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A meta-heuristic clustering method to reduce energy consumption in Internet of Things

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Abstract

The Internet of Things (IoT) is an emerging phenomenon in the field of communication, in which smart objects communicate with each other and respond to user requests. The IoT provides an integrated framework providing interoperability across various platforms. One of the most essential and necessary components of IoT is wireless sensor networks. Sensor networks play a vital role in the lowest level of IoT. Sensors in sensor networks use batteries which are not replaceable, and hence, energy consumption becomes of great importance. For this reason, many algorithms have been recently proposed to reduce energy consumption. In this paper, a meta-heuristic method called whale optimization algorithm(WOA) is used to clustering and select the optimal cluster head in the network. Factors such as residual energy, shorter distance, and collision reduction have been considered to determine the optimal cluster head. To prove the optimal performance of the proposed method, it is simulated and compared with three other methods in the same conditions. It outperforms the other methods in terms of energy consumption and the number of dead nodes.

Keywords: Internet of Things, clustering, routing, energy consumption, whale optimization algorithm.
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1. Introduction

The Internet of Things is a new concept in the world of information and communication technology in which any creature (human, animal or object) is able to send and receive data through communication

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networks, such as the Internet or intranet. The IoT network is a self-configured network consisting of a set of nodes that are inter-connected by various connections [1, 2]. One of the features of IoT networks is the lack of any infrastructure or central management for operations. Traffic control is one of the most important and vital issues in IoT networks.

The Internet is a global network that connects all users, but the structure of this network is changing. We all use laptops, tablets and smart phones to communicate with our friends. Most of the information between us and our friends is exchanged through the servers that are responsible for opening the web site and the email software. Finally, it can be said that the Internet is made up of users, client devices and servers, but a new member is being added to this. This new member is not a user and is referred to as (Things) , this word is derived from the phrase (of the Things). A thing may be addressed to any device that has a sensor to exchange information. Examples of such sensors include temperature sensors, traffic sensors, and energy sensors. For example, a temperature sensor can be placed in a thermostat, a sensor to measure the amount of electricity consumed in homes, and a traffic sensor in traffic signals. All of these sensors send information to the destination device so that these devices can make decisions based on this information. In the near future, much of our work and information will be exchanged via the Internet and between different people by smart devices. Smart devices such as smart phones, the Internet, email and social networks have made our personal affairs and work done differently. It can be clearly said that the Internet of Things will have a great impact on the lives of all users[3, 4].

Data transfer is important for communication. In human-to-human or human-to-machine or machine-to-machine interactions, time plays a very important role in transmitting data, so that a message will reach its destination within a permitted time period. Therefore, in such a way, the data must use the minimum or the shortest path to reach the destination. Routing is the process of creating and maintaining a path between mobile states in wireless networks. Routing on IoT networks is an important and fundamental issue. Developing routing algorithms in IoT networks has become a major challenge for researchers. Numerous studies have been conducted on energy saving issues in wireless sensor networks. Clustering-based techniques are one way to reduce energy consumption in wireless sensor networks. In this technique, nodes are grouped into a cluster. A cluster head is selected in each cluster[5, 6].

At the lowest level of the Internet of Things, wireless sensor networks play an important role. Because it is not possible to replace the sensor batteries in the WSN, Energy consumption management is an important issue in this type of network. Most energy is consumed during data transfer. Also, the longer the transmission distance, the more energy is consumed. Therefore, proper and optimal routing can reduce energy consumption and thus increase the lifetme of the network. So far, much research has been done into data transmission routing in wireless sensor networks. Delivering data from the origin to the final destination is usually done in two ways. In the first method, the source sensor transmits its data to the destination (BS) with a few hops and through a number of sensor data interfaces. In the second method, the sensor network is clustered, and a cluster-head sensor is specified in each cluster. Non-cluster-head sensors first transmit their data to the cluster-head sensor, and the cluster-head transmit the data to the BS. Given that the position of the sensors in the network is not already known, the presence of an appropriate routing protocol for transmitting information is of great interest. The mentioned protocol must perform routing operations independently. The most important parameter in designing each routing protocol for wireless sensor networks is the amount of power consumption and the network lifetime. Routing protocols that save energy will increase network lifetime. The cluster head communicates with other cluster heads to transfer the packet. This ultimately saves the node energy by communicating through the cluster head. A non-cluster head node can only monitor its surroundings and send data to its cluster head node. Because an non-cluster head node cannot send data directly to the base station, the data transmission distance is short[7, 8].

