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Increasing Lifetime Using Whale Optimization Routing Algorithm in Wireless Sensor Networks

Hassan Nouri[a,*], Esmaeil Zeinali [a]

Faculty of Computer and Information Technology Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran.

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Abstract

Following the development of wireless sensor networks, the need to design a low-waste, scalable, and long-life network is felt more than ever. Clustering and routing are widely used to minimize energy consumption and increase network lifetime, as important issues in wireless sensor networks. Since, in these networks, the largest amount of energy is spent on sending and receiving the data, the clustering technique done by collecting data on cluster heads has been found to influence the overall network performance; along with this, routine and efficient routing has also found to improve the network throughput. Therefore, multi-hop routing can increase the network lifetime and reduce the energy consumption by sensor nodes. In this paper, the main approach was using the mobile sinks attached to the public transportation vehicles, such as the bus to collect data in wireless sensor networks. The proposed protocol used multi-hop routing as well as Whale Optimization Algorithm to select cluster heads based on a fitness function, in which the amount of the remaining energy of the sensor nodes and the sum of the remaining energy of the adjacent sensor nodes were taken into account. Adopting this approach created a balance in the amount of energy consumption in sensor nodes. The proposed protocol was studied to validate the results obtained for the network lifetime and energy consumption. Independent and consecutive simulation results and statistical analysis indicates the superiority of the proposed protocol compared to other protocols. Also, the network lifetime improved by averagely 20% and the energy consumption reduced about 25% during the network activity.

Keywords: Lifetime, Data Collection, Whale Optimization Algorithm, Clustering, Wireless Sensor Networks

1.Introduction

Each sensor node consists of four main components: sensor unit, data processing unit, wireless transmitter/receiver and power supply. Depending on the type of application, there can be additional parts, such as mobilizer unit, Global Positioning System (GPS) and power generation [1, 2]. In case of the software used for managing resources and foreseeing the implementation of the programs, it requires operating systems such as Contiki, LiteOS, YetiOS, TinyOS or etc [3, 4]. A wireless sensor network comprises a set of sensor nodes with a random or predefined deployment in a specific area to view the status of the targets. Generally, these sensor nodes sense the status of the targets alternately, then processing the data and transferring them to a base station. All sensor nodes interact with each other cooperatively to provide reliable and trustful

[*] Corresponding Author. Email: hassan.nouri.hn@gmail.com

network services [5]. In the wireless sensor network, collaborative and constructive interaction between sensor nodes are important for two reasons: I) After processing and analysis, the data collected by the multiple sensor nodes can provide inferences and valuable arguments about the conditions governing the environment. II) Collaboration and interaction between network sensors can make a balance between reducing the communication costs and the computation energy.

In wireless sensor networks, the data transmission process consumes most of the energy [6] . Therefore, using energy-efficient routing protocols is very important. Energy consumption is a multi-layered issue [7]. For example, in the physical layer, the model must consider the energy consumed in the hardware components and its effect on the channel condition, physical overhead, and the possibility of error. In the MAC layer, issues such as overheads, overhearing, and collisions should be checked. At the network layer, we have to deal with the influencing factors such as the types of routing protocols, power consumption in the initial phase, and packet loss. Therefore, Ms. Wendi Heinzelman's research [8] is a conventional and reference model for energy consumption in most researches. In Section 3.2, details of the energy consumption model will be explained.

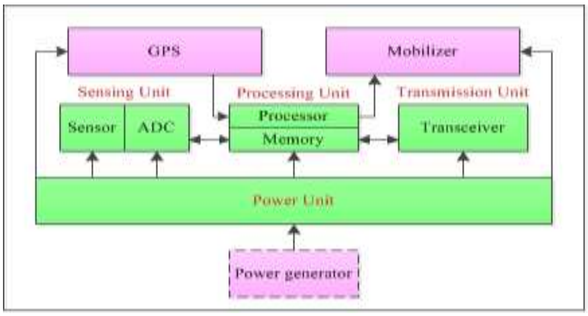


Fig. 1. The Structure of a sensor node [2].

Various approaches have been proposed for collecting and transmitting the data from the sensor node to the base station in wireless sensor networks, each of them has its own advantages and disadvantages [6, 7]. The division of sensor nodes into several groups (each of these groups is called a cluster), and selecting a node as a cluster head is known as an efficient model. Clustering has many benefits, including the removal of data redundancy by the cluster heads, reducing the energy consumption by the sensor nodes [11]. It also facilitates the routing management and improves the scalability, ultimately adjusting the load balance between sensor nodes and increasing the network lifetime. On the other hand, the type of sinks used in the network, (static or mobile), has a significant effect on the efficiency. Static sinks, along with their special applications, are not widely used due to the occurrence of the funneling effect [8, 9, 13] and the increased energy consumption by the adjacent sensor nodes of the sink and the endurance of high working pressures. Therefore, the mobile sinks are used to balance the energy consumption of sensor nodes as a way to overcome this problem. But, this method has also some challenges regarding how to move the sink for achieving more accurate and efficient data collection [14].

In this paper, mobile sinks attached to mobile vehicles were used depending on the area of the current location; for example if the location is within an urban area and there is a need to monitor the parameters such as air pollution, temperature, humidity, etc. it would be an excellent option to use the public transportation vehicles such as a bus or taxi with a predetermined route to travel. The idea can also be extended by attaching a mobile sink on the military equipment in war zones to analyze chemical, microbial, radioactivity, as well as the amount of wireless communications waves emitted from the enemy in the environment.

The proposed protocol was designed to meet these two goals: diminishing the energy consumption of sensor nodes and maximizing the network lifetime (improving the time to reach the FND). In this regard, using the multi-hop routing within clusters and between cluster heads reduces the energy consumption, as the energy consumption has an exponential model with the distance, and sending the data to the remote destination using the multi-hop technique is better than sending the information as a single-hop [15]. To have a suitable network lifetime, using the whale optimization algorithm [16] to opt different cluster heads among all the cluster head candidates guarantees the achievement of these goals with the best performance.

The remainder of the present paper will be as follows: In the second section, the background of the researches related to the proposed protocol will be presented along with an analysis of the approaches. In Section 3, the assumptions considered for the proposed algorithm will be expressed. Section 4 outlines the proposed routing protocol. The fifth section involves the evaluation of the simulation results of the proposed protocol, and Section 6 includes a summary of the findings as well as presenting suggestions for further and future researches.

2. Related Studies

Since the regular data collection in the wireless sensor networks is one of the main goals of these networks; despite of some constraints such as sensor nodes dependency to the battery, routing, network topology, sensor nodes distribution (either homogeneous or heterogeneous) the proper data collection has a noticeable effect on the network lifetime.

According to the review of the literature, many methods proposed by researchers to clustering and data aggregation in wireless sensor networks [17]. Each of these data aggregation methods is not comprehensive and has its own problems [18]. In this paper, a number of these protocols in line with the idea presented here were selected and divided into two different categories: 1) Protocols used the whale optimization algorithm for solving the problems. (In Section 2-1, the whale optimization algorithm will be introduced). 2) Protocols used along with a mobile sink (method of trajectory) attached to the public transportation vehicles.

2.1. Introduction to the Whale Optimization Algorithm

The Whale Optimization Algorithm is a meta-heuristic algorithm inspired by the nature, based on the imitation of the hunting behavior of the humpback whales [16].

Using meta-heuristic algorithms for solving optimization problems and finding an optimal solution is a useful technique. Most meta-heuristic approaches share a common feature which includes two stages of exploitation and exploration for searching method.

