energy and its position within the communication range of all nodes in the same cluster. Three metrics will be measured: throughput, packet delivery ratio and end-to-end delay. The first scenario is the traditional WSN. The parameters of this scenario are given in Table 1. Figure 7 shows a traditional WSN using a static sink. Problems with this method include not necessarily providing sufficient coverage and a disparity in energy consumption between the nodes.

- **Single Mobile Sink**

The second experiment aims to implement Adapted Moving Strategy (AMS) in the (same) area to evaluate performance metrics. AMS is an algorithm that was developed in [13] as a method for gathering data from large scale applications. In order to implement AMS using real hardware, a mobilizer should be used. The mobilizer allows the sink to move around the network to gather data from all clusters. It moves inside the sensing area and has a fixed path with twelve stop points to collect the data from cluster heads. The CHs are selected based on residual energy and proximity to the fixed path of the mobile sink. It has been assumed that each cluster head will not be able to communicate with the other CHs due to the distance between them. The mobile sink is moving; to determine the positions of stop points the clusters broadcast a control message. When the mobile sink receives such a

Table 1: Scenario of Static Sink of WSN

Parameter	Parameter Value
Size of Area	300m*300m
No. of Nodes	120
Mobile Sink	1
Transmission Range of Sensor Nodes	20m
Transmission Range of Sink	30m
Data Packet Size	100 bit
Mobile Sink Speed	30 m/s
Number of Stop-Points	14
Initial Energy of a Node	0.5J
No. of Rounds	5000

message, it calculates the value of the Received Signal Strength Indicator (RSSI). When the RSSI > -60dB, this means that the mobile sink is in the right place to stop and receive data from the cluster head. After collecting the data, the mobile sink moves further along the path. If the mobile sink receives another broadcast, it repeats the previous process and continues the movement until returning to the start point. After it reaches the starting point it will transfer the available data to the base station. The same three metrics will be measured to evaluate the performance of AMS. Ongoing investigations will address any problems and will compare the harvested data to data from a traditional network. These expected problems include the isolation problem, imbalance of energy consumption, and imbalance of lifetime. Additionally, increasing the number of stop points will increase the time needed to collect data and send it to the base station, which leads to an increase in the delay of data. Also, because of the long path of the mobile sink, overflow buffer problems may appear which leads to a loss of data. The simulation of the second scenario is shown in Figure 8 (single mobile sink).

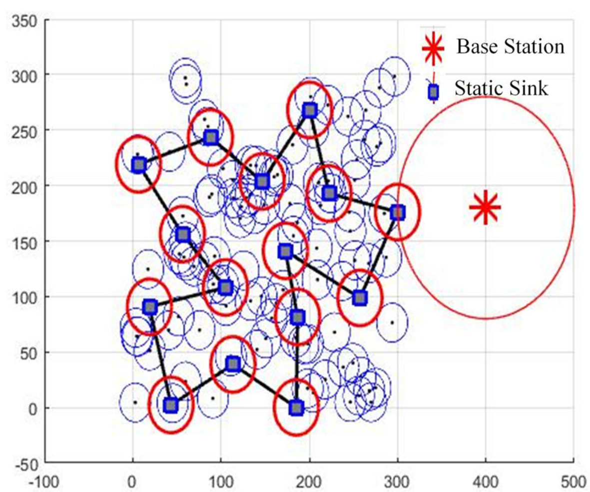

***Fig. 8.** Single Mobile Sink* WSN

In this scenario, the mobile sink is moved inside the sensing area and collects available data from cluster heads, and transfers it to the base station. The stop points have been taken to be when the mobile sink stops for a certain period to collect data, and the end to be when it returns to the starting point and transfers the data to the base station. The Travelling Salesman Path Genetic Algorithm (TSP-GA) was used to find the optimum path for the mobile sink. Different parameters of this scenario are given in Table 2.

Table 2: Scenario of Single Mobile Sink of WSN

Parameter	Parameter Value
Size of Area	300m*300m
No. of Nodes	120
Mobile Sink	4
Transmission Range of Sensor Nodes	20m
Transmission Range of Sink	30m
Data Packet Size	100 bit
Mobile Sink Speed	30 m/s
Number of Stop-Points	9
Initial Energy of a Node	0.5J
No. of Rounds	5000

- **Multiple Mobile Sinks**

The goal of this experiment is to implement a new method that can be employed to address the isolated nodes problem for gathering data and to cover the whole network area as much as possible. The proposed area (the hall) is divided into four rectangular parts. Each part has many clusters. The methodology of experiment 2 (described previously) is applied to each region in this experiment. The selection of cluster heads was mentioned in detail above. Each region has one mobile sink. Its task is to gather available data from CHs, using four stops, and transfer it to the base station (BS). In this case, there will be a need for 36 nodes to cover all of the fields. Each part of the field has a mobilizer carrying sink which moves inside the area. The same three metrics will be measured to evaluate the performance of the network. In this experiment, increasing the number of mobile sinks means the data will be distributed between these sinks, which leads to a reduction in the time required to access the data at the base station. Reducing this time means a reduction in the data delay between source and destination. Additionally, the multiple mobile sinks will address the buffer-overflow by distributing the data between several mobile sinks. The mobile sinks in all of the experiments are equipped with a powerful transceiver, of type XBee-Pro, which has been mentioned previously.