In this paper, we use the whale meta-heuristic optimization algorithm for clustering and routing in the Internet of Things. First, Whale optimization algorithm(WOA) is used for clustering and selection of optimal cluster heads, and then again, the WOA metaheuristic algorithm with a new fitness function is used to send data from cluster heads to Base station. In the proposed method, service quality parameters, such as energy consumption and network life, are examined separately. To improve scalability, sensor nodes are first clustered and then the best cluster heads are selected. The cluster heads first aggregate the received data and then use a multi-hop optimization routing algorithm by WOA to send the data to the base station. The results of network performance analysis show that the proposed method can improve network performance in terms of energy consumption and network life.

In the continuation of this article, in the second part, the past methods are given. In the third section, we explain the whale metaheuristic algorithm. In the following and in the fourth section, we have explained the proposed method. Then, in Chapter 5, we simulate the proposed method and compare it with other methods. Finally, Chapter 6 provides conclusions and suggestions for future work.

2. Related Studies

A energy-efficient routing protocol was proposed in [9] to improve network performance in IoT using WSN. It consists of three main parts. The first part includes a new distributed cluster formation technique that enables a local node to organize itself. In the second part, a new set of algorithms are used for cluster adaptation and cluster head rotation (CH). A new mechanism is used in the third part to reduce energy consumption for telecommunications. In particular, the residual energy of the nodes is considered to calculate the center position. This protocol is also suitable for networks that require a long lifetime.

In [10], a routing protocol called Balanced Energy Adaptive Routing (BEAR) was proposed. It worked in three stages including preparation, tree construction, and data transfer stage. At preparation stage, all nodes shared information about their energy levels and their residual location, and at tree construction stage, the algorithm utilized location information. Particularly, BEAR selects nodes with residual energy relatively higher than the aver-age residual energy of the network. This can balance the energy consumption between surrogate and facilitator nodes.

In [11], a simple routing method called direct transmission was proposed. In this method, when a source node generates a message, it stores it into its buffer and carries it until there is a collision with a destination node so that it can deliver the message to this node. In this method, only one version of the message is generated, which results in the lowest data transmission in message delivery, and, thereby, a minimum overload on the network. The message delivery may be delayed a lot since there is no limitation on delivery delays.

In 2016, researchers used content-centric routing technology to solve the traffic congestion problem in the central network [12]. By routing the data connected to intermediate relay nodes for processing, data collection can be achieved at a higher rate; hence, the network traffic is effectively reduced. As a result, a significant decrease in latency can be achieved. In addition, the transfer of duplicate data after data collection can be eliminated, which largely reduces energy consumption on wireless communications and, consequently, saves the battery lifetime. In this paper, two methods have been proposed and simulated to implement this technology. The first method is content-centric routing (CCR), and the second integrates the first method with the IETF RPL protocol, both of which are implemented on the Contiki platform using the TelosB. The simulation results show the superiority of the first method in terms of low network latency, high energy efficiency, and reliability.