In the whale optimization algorithm, the exploration stage is a global search for finding optimal solutions, concerned with investigating a region of the search space aimed at discovering other solutions, while the purpose of the exploitation stage is local search. Exploitation aimed at investigating a limited area of search space that has already been known will lead to an increase in the appropriate S solution. Repeating this operation causes a diversification in the search as well as preventing from getting stuck in a local optimal. The location of the prey in this algorithm is the best possible solution. At the initial loading step of the whale optimization algorithm, the populations and the random position of each whale (solutions) are created. At first, search agents update their current positions with a random search agent. From the second recurrence, updating the location of the search factors takes place in agreement with the best solution ever achieved. Encircling, attacking the prey and searching are considered as three stages of hunting behavior.

2.1.1. Encircling the Prey

Whales can encircle the preys by detecting the position of them. Given the unknown optimal position at the outset, the candidate of the current solution is assumed as an optimal target or close to the optimal mode by the algorithm. After the best search agent has been defined, other search agents try to update their positions to the best search agent. (See below for more details). This behavior is shown in equations 1 and 2:

$$\vec{D}=|\vec{C}.\vec{X}^*(t)-\vec{X}(t)| \quad (1)$$

$$\vec{X}(t+1)=\vec{X}^*(t)-\vec{A}.\vec{D} \quad (2)$$

The coefficients of the vectors *A* and *C* are also calculated by equations (3) and (4):

$$\vec{A}=2\vec{a}.\vec{r}-\vec{a} \quad (3)$$

$$\vec{C}=2.\vec{r} \quad (4)$$

Equation (2) updates the position of the search factors toward the best solution, and then encircling of the prey will be imitated.

2.1.2. Bubble-Net Attacking (Exploitation)

For the mathematical modeling of the bubble-net behavior, the following two approaches are considered:

- *Shrinking Encircling Mechanism*

By reducing the amount of *a* in equation (3), this mode is obtained based on the behavior of the humpback whales. Also, *a* decreases the fluctuation range of *A*.

- *Spiral Updating Position*

The distance between a humpback whale located at a position (*X*,*Y*) and the prey located at a position (*X**,*Y**) will be calculated, and then a spiral equation will be created between them to imitate the humpback whales movement strategy. Such an approach is mathematically modeled in equation 5:

$$\vec{X}(t+1)=\left\{\vec{D'}.e^{bl}.\cos(2\pi l)+\vec{X^*}(t)\right. \quad (5)$$

Also, by modeling these two concurrent behaviors, it is possible to choose one of two methods for updating whale positions. The probability of this choice is 50%. The mathematical model is given in equation 6:

$$\vec{X}(t+1)=\begin{cases}\vec{X^*}(t)-\vec{A}.\vec{D} & p\le 0.5\\ \vec{D'}.e^{bl}.\cos(2\pi l)+\vec{X^*}(t) & p\ge 0.5\end{cases} \quad (6)$$

2.1.3. Search for the Prey (Exploration)

In addition to the bubble-net attacking method, the prey is also searched randomly by the humpback whales. The mathematical model of the search method is expressed in equations (7) and (8). In fact, the random search process is based on the position of the humpback whales.

$$\vec{D}=|\vec{C}.\vec{X}_{rand}-\vec{X}| \quad (7)$$

$$\vec{X}(t+1)=\vec{X}_{rand}-\vec{A}.\vec{D} \quad (8)$$

2.1.4. Reason and Advantage regarding the Use of the Whale Optimization Algorithm

Many issues in various sciences, such as mathematics, engineering, and management, are optimization issues. In these types of problems, we want to find the best solution from a set of possible solutions which proportionate to the objective function. Many of the optimization problems in the real world are large and complex. Reaching a solution that is optimal and definite is very time-consuming. Using meta-heuristic algorithms significantly reduces search space and computation time [19]. These algorithms can approach the optimal solution with an acceptable percentage of error.

From a theoretical point of view, and according to the comparisons, the whale optimization algorithm can be considered as a global optimizer because it has exploration/exploitation capability and prevents getting stuck in local minimums. In addition, searches made by other agents allow using the current record within that domain. Interestingly, the whale optimization algorithm depends on only two particular parameters (A and C) needed to be set, and this makes it relatively easy to find the optimal points.

In the proposed method, the whale optimization algorithm is used for the cluster head selection process. Because the problem of cluster head selection is an NP-Hard problem, and there is a need for an excellent global optimizer algorithm; the whale optimization algorithm can be applied to solve this problem. In the following, some equations and mechanisms will be used for updating problem solving.

2.2.Protocols Used Based on the Whale Optimization Algorithm

As far as it is known, possibly, the first step in using the whale optimization algorithm in wireless sensor networks has been taken in a previous study [20] called WOTC. The WOTC protocol is a topology control protocol based on the smart optimization method using the whale algorithm for wireless sensor network nodes, providing a discrete binary version of the main whale algorithm in which the position of each whale is computed and displayed in a binary format. In addition, the proposed fitness function in this algorithm is considering the two main objectives, namely to minimize the number of active sensor nodes and maintaining low power consumption in selected sensor nodes, without losing the network coverage and connection characteristics, designed to enhance the network lifetime. Obviously, in this paper, the approach of minimizing the number of active sensor nodes will not always guarantee a reduction in energy consumption and a prolong network lifetime, because the nature and scenario of some wireless sensor networks is concerned with the full-time monitoring of the environment, regularly sending and collecting the data needed to be transmitted to the base station.

In a previous study [21], an algorithm was presented for choosing an energy-efficient cluster head in the clustered model of the wireless sensor network based on the whale optimization algorithm called (WOA-C). Accordingly, the proposed algorithm acted as the energy efficient in choosing the head of the clusters and based on the presented fitness function, remaining energy of the sensor node and the sum of the energies of the adjacent nodes were considered. Despite of the acceptable results in favor of network lifetime, energy efficiency and network performance, this algorithm faced the problem of funneling effect due to the use of a static sink.

Exact positioning sink nodes in wireless sensor networks play an important role in energy consumption in data exchange. In research [22], a multi-objective whale optimization algorithm (MOWOA) was presented to determine the minimum number of sink nodes that can cover the entire wireless sensor network. The proposed algorithm is a multi-objective version based on the whale optimization algorithm that uses a neighborhood topology to exchange information. The main purpose of MOWOA is to reduce the distance between the sink and the sensor nodes also tries to reduce the energy consumption of the sensor nodes, which are located further away from the sink node.

2.3. Protocols Used Based on the Trajectory Method

In another study [23], a data collection approach (MASP) was introduced for wireless sensor networks. This method improved the network efficiency as well as energy conservation by optimizing the allocation of sensor nodes; the proposed protocol was formulated as a general linear programming problem and then was solved using a genetic algorithm. A 2-step communication protocol was designed based on the partition of the area to run the MASP program. Also, the effect of various overlapping partitioning techniques was reviewed.

In a study [24] a protocol called MobiCluster was provided aimed at decreasing the network total costs and energy associated with the data access process while ensuring the energy balance between sensor nodes and longer network lifetime. MobiCluster as a protocol was used by the urban buses carrying a mobile sink, to receive the information from segregated (isolated) parts of the wireless sensor networks.