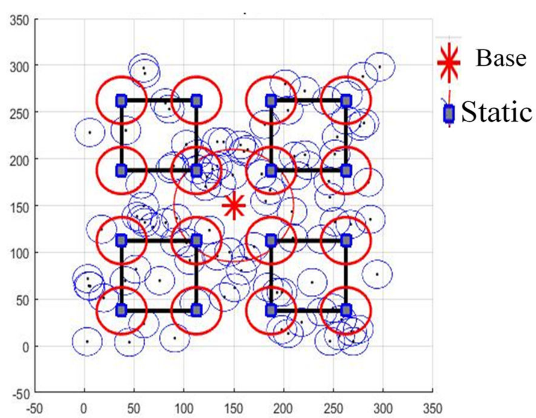

***Fig. 9.** Multi Mobile Sink of WSN*

In the third scenario shown in Figure 9, there are multi-mobile sinks that move inside the area to collect the available data and send it to the base station.

It should be noted that the number of stop points in this scenario is less than in the previous scenario because of the reduced area that each mobile sink needs to cover, which leads to a reduction in the total time it takes to collect data from the stop points. The parameters of this scenario are given in Table 3. A comparison was performed between the use of a single mobile sink and multi-mobile sinks in terms of the number of Alive Nodes, and the number of packets delivered to the base station. This in terms of the number of rounds, is shown in Figures 10 and 11. Figure 10 shows that both methods (single and multiple) give nearly the same number of living nodes to just above 1000 rounds, after this point, a benefit was seen from multi-mobile sinks.

Table 3: Scenario of Multi Mobile Sink of WSN

Parameter	Parameter Value
Size of Area	300m × 300m
No. of Nodes	120
Static Sink	1
Transmission Range of Sensor Nodes	20m
Transmission Range of Sink	30m
Data Packet Size	100 bit

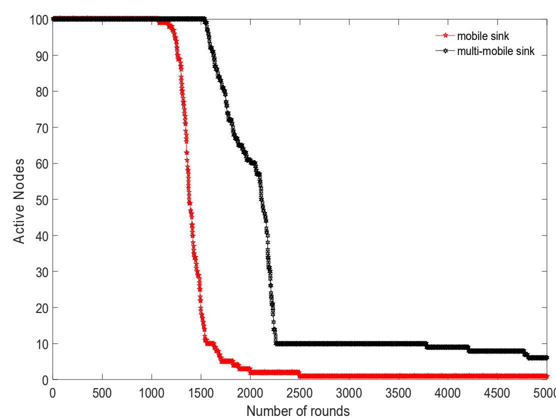

***Fig. 10.** Alive Nodes in terms of Rounds*

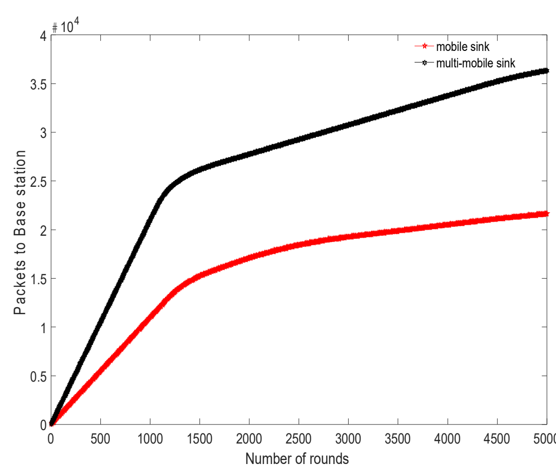

***Fig. 11.** Base Station in terms of number of Rounds*

However, as seen in Figure 11, the number of packets delivered to the base station is much higher with multi-mobile sinks than with a single sink. According to these data, it can be inferred that it is better to employ the method of multi-sinks in view of both the number of sent packets and the number of nodes that can survive. Several issues remain under investigation at present and will be dealt with fully at an appropriate stage in the research project.

6. Conclusion

The aim of the present project was to use the same number of mobile sinks in a Wireless Sensor Network as it is intended to apply in large scale areas. The random positioning of nodes in a WSN results in random connectivity, and this can cause large variation within the WSN key parameters such as data latency and battery lifetime. It can also lead to the isolation of nodes. These problems may be alleviated by using mobile data sinks, which travel between nodes that have connection problems. Assessing the use of mobile sinks in such a way was the main objective of this paper. Our ongoing study has found that it is generally possible to solve the delay in connectivity between nodes by using an appropriate route. The findings of this paper provide insight into ways to deal with energy consumption issues through the use of mobile sinks. The scope of this study was limited in terms of the environment since it has been conducted in an area with sides of the order of a few meters, hence there is a need to enlarge the distances involved. The main strength of the present research is the employment of such tools (nodes, sink and mobiliser) in several scenarios. Ongoing experiments and simulations in this project include larger areas and implementation with transportation systems, such as helicopters in agricultural applications. There are different issues that will be tackled with this work, which will provide a contribution to knowledge. These include: the imbalance of energy consumption, the imbalance of lifetime, the isolation problem, the buffer overflow problem and the hotspot problem. All of the problems that are mentioned occur with a traditional WSN that has static nodes and a sink that is unable to change its position. Adaptive Moving Strategy (AMS) methods help in improving most of the issues but there is a need for ongoing work to deal with the increase of delay, and buffer overflow of sink memory, due to the moving of the mobiliser. More broadly, it would be interesting to test if it is possible to join this study with the Internet of Things (IoT) applications. Further experimental studies need to be carried out in order to validate the methodology before starting work on agricultural applications.

7. Acknowledgments

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