Another efficient way to reduce energy consumption is the Energy-Efficient Content-Based Routing (EECBR) protocol for the Internet of Things. This method was proposed by Chelloug [13]. Internet convergence, sensor net-works, and Radio Frequency Identification (RFID) systems have led to the concept of IoT, which is capable of establishing daily communications between objects and making them intelligent through sensitivity, reasoning, and collaboration with other objects. In addition, RFID technology [14] can facilitate the tracking of an object and assigning a unique identifier. Internet of Things has the potential of a wide range of applications related to health care, environment, transportation, cities, etc. In addition, mediation tools are essential components of IoT architecture. They manage heterogeneity across IoT devices and establish a common framework for communication. Recently, there has been an interest in focusing on developing Publish/Subscribe Middleware (PSM) systems for the IoT to allow incompatible communications between IoT devices. The scope of this article is to study routing protocols for publishing and/or sharing designs that contain content- and context-based routing[13].

In the article [15], a routing algorithm is proposed to reduce the uniform energy across all nodes and extend the lifetime of the wireless sensor network. The proposed algorithm divides the area of interest into virtual regions, each having some distinct cluster head nodes. Throughout the process, a node can be part of a cluster or may remain an independent entity. A non-cluster member transmits its data using the Intelligent Routing Protocol (IRP) through which it transmits its data to the next-hop node based on the exchange between its residual energy and that of its neighbor. It also contains the energy required to transmit packets to its neighbor. If some members of the cluster are selected as the next hop in the transmission channel, it rejects the IRP and moves the packets to the cluster head.

A multipurpose routing protocol for wireless sensor networks based on network clustering is proposed in the article [16]. A multidimensional routing protocol based on network clustering is also proposed to improve network performance in the wireless sensor network.

Heinzelman and colleagues [17] introduced an Application-Specific Protocol (ASP) for wireless microsensor networks. They created a Low-Energy Adaptive Clustering Hierarchy (LEACH). LEACH incorporates a distributed cluster formation technique that allows self-organizing a large number of nodes, using algorithms for cluster adaptation, and rotating cluster head positions to uniformly load energy across all nodes and use possible techniques to process the distributed signal to save energy for establishing communication.

Metaheuristic algorithms have been employed for routing in several recently published approaches. The whale optimization algorithm has been recently used for the routing problem. Ahmed employed a discrete version of the whale optimization algorithm for routing [18]. He calculated the position of each whale and displayed it in binary. In [19], a clustering method is presented using the whale algorithm based on the SDN concept. It divides the network into virtual zones by the SDN controller. The number of headers is determined by the density of the sensors in each virtual area. Finally, the optimal cluster heads for each region are selected by the whale algorithm.

In many articles, researchers have used genetic algorithms to route networks [20, 21, 22, 23]. In [20], GA is used for clustering, and then the data is sent to BS by PSO algorithm. Also, in[21], the LEACH algorithm is optimized by the GA algorithm, and a method called G-LEACH for clustering is introduced, which has a much better performance than LEACH.

In the above reviewed articles, one of the main problems was the non-simultaneous implementation of some benchmarks such as energy level, collision reduction, distance between cluster head node and destination, and neighbor energy in clustering. In the present study however, there has been an attempt to simultaneously apply these benchmarks in clustering and to use the whale optimization model for routing and transmitting information.

3. Whale Optimization Algorithm (WOA)

Since WOA is theoretically a metaheuristic algorithm, it can be used for optimization issues from a theoretical perspective. This is because it has both extraction and exploration capabilities. It helps the other agents take advantage of the best records in the domain. By adaptive variation of the search vector A, the WOA clustering algorithm can gently move among exploration and exploitation. More specifically, reducing A can lead to exploration for certain iterations ($|A| >= 1$) while others are assigned to exploitation ($|A| < 1$) [24]. It is worthy to mention that the WOA only encompasses two adaptive internal parameters (A & C).