In another research [12], a cluster-based routing protocol was provided to uphold the data collection in wireless sensor networks through non-uniform distribution of the nodes and using a mobile sink in a fixed path. It was called as the Energy Efficient Data Collection Routing Protocol (EEDCRP). This approach included an energy efficient clustering and an energy aware routing technique. The clustering algorithm creates clusters unevenly based on the local density of the nodes and the distance to the mobile sink. Created clusters have low coverage, where there are many clusters or nodes close to the sink. Routing algorithm plans to each cluster head select another cluster head with a short distance to the sink path and the most remaining energy and cluster members, as the cluster head of the relay. In addition, since Euclidean distance measurement is not needed; the cost of the system is low, making the proposed protocol to have reasonable scalability.

In a study [25], the protocol (TSCR-M) was proposed for large-scale wireless sensor networks with multiple mobile sinks. In this method of trajectory scheduling, sensors use single-hop connections. The protocol has two main parts: sink parking position and multi-path scheduling. The authors used optimization algorithms to enhance the network lifetime. According to the network coverage, they use an improved form of the particle optimization algorithm in the part of determining the multiple mobile sinks parking positions. Mobile sinks regularly move and stop at the park positions for data collection. After park locating of the sinks, the second part of the protocol uses a genetic algorithm to determine the path of multiple mobile sinks.

In research [26], the authors proposed an evolutionary game-based model for moving the mobile sink in wireless sensor networks. In this model, a clustering algorithm divides the network into several units. The protocol calculates the average residual energy of clusters and the average energy consumption of clusters and designs the utility function. The mobile sink selects the cluster with the most value of the utility function as its new location. Consequently, the mobile sink moves near the cluster head that has the most residual energy and the shortest distance to the other cluster heads. With moving the sink to the new location, cluster members begin to collect data and transmit it to the corresponding cluster heads.

The authors in [27] used the Hilbert curve as an efficient way to collect data by the sink. In this method, the optimization process is performed at two levels: clustering and data collection. First, they divide the sensor field into a virtual cluster. In the second step, an integer linear program (ILP) determines the optimal virtual appointment points, and then the sink follows the Hilbert curve from one VRP to another. Sensor nodes send data in a single hop way.

Combining the strengths of the protocols presented in the reviewed papers [12] and [21], the present study was aimed to provide a protocol for collecting data in wireless sensor networks using the whale optimization algorithm.

3. Assumptions

To model and specify the scope of the proposed protocol, and describe the conditions governing the problem solving for a wireless sensor network, two categories of assumptions were considered:

3.1. Network Model

The network model was considered as a free space model. The transmitter and receiver were placed apart with the distance *d*. The amplifier circuit was also available in both *Tx* and *Rx*. The following features were assumed for the Wireless Sensor Network:

- All sensor nodes are accidentally deployed and fixed.
- All sensor nodes are homogeneous and have a unique identifier and limited energy.
- A mobile sink attached to the bus is used according to the predetermined trajectory.
- Each node collects information periodically and always sends the data.
- Sensor nodes are self-organized, and each node does not know its exact position and other sensor nodes.
- Each node has the ability to act as a cluster head and then has the ability to aggregate the data.

The wireless sensor network scenario considered for the simulation had all of the above features and limitations. The sensor nodes are capable to calculate the hop distance between the base station and the other nodes by comparing the received signal strength. Hence, there is no need for an additional system with the location services such as GPS. Also, a node becomes a cluster member of a cluster whose cluster head is in close proximity to the sensor node.

3.2. Energy Consumption Model

To maximize the lifetime of the sensor nodes, powered by a battery, it is essential to reduce the energy consumed in the measurement and monitoring process. The first step towards achieving this goal is to fully understand the energy sources used in the various communication layers of the wireless sensor networks. In addition, in a study [28], existing models were presented for the energy consumption in the wireless sensor network. Generally, energy models can be categorized into three categories according to the protocol stack structure of these networks: Physical layer, MAC layer, and Cross-layer.

Herein, the energy model used is based on the radio model employed in [8] and other similar papers, such as [9, 15], and [29]. In this particular model, the transmitter needs radio electronics and power amplifiers, and it also consumes the energy. Similarly, the receiver uses the energy to receive radio frequency. Additionally, sensor node power consumption is proportional to the size of the data and distance needed to be sent.

The energy consumption model is proportional to the distance d_{ij}^2 for relatively short distances, while d_{ij}^4 is used for long distances, d_{ij} is the distance between the sensor nodes i and j. Therefore, the propagation distance d is compared to the threshold d_0; when the propagation distance is less than d_0, the energy consumption of a node is proportional to d_{ij}^2, otherwise, it is proportional to d_{ij}^4.

The total amount of energy consumed by a sensor node for transmitting an l-bit data packet is shown in the equation (9).

$$Erx(l,d) = l.E_{elec} + l.E_{elec}\,\varepsilon_{fs}\,d^2 \qquad d \le d_0 \qquad (9)$$
$$= l.E_{elec} + l.E_{elec}\,\varepsilon_{fs}\,d^4 \qquad d > d_0$$

Also, the energy consumed by the receiver in case of the given data of l bits is represented by the equation (10):

$$E_{RX}(l) = l.E_{elec} \qquad (10)$$

In addition, equations (11) and (12) show the energy consumption for sensing and aggregating the data, respectively.

$$E_s = l \times E_{sens} \qquad (11)$$
$$E_a = l \times E_{aggr} \qquad (12)$$

In the above equations, E_{sens} depends on the electronic factors, and E_{aggr} relies on the aggregation algorithm applied in the network.

4. Proposed Protocol

The general schema of the proposed protocol is an extended form of the protocols proposed in [12] and [21], consisting of two phases: the initial loading phase and the data collection phase. Figure 3 shows how the proposed protocol works over time. The initial loading phase consists of three sink trips attached to the bus on a designated route in metropolitan areas, aimed to obtain the information about the location of the sensor nodes and the hop distance. This information will be used in the second phase. The data collection phase consists of the clustering stage and the sending and receiving of the data; the clustering stage consists of three steps. At this point, the sensor nodes transmit a series of control messages to their neighboring sensor nodes and create a network structure in a distributed manner. Selecting a cluster head is done using the whale optimization algorithm, and then for the selected cluster head, the allocation of the members is done taking into account the hop distance. In the third step of the clustering stage, cluster head-cluster head association takes place using multi-hop routing to decrease the energy consumption, aimed at finding a route for transferring information from distant sensor nodes to the mobile sink. Afterward, cluster members send sensed data to the corresponding cluster heads. Then, the cluster heads forward the data to the mobile sink by aggregating the received data (deleting the duplicate and redundant data) directly or using the cluster head-cluster head association. The details of each phase are presented in the following.

4.1. Initial Loading Phase

This phase and some types of control messages are as simple as the approach presented in the previous study [12]. In the initial loading phase, the mobile sink is required to carry out three trips along its predetermined route. The goal of such an action is getting the hop distance of the local sensor nodes to the mobile sink. For this purpose, some messages are sent and received to access the network information.

First Trip: When the mobile sink attached to a bus starts moving, it regularly broadcasts the Initial loading message, containing the mobile sink ID and hop distance (at first h=0). A sensor node within the boundary of the mobile sink communication receives the message packet and by modifying the contents of the message, it sends the modified message to its neighbors. If a sensor node receives more than one message and the received hop distances are different, the smallest one is chosen; otherwise, the hop distance received earlier than the other one is chosen. Meanwhile, the number of neighbors of each sensor node is specified by the number of received messages. At the end of the trip, each sensor node *i* knows its hop distance to the mobile sink and the number of neighbors (see Figure 3. for example). When the mobile sink is in the position *X*, the node *a* is located within the communication boundary of the mobile sink and the hop distance *a* is equal to 1. Since the sensor nodes, *b* and *c* are within range *a*, their hop distance is equal to 2. When the mobile sink moves to *Y*, the sensor node *b* is placed within the sink communication boundary and the hop distance changes from 2 to 1 (the hop distance decreases). The sensor node *c* never falls within the communication boundary of the mobile sink, so the hop distance 2 remains constant for it.

Second Trip: Each sensor node sends the response message to its parent sensor node containing its hop distance with the mobile sink. Finally, the lowest and highest hop distances of the sensor network nodes are obtained by the mobile sink.

Third trip: Mobile sink broadcasts the hop message, containing *h (min, max)*, to all sensor nodes in the sensing field. The sensor nodes receive the message and extract *h (min, max)* from it, and then send it to all the sensor nodes within their communication range. Finally, each sensor node knows its own *h (min, max)*.

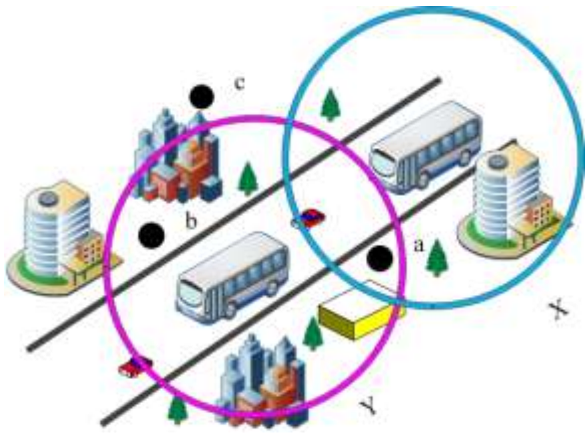


Fig. 2. Describing the hop distance.

4.2. Data Collection Phase

Regarding the data collection phase, there has been a fundamental shift towards similar and related studies, indicating that there are a number of data collection cycles. At the start of each cycle activity, they reorganize their sensor nodes by making new clusters. Subsequently, the cluster members send the sensed data to the corresponding cluster heads, and the cluster heads send the aggregated information to the mobile sink directly or through the other cluster heads. When the bus ends its trip successfully, one round of data collection is completed; therefore, each cycle comprises clustering and *r* data collecting rounds. Obviously, clustering results play an important role in collecting data, since they directly influence the energy consumption of the cluster head and its members. The parameter *r* also influences the energy consumption. Small *r* values mean that, the network needs to rebuild most clusters and generate a lot of control messages to exchange information between the sensor nodes. On the other hand, large amounts of *r* cause the network to work under a single cluster formation for a long period of time, leading to the phenomenon that some cluster heads are not capable to remain the cycle any more due to the lack of a plan for balancing the energy consumption resulting in the death of the sensor nodes. In the following, the main stages in the data collection phase will be described in detail.

4.2.1. Cluster Head Selection

In this study, the combination of the centralized clustering and energy-aware algorithm, called WOA-C was developed. The algorithm is designed to use a sensor node with a higher energy level as the cluster head, and clusters and sensor nodes are distributed unevenly in the entire topology of the wireless sensor network. The operation of the proposed algorithm is based on a central control algorithm which runs from the Base Station (BS). At the beginning of each setup stage, all sensor nodes send the information about their energy status and current location to the base station. Using this information, the base station calculates the average energy, and then it ensures that only the sensor nodes with a residual energy level greater than the average energy value are eligible to be selected as a cluster head. Then, the base station executes the WOA algorithm to determine the 5% of the total network sensor nodes as the best cluster heads according to the fitness function. It should be noted that, for choosing a cluster head in the first round, the proposed algorithm is used in a random and equal chance approach, such as LEACH, in which the cluster head selection process is random and there is an equal chance for all sensor nodes, because in the first round even after the initial loading phase, most sensor nodes have the same remained energy in relation to each other. The proposed WOA implementation takes place on the fixed sensor nodes randomly deployed in an urban area.At first, the search agent is randomly placed, and then the nearest sensor node clones to its position. The fitness function is calculated for all search agents and the best value is selected as the reference. As other search agents update their position pursuant to the best search agent, WOA parameters are also updated.

The cluster head selection is performed according to the fitness function, in which the remaining energy of the sensor node and the number of neighbors are the main characteristics. This function plays a major role in the hunting exploration component of the whale optimization algorithm. Equation 13 shows the fitness function used here, based on the previous study [21].

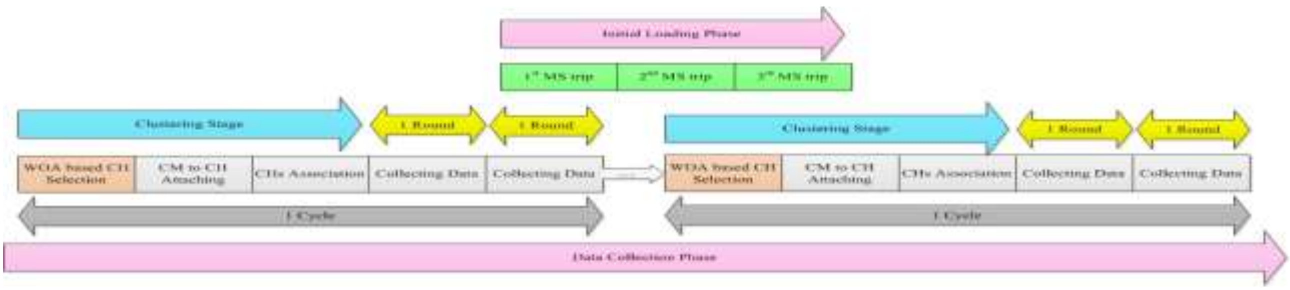


Fig. 3. The operation of the proposed protocol

$$f(CH_i) = p_1 |N(CH_i)| + p_2 \sum (CH_E) \qquad (13)$$

$$\begin{cases} p_1, p_2 \in [0,1] \\ N(CH_i) \rightarrow list\ of\ all\ neighbors\ around\ (CH_i) \\ CH_E \rightarrow the\ neighbor\ nodes'\ residual\ energy\ level \end{cases}$$

The best solution is to have the highest value of the fitness function; in this case, the amount of remaining energy and the number of neighboring sensor nodes are sufficient for selecting the cluster head. When the base station detects an optimal sequence of the clusters, the process of joining the members of the sensor nodes to the cluster heads and forming a cluster is performed, as illustrated by the flowcharts in Fig. 6. The cluster head is selected as the control center in its neighborhood location in order to communicate with the mobile sink and organize the transmission of information to it. The flowchart of the proposed algorithm is shown in Figure 4. Additionally, TDMA scheduling is used to prevent the data collision among the cluster members. This creates a sleep-wake cycle where cluster members just need to be awake in their time slot specified by the TDMA scheduler, and conserve the energy throughout their sleep cycles. Low power mode and energy saving are the characteristics of the sleep cycle. After receiving data from all cluster members at the end of each round, the cluster head transmits them to the base station by aggregating all the data. The CDMA method, similar to the approach proposed in a previous study [30], is also used to prevent the collisions during data transfer from cluster heads to the base station.