3.1. Encircling Prey

Whales can detect the place of their preys and catch them. The optimal position in the search area is not recognized by analogy. The WOA method therefore presumes the best candidate solution is the target prey or a nearly optimum condition. This phenomenon is presented in Eq. (3.1) and (3.2):

$$D = C.X^*(t) - X(t) \tag{3.1}$$

$$X(t-1) = X^*(t) - AD \tag{3.2}$$

where t shows the current iteration,A and C denote the coefficient vectors, and X stands for the position vector. The position vector of the best solution is indicated by X^*. It should be noted that X^* must be updated if there is a better solution. The coefficient vectors A and C can be computed as follows:

$$A = 2a.r - a \tag{3.3}$$

$$C = 2.r \tag{3.4}$$

where a linearly decreases from 2 to 0 over the course of iterations (in both exploration and extraction phases), and r is a random vector with values ranging from 0 to 1.

3.2. Bubble-Net Attacking Method (Extraction Phase)

The bubble-net behavior of humpback whales can be mathematically modeled by: The shrinking encircling mechanism: This action is achieved by reducing the value of a in Eq. (3.3). It must be noted that the variation range of A decreases by a. More specifically, A is a random number in [-a, +a], and a ranges from 2 to 0 over the course of iterations. By selecting random numbers for A in [-1,1], the new position of a search agent can be determined everywhere among the original positions of the agent and the positions of the best current agent. Note that the humpback whales swim along a spiral-shaped path and within a shrinking circle at the same time. A probability of 50% was assumed for the whale to select either the shrinking encircling mechanism or the spiral model in order to update the whale position over the course of optimization. The mathematical model is as follows:

$$X(t+1) = \begin{cases} \rightarrow X^*(t) - AD & ifp < 0.5 \\ D.e^{(bl)}.cos(2\pi l) + X^*(t) & ifp \geq 0.5 \end{cases} \tag{3.5}$$

In this equation, P is a random number in [0, 1], D indicates the distance between the ith whale and the prey (the best solution so far), b is a constant to define the spiral logarithmic form, and l is a random number in [1, 1]. The various steps of the whale optimization algorithm are shown in Figure 1[24].

```
Initialize the whales population Xi (i = 1, 2, ..., n)
Calculate the fitness of each search agent
X*=the best search agent
while (t < maximum number of iterations)
    for each search agent
    Update a, A, C, l, and p
        if1 (p<0.5)
            if2 (|A| < 1)
                Update the position of the current search agent by the Eq. (2.1)
            else if2 (|A| ≥ 1)
                Select a random search agent (Xrand)
                Update the position of the current search agent by the Eq. (2.8)
            end if2
        else if1 (p≥0.5)
                Update the position of the current search by the Eq. (2.5)
        end if1
    end for
    Check if any search agent goes beyond the search space and amend it
    Calculate the fitness of each search agent
    Update X* if there is a better solution
    t=t+1
end while
return X*
```

Figure 1: Whale optimization algorithm

4. The Proposed Method

Clustering is one of the most effective ways to reduce the energy consumption of sensors in the Internet of Things and increase their lifespan. In this paper, a new clustering and routing method using the whale meta-heuristic algorithm is presented. This method is performed in the lower layer of the Internet of Things and on the sensor network in this layer. The proposed method is done to reduce energy consumption in two phases. First, the initial clustering is done based on several main factors. Then, in each cluster, the optimal cluster heads are selected by the whale algorithm. The nodes then send their data to the corresponding cluster heads. After receiving the data, cluster head first aggregates them. It then sends the aggregated data in several hops to the base station. To select the optimal route from the cluster head to the base station, we use the whale optimization algorithm again. The figure 2 shows the main steps of the proposed method.

In the following, we describe the different steps of the proposed algorithm.