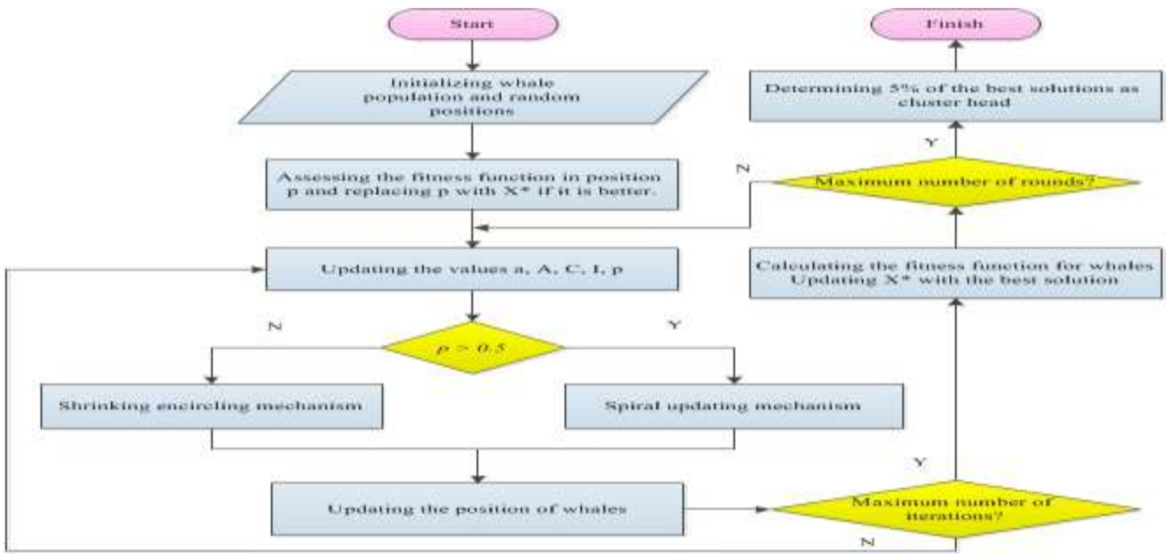


Fig. 4. Flowchart of cluster head selection algorithm

4.2.2. Attachment of the Cluster Members to the Cluster Heads

When the first step is completed (cluster head selection), cluster members must be attached to the cluster head to form a cluster. At this point, using a communication channel, the cluster head and members are intermittently busy sending or listening to the communication channel. Initially, the cluster head broadcasts the offer message in its communication cover range. When a sensor node which is not a cluster head and does not have a cluster head receives the offer message, it sends the request message to the cluster head for cluster membership. Then, the cluster head sends the confirmation message to all the cluster membership messages, acknowledging their membership.

If the sensor node does not receive the offer message from any cluster head, it broadcasts the request message by increasing its communication range (up to twice) so that it can be placed as a member in a cluster. At the end of this step, each cluster member knows the corresponding cluster head.

To support the process of joining members into clusters, several timers are used, such as the model presented in the previous study [12]. The members listen to the offer message until T_{offer}. During this time, the cluster heads are also listening to the channel for the request message until T_{asso}. After T_{offer}, it does not matter if a member node receives the offer message or not, because the member sensor node sends the request message and listens to the communication channel until it receives the confirmation message up to $T_{confirm}$. The details related to this process are presented in Fig. 5.

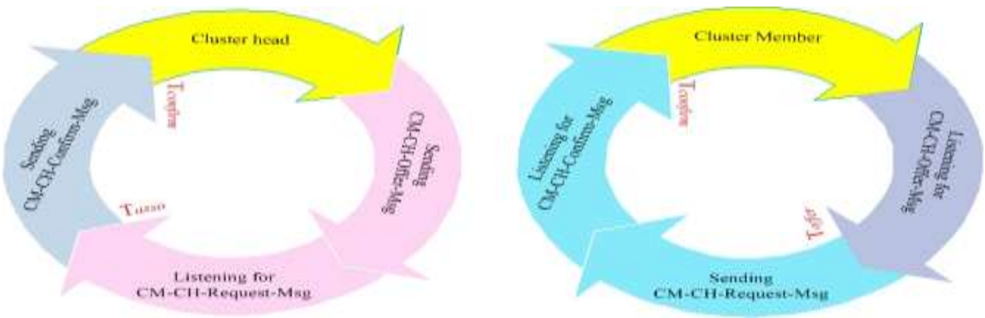


Fig. 5. Attaching members to the corresponding cluster head in accordance with the timer.

The intra-cluster data is collected using TDMA scheduling. The cluster head adjusts the TDMA scheduling based on the number of cluster members and transfers it to its members. When the TDMA scheduler is recognized by all members of the cluster, the member attachment stage is completed to the cluster head. Figure 6 illustrates the flowchart related to the process of joining cluster members to the corresponding cluster head.

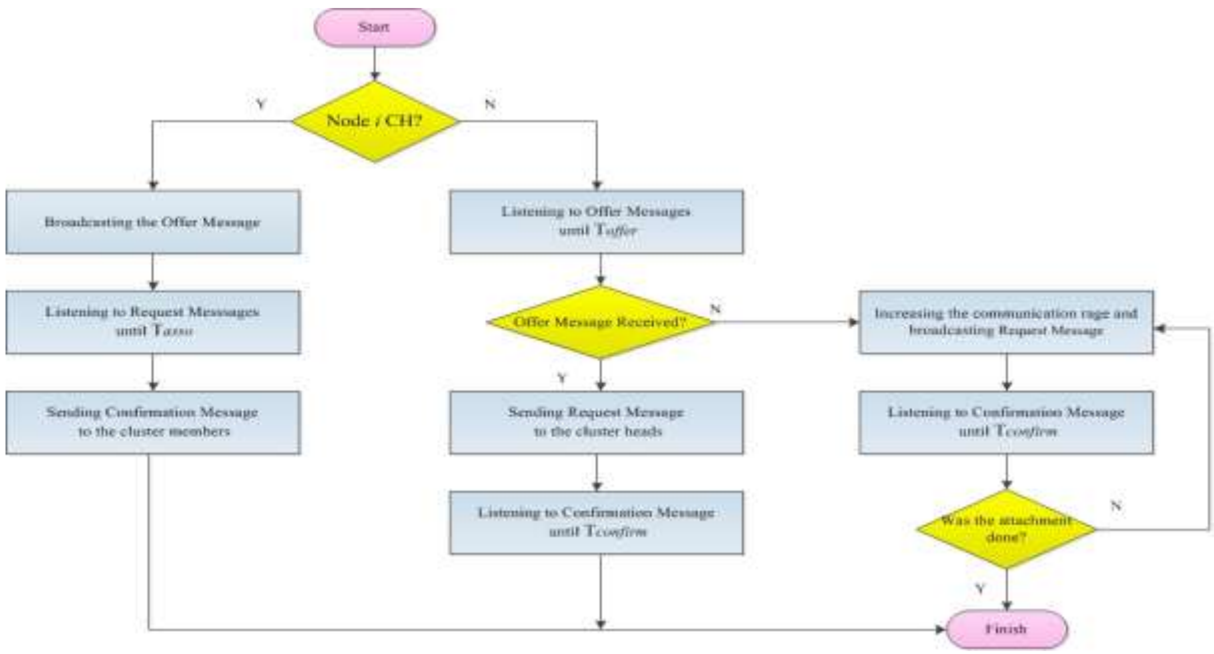


Fig. 6. Flowchart of attachment of member sensor nodes to the corresponding cluster head.

4.2.3. Cluster Heads Association

The next step in the protocol is concerned with the collaboration of the cluster heads with each other. The purpose of the interaction among cluster heads is finding a path for each cluster head to transfer its data to the mobile sink. If a cluster head is not capable to directly send its data to the mobile sink, it needs to cooperate with other cluster heads. For this purpose, a cluster head whose hop distance to the mobile sink is greater than 1 sends the request message to the other cluster heads to find a cluster head as a next hop.

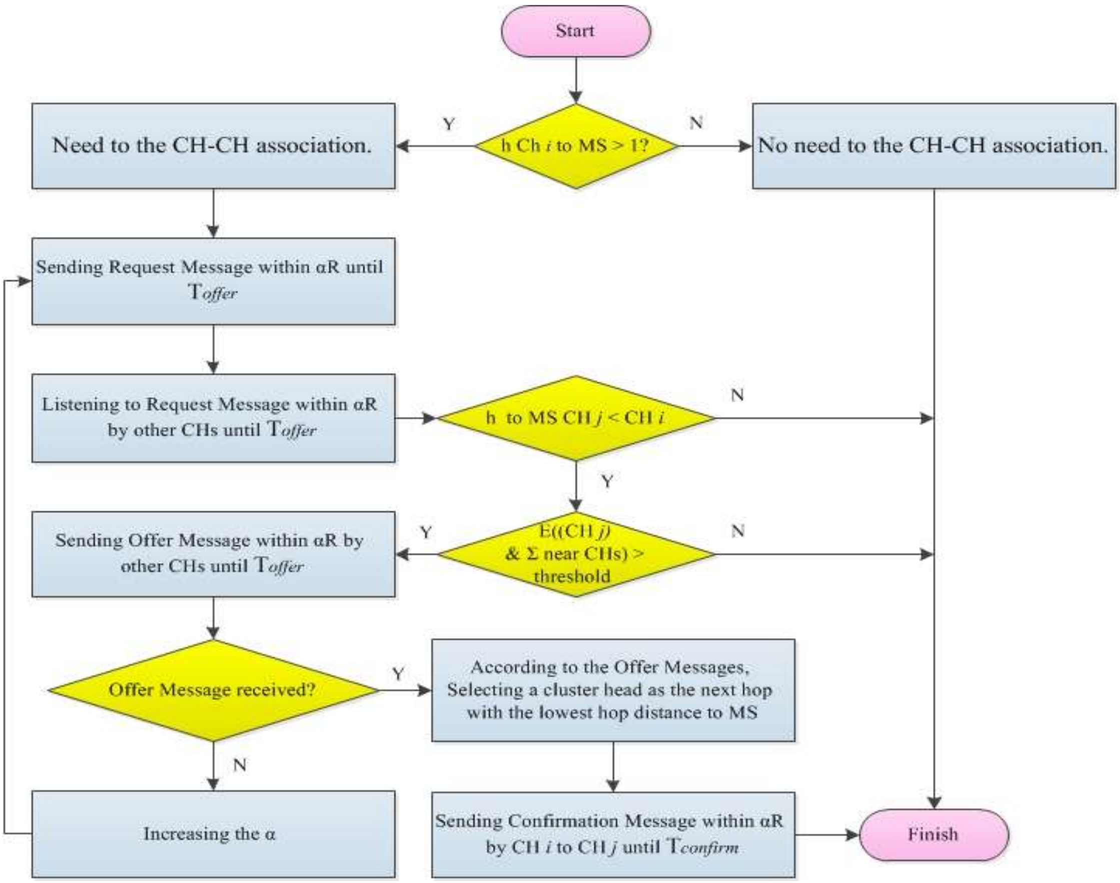


Fig. 7. Flowchart of the interaction among cluster heads.

When other cluster heads receive such a message if their hop distance from the mobile sink is less than that of the sender cluster head, and also their remaining energy and the total energy of their neighbors are higher than the threshold, the offer message is given in response to the message received from the applicant cluster head. Here, there are two modes: In the first mode, the cluster head receives the messages for the association and due to the lower hop distance and the priority of the arrival.

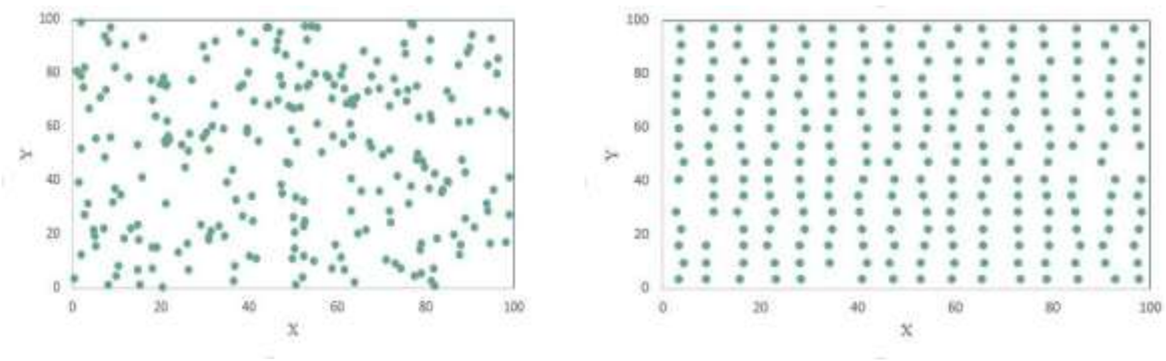
time for the offer messages, selects one of the cluster heads as the next hop. The second mode occurs when the cluster head has not received any messages from other cluster heads. Because, following the loss of neighbor cluster heads, the range of communication increases, and the cluster head must increase its communication range and restart requesting again. Therefore, cluster heads with fewer members have a very active role in relaying information. The flowchart of this step is shown in Fig. 7. Sending the data from the cluster head to the mobile sink begins with the receipt of the data request message from the mobile sink.

Wireless sensor networks are facing problems such as accurate cluster head selection, efficient energy consumption model, continuous connection to the sink, network coherence, and coordination. For this reason, the proposed protocol uses a meticulous solution to selecting the cluster heads and ensures that it consumes less energy and delays the first sensor node die. Incorrect selection of cluster heads has many negative consequences. For example, it causes incorrect communication links, increases traffic and energy consumption in the network. If this process continues, it will disrupt the network load balance over time. So if the cluster heads are selected correctly can somewhat delay the first sensor node die.

The overhead caused by the implementation of the whale optimization algorithm, which has an iterative approach, as well as the message exchanges between the sensor nodes and the sink, are factors that affect the complexity of the proposed algorithm. If we consider the total number of sensor nodes as *n*, the complexity of the proposed algorithm in the initial loading phase is related to the number of exchanged Initial Loading Msgs, Response Msgs, and Hop-Msgs. Therefore, the complexity of the messages in the three trips is equal to $n + n + n = O(n)$.

Data collection phase, which consists of three parts; In the cluster head selection stage, the complexity of the proposed algorithm is related to the overhead of the whale optimization algorithm, the number of iterations, and the number of times it is used (*k*). In attaching members to the corresponding cluster head stage, if we consider the number of cluster heads as *m*, then *m* CM-CH-Offer-Msgs will send. Member nodes transmit *n-m* CM-CH-Request-Msgs. Also, Cluster head nodes send *n-m* CM-CH-Confirm-Msgs to confirm requests. In the cluster heads association stage, cluster heads exchange communication messages such as offer, request, and confirm. In general, the complexity of the proposed algorithm is equal to:

$$\begin{aligned} & n+n+n+kC_{WOA}+m+2(n-m)+3m \\ & = 5n+2m+kC_{WOA} = O(n)+kC_{WOA} \end{aligned}$$



(a) (b)

Fig. 8. Wireless sensor network topology. (a) Uniform distribution of sensor nodes (b) Random distribution of sensor nodes.

Since the core of the proposed protocol has an iterative but precise approach, not recommended for use on small networks. Controlling and organizing networks with many sensor nodes leads to solving the NP-Hard problem. In this case, the proposed protocol will show its effective efficiency with solving the problem more quickly.