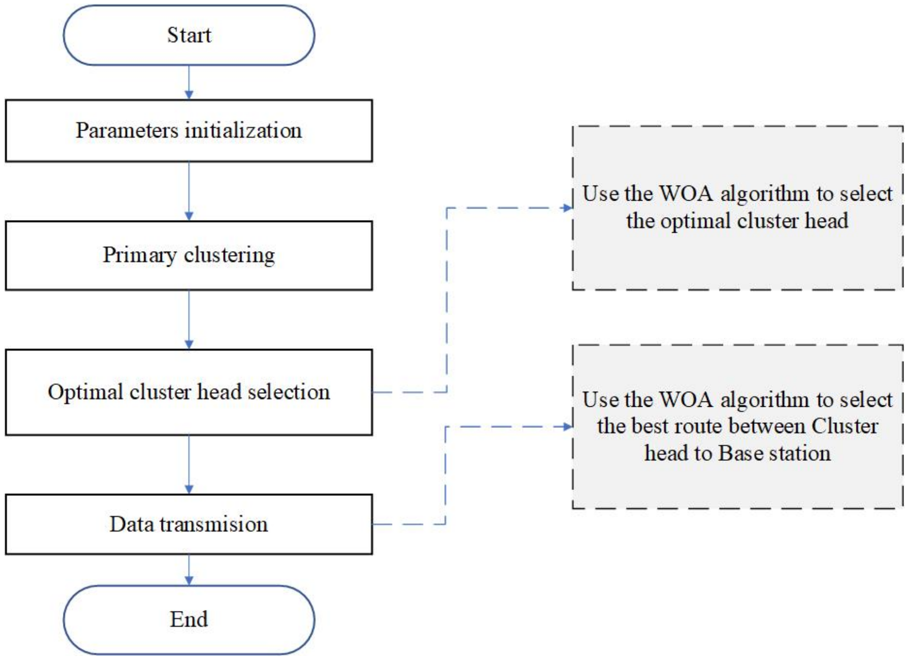

Figure 2: Routing in IoT

4.1. Clustering

This section describes how to cluster and select the optimal cluster heads. To do this, the network is first divided into a number of clusters. At this stage, nodes that are less distant from each other and also similar to each other are placed in a cluster. The WOA uses a base station (BS) to perform the clustering operation. The base station sends the full network details to all sensor nodes through public broadcast. The message sent by the base station includes the number of cluster heads, the members associated with each cluster head, and the number of transfers for this configuration. All nodes receive packets sent by the base station, and so do the clusters. Therefore, the cluster formation stage is completed, followed by the data transfer phase by the second phase of the proposed method.After the clusters are formed, one node in each cluster should be selected as the cluster head. Since cluster head is responsible for receiving, aggregating and sending data, it consumes the most energy. If a proper cluster head is not selected, it will cause the cluster head to die prematurely. In this article, we use the whale optimization algorithm to select the optimal cluster head.

To implement the whale algorithm in clustering, after calculating the average energy at the base station, nodes with higher energy are selected and with the help of the whale algorithm, a number of cluster head nodes with a higher fitness function value are selected. Now n cluster head nodes are considered as search whales:

CH = CH1, CH2, ..., CHn

The best position of the search whale is used to determine the best solution, which is used to select the most optimal cluster head. For implementation, the position of the search whale on the page is first randomly selected and then replaced with the nearest node. Next, the fitness function value is calculated with the corresponding fitness function for all search whales, and then the best search engine is selected. The WOA parameters are then updated based on the position of the other search whales and the consideration of the superior search whale. The selection of the optimal cluster head will be based on the fitness function. In the whale optimization algorithm, the fitness function plays a vital role in identifying or detecting prey (target nodes). In the following, we first introduce the parameters of the fitness function and then we introduce an efficient objective function. To select the optimal header, we use the relationships defined in the third part of the article. The fitness function is used to minimize energy consumption and extend network lifetime. So for this purpose we have to reduce the total distance sent. Fitness function parameters are described in this section:

- Residual energy: The more residual energy the selected cluster head, the later it disappears. This helps to extend the life of the network.
- Number of neighbors: The more neighbors, the greater the chance of being chosen as a cluster head.
- Distance to base station: The shorter the distance from a node to the base station, the less energy it takes to send data to the base station. So a shorter distance increases the node's chances of being selected as a cluster head.