5. Performance Evaluation

The performance of the proposed protocol was simulated and evaluated using two scenarios. In the first scenario, the nodes of the sensor network are uniformly deployed in the sensing field (Fig. 8(a)); in the second scenario, the distribution of the nodes in the wireless sensor network is done randomly and unevenly (Fig. 8(b)). In both scenarios, the dimensions of the simulation environment are 100×100. The

total number of sensor nodes is equal to 200-250-300. We considered 500 iterations for the whale optimization algorithm.

The simulation of the proposed protocol was done in MATLAB2016b software. Since, selecting the cluster head was done using the

whale optimization algorithm and the proposed method had no definite and unique solution, the

proposed protocol must have at least 100 consecutive and independent executions. Since, regarding the convergence of the results at an acceptable level a close number of simulation repetitions were achieved in this study, thus the averaging of this number of consecutive and independent implementations was performed and reported. Based on the equations in Section 2-3, the distance is measured for all sensor nodes that send and receive data. Information about sensor features is reset after each round. So the sensor nodes can become head or member of the cluster again.

The warm-up time in computers and systems is the amount of time a device or system runs from the cold start to the working temperature. The warm-up time is usually measured in seconds or minutes, and according to the results obtained, this time was not such enough to have a significant effect on the results. The simulation parameters of the proposed protocol are presented in Table 1. As observed, the results of consecutive and independent simulations were almost close to each other and did not show any outlier points.

Table 1
Simulation parameters.

Parameter	Value
Target area	100×100 m^2
Number of Nodes	200 - 250 - 300
Initial Energy of Node	1 J
Transmitter/Receiver Electronics - E_{elec}	50 nJ/bit
Transmit amplifier (free space) - E_{fs}	10 $pj/bit/m^2$
Transmit amplifier (multipath) - E_{mp}	0.0013 $pj/bit/m4$
Data Aggregation Energy Cost	5 nJ/bit
E_{sens}	1 nJ/bit
Packet Size	4000 $bits$
Control Message Size	400 $bits$
d_0	87 m
Number of Agents	5% of nodes
Number of Iterations	500

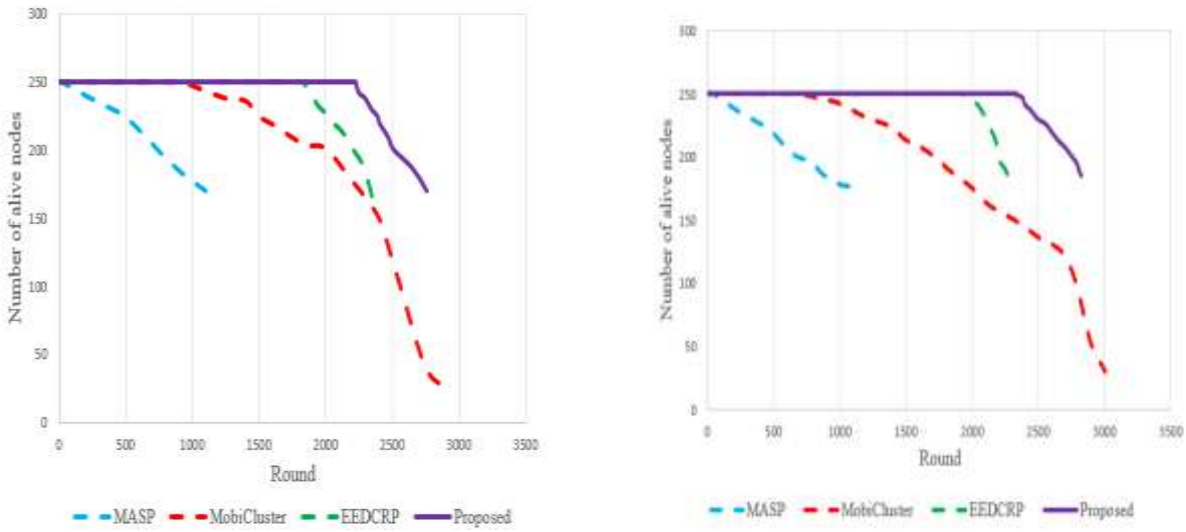
5.1. Comparison with the Related Studies

Considering the advantage of using a mobile sink to collect the data in a wireless sensor network, as mentioned in a previous study [12] for a fair evaluation, the proposed protocol was compared with those discussed a particular pathway for a mobile sink. Table 2 presents the characteristics of the related approaches to which the proposed protocol was compared. In a study [24], a protocol called the MobiCluster was introduced to obtain the communication coverage between the cluster head and the mobile sink using the Euclidean distance. In this case, the sensor nodes must be able to extract the information based on the intensity of the received signal. This causes the sensor nodes and the sink to be within a communication boundary, implying that a distance of 100 meters should be considered as the communication range of the sink in order to provide a broad coverage. In another research [23], the MASP protocol was introduced. In all three protocols, including MASP, EEDCRP and our proposed protocol, the hop distance was used instead of the Euclidean distance. The network structure was clustered in the MobiCluster, EEDCRP and our proposed protocol. In contrast, the network structure presented in the MASP protocol was reported to be flat. Our proposed protocol was an improved form of the EEDCRP approach.

5.1.1. Comparison of the Network Lifetime

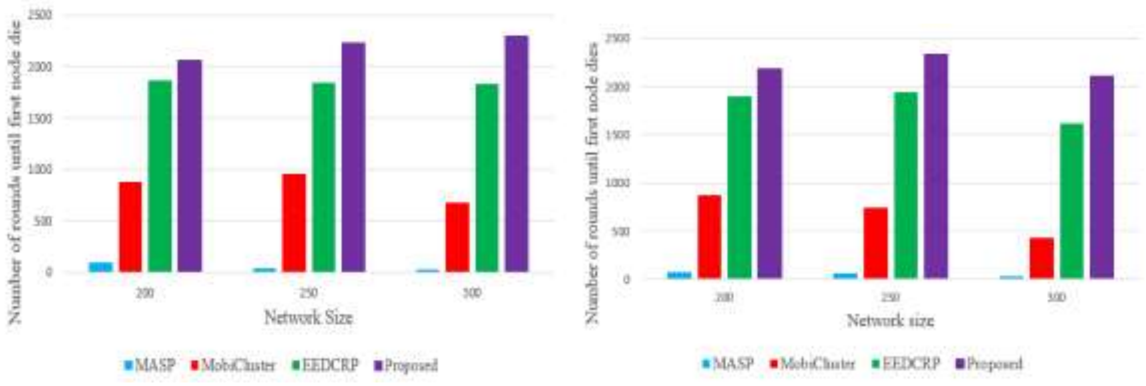
In this section, the performance of the proposed protocol is evaluated regarding the network lifetime. In Fig. 9, life cycle graph for the sensor nodes and the results of comparison between our approach and other protocols are shown. In both scenarios (a) and (b), regardless of the distribution of the sensor nodes (uniform or non-uniform) the proposed protocol with the same amount of initial energy considered for both scenarios had the longest network lifetime ensuring the long term coverage of the desired areas in the sensor network. Given the flat structure of the MASP approach, the distribution and deployment of sensor nodes do not have much effect on its performance, and due to the occurrence of the funneling effect, it acts similarly in both scenarios. As a result, a good performance was not observed in this regard. However, the MobiCluster approach has a different performance in both scenarios, and according to the simulation results, when the distribution of sensor nodes is uniform, contrary to other approaches; a better performance for this approach was observed in terms of FND. Because of the similarity between the EEDCRP and the proposed protocol, both protocols showed better performance in both scenarios than other approaches in terms of FND; but it was found that, in the proposed protocol due to the optimal selection of the cluster heads, the energy consumption of the alive and active sensor nodes reached a balance and the number of alive sensor nodes in our proposed protocol was more than the EEDCRP. Possibly, the reason for a large number of rounds in the MobiCluster approach lies in Table 2 (broad communication range). But over time, the density of the sensor nodes reduces in this approach. After at least 100 consecutive and independent executions, the average of results is calculated and rounded. In 100 consecutive and independent experiments, a flag reports FND in which round it occurred. Regarding the results obtained in both scenarios of uniform and non-uniform (random) distribution of sensor nodes,

the superiority of the proposed protocol was confirmed, due to the optimal selection of the cluster heads and its effect on optimal sending/receiving messages among sensor nodes in the network.



(a) (b)

Fig. 9. Number of alive sensor nodes in each scenario. (a) Uniform distribution of sensor nodes (b) Random distribution of sensor nodes.



(a) (b)

Fig. 10. Network sizes and FND in them. (a) Uniform distribution of sensor nodes (b) Random distribution of sensor nodes.

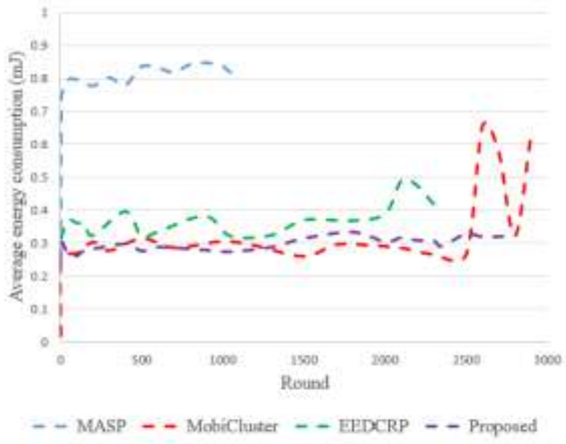
5.1.2. Comparison of the Network Energy Consumption

In this section, the performance of the proposed protocol is examined regarding energy consumption in the network. As mentioned earlier, due to the implementation of the whale optimization algorithm in the sink, the computational costs do not affect the energy consumption of the sensor nodes. The results of comparison between our proposed protocol and other protocols are shown in Figure 11. In this section, the performance of the proposed protocol is examined regarding energy consumption in the network.

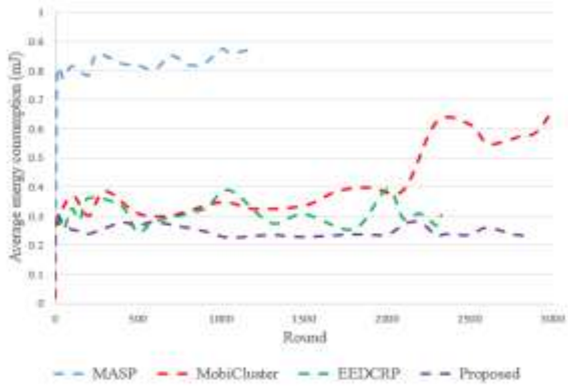
Table 2
The characteristics of the approaches

Approach	MASP	MobiCluster	EEDCRP	Proposed
Network structure	Flat	Clustered	Clustered	Clustered
Measuring distance	No	Yes	No	No
MS communication range	30 m	100 m	30 m	30 m
Node communication range	30 m	60 m	30 m	30 m

As mentioned earlier, due to the implementation of the whale optimization algorithm in the sink, the computational costs do not affect the energy consumption of the sensor nodes. The results of comparison between our proposed protocol and other protocols are shown in Figure 11.



(a)



(b)

Fig. 11. Average energy consumption by alive nodes. (a) Uniform distribution of sensor nodes (b) Random distribution of sensor nodes

According to the energy consumption graph presented in Fig. 11, the information about the energy consumption in the proposed protocol phases can be obtained. The values on the zero round represent the average energy consumption at the initial loading stage, while the next values are related to the data collection phase. Like the EEDCRP approach, for the initial loading phase, our proposed protocol required three mobile sink trips on a predetermined urban road as well as send/receive control messages. Obviously, the proposed protocol and the EEDCRP approach had the same level of energy consumption in this phase and consumed more energy than the MASP and MobiCluster protocols. In the data collection phase, contrary to the EEDCRP approach, when the energy of some sensor nodes ends, the average energy consumption increases for data transmission with the increase in the average transmission distance. This problem does not have a significant effect on the proposed protocol due to the optimal selection of the cluster heads.

The average of every 100 consecutive and independent executions for each round is reported after rounding.

Given the results obtained in both scenarios of uniform and non-uniform (random) distribution of sensor nodes for the average energy consumption in the network, increasing the search space and the number of sensor nodes transformed the problem into an NP-hard problem, requiring an optimization approach to solve the problem. The superiority of the proposed protocol, using the whale optimization algorithm was confirmed again over other protocols. Also, the use of hop distance instead of the Euclidean distance reduced the energy consumption. Table 3 gives an overview with respect to the advantages and disadvantages of the mentioned protocols.

Table 3
Advantages and disadvantages of the compared protocols.

Protocol	Advantages	Disadvantages
MASP	Using the shortest path to send/receive data. Low delay.	Complexity intensification by using Genetic Algorithm. High power consumption.
MobiCluster	High throughput. Maximum connection and coverage.	Relatively high energy consumption. Medium network lifetime.
EEDCRP	Energy efficient. Reducing computational cost.	Overhead arising from control messages.
Proposed	Energy efficiency in line with scalability. Selecting the optimal cluster head. Reducing computational cost.	Not suitable for small sized networks.

6. Conclusion

In wireless sensor networks, a routing protocol is required when a sensor is not capable to send its data packet directly to the destination sensor, and there is a need for interaction and collaboration of other sensors to send the packet. One of the basic objectives in designing wireless sensor networks is increasing network lifetime during data transmission and preventing the failure of connections using power management methods. Routing protocols in such networks are influenced by a multitude of the challenging factors. Since these networks are different from other networks, such as Ad-hoc or traditional networks, they must have their own communication protocols. Many protocols have been proposed so far to improve the energy efficiency.

In this study, in order to eliminate the limitations of the previous studies, an energy efficient routing protocol was proposed using the whale optimization algorithm with the ability to select the appropriate cluster heads in each cycle to maximize energy savings. Comparisons and simulations showed that the proposed protocol had an extraordinary performance in terms of the assessment standards for the network lifetime. When the search space got larger, a better performance was observed due to the use of the whale optimization algorithm in the proposed protocol, because in general, this problem has no definitive solution, and no precise method has been suggested so far to solve it. Compared to other protocols, the energy consumption significantly reduced in the proposed protocol due to its clustering structure and the use of optimized and multi-hop routing. The proposed protocol also acknowledged the advantage of using the clustering technique over other common topologies as an effective approach to reduce the energy consumption and data transfer. To date, each of the protocols mentioned in this paper is designed for specific purposes and applications and has its own strengths and weaknesses compared to other protocols. Hence, the use of each of them depends on the problem conditions, the environment to be monitored, as well as the demands of the network administrators.

Accordingly, it is not possible to find and deliver a protocol with strong points in all aspects and without any shortcomings.

For the future studies, it is recommended to focus on developing the proposed protocol to provide a mechanism for reducing the sending/receiving control messages in order to prevent the network congestion and reduce the time of the initial loading phase.

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