According to the above parameters, the fitness function to select the optimal cluster head is defined as follows (Equation 4.1):

$$F = \alpha E_{ni} + \beta(N(node_i)) + \lambda D_{ni} \tag{4.1}$$

Where Eni represents the residual energy of node i. N(nodei is the number of neighbors of node i in its cluster. Finally, Dni represents the distance from node i to the base station. α, β, and λ are also random variables and their value is between one and zero.

Here the clustering phase is over and the optimal cluster heads are selected by the WOA. The specifications of the selected cluster heads are transferred to the next phase and the data transfer phase is performed by them.

4.2. Data Transmission Phase

At this stage, the clustering phase is over and the optimal cluster heads are selected by the whale algorithm. Now the received data must be transferred to the base station. To do this, cluster head first aggregates the received data, then selects an optimal path between the cluster head to the base station using WOA. The data transfer phase is done in multi-hop sending and the appropriate cluster heads for this sending are selected by the whale optimization algorithm. The whale algorithm uses an efficient fitness function to select the optimal path. In the following, we will explain the parameters used in the fitness function.

- Residual energy of cluster heads: Cluster heads are selected for routing that have more energy. It causes cluster heads with low energy should not be included in the routing and their energy should be used less.
- Cluster head distance to the base station: It is better for each cluster head to send its data to a cluster head that is closer to the base station.

Paying attention to this factor causes the transmission distance to be shorter, which in turn leads to less energy consumption. According to the above two factors, the proportion function is defined as Equation 4.2:

$$F = 10E_{C_i} + \frac{100}{D_{C_iBS}} \tag{4.2}$$

Eci represents the energy of the i-th cluster head. The coefficient of ten is used to increase the effect of this factor on the function. DciBS indicates the distance of cluster head number i to the base station. The lower the value of this parameter, the higher the value of the function and also the use of a factor of 100 will increase the effect of this parameter. The next cluster head is selected by the whale algorithm (Equation 3.5) using the above fitness function.

4.3. The Energy model

In this paper, we have used the radio model described in [17] to calculate energy consumption. It examines the energy consumption in data transmission (ETX), data reception(ERX) and data aggregation(EDA). The energy required to send or receive s bits is calculated from the following equations:

$$E_{amp} = \begin{cases} \varepsilon FSd^2 & if \quad d < d_0 \\ \varepsilon TRd^4 & if \quad d \geq d_0 \end{cases} \tag{4.3}$$

$$E_{TX}(s,d) = sE_{elec} + sE_{amp} \tag{4.4}$$

$$E_{RX}(s,d) = sE_{elec} \tag{4.5}$$

Here, d represents the distance between two nodes, and EFS, EDA and Eelec are defined in Table 1.

5. Simulation and performance evaluation

In this section, we simulate and present the results and compare the proposed method with different methods.

5.1. Simulation Parameters

It is worth mentioning that the environment assumed for simulation is intended to be a 100x100 square environment, and the number of simulation iterations was assumed to be 50. MATLAB software was used to simulate the proposed method. The structure of the wireless sensor network is based on the parameters in Table 1, much like the parameters in article [24].

5.2. Simulation Results

First we show the energy consumption by the proposed algorithm. Figure (3) shows that after about 25 of the 50 cycles considered for the simulation, an average of 30% of the initial energy of the network nodes is consumed. This indicates the high energy consumption of the network in its early stages. As can be seen, at the bottom of the fiftieth round, almost fifty percent of the energy is consumed. This indicates that the proposed method performs better over time. Less energy consumption in subsequent cycles will increase network lifetime.

In Figure 4, the mean energy variance of 50 simulation iterations is shown. This figure indicates that the energy variance is surprisingly low. It is due to the close relationship between node energies in the network. This is be-cause the goal is to use all the nodes in the routing.

Table 1: parameters used in simulation

parameter	value
Network area(meter)	100 * 100
Number of nodes	200
The structure of the arrangement of nodes in the network	Uniform and random playback
Base Station Position	(50,100)
Initial Energy of node	0.5 J
ETX	50 nJ
ERX	50 nJ
Transmit amplifier (multipathEmp	0.0013 pJ/bit/m4
Transmit amplifier (free space)Efs	10 pJ/bit/m2
Transmitter/Receiver Electronics Eelec	50 nJ/bit
d0	30 m
Number of simulation rounds	50
Number of Sinks	1

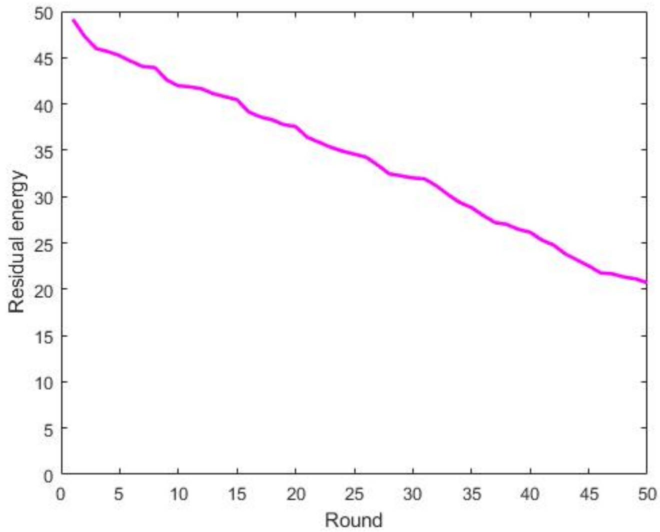

Figure 3: Remaining energy after 50 round

5.3. Comparison Results

In this section, we compare the performance of the proposed method with other methods. To compare and measure the performance of the proposed method, we use the following parameters:

- Residual energy: The value of this metric can indicate the energy efficiency of the algorithm. This value decreases with increasing repetition of the algorithm. Less energy consumption will increase the life of the network and also more residual energy indicates better performance of the algorithm.

- Number of nodes surviving: If energy is used optimally, more nodes will survive. The lower number of missing nodes also indicates an improvement in the performance of the algorithm.

In the following, the proposed method will be compared with three other methods. To do this, we compare the proposed method with methods EECRP [9], BEAR [10], and CCR [12].For better

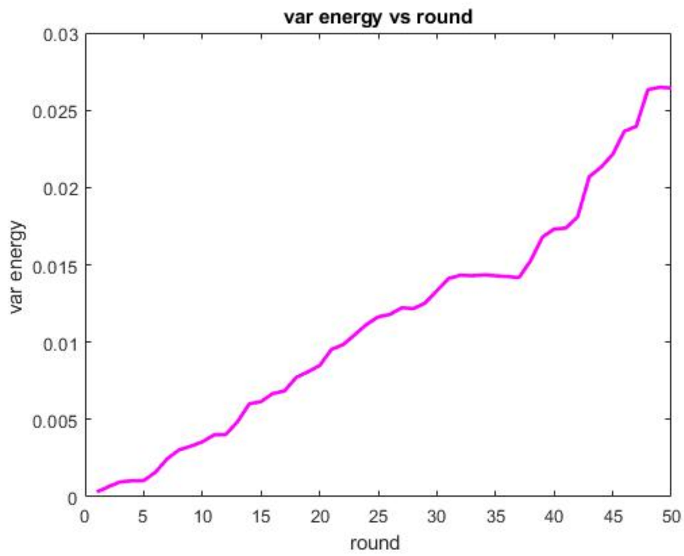

Figure 4: Mean energy variance in 50 simulation round

comparison, these methods are simulated in similar conditions to the proposed method. The details of the comparison are discussed below.

In Figure 5, the remaining energy for each algorithm is shown. As can be seen, the proposed algorithm shows better results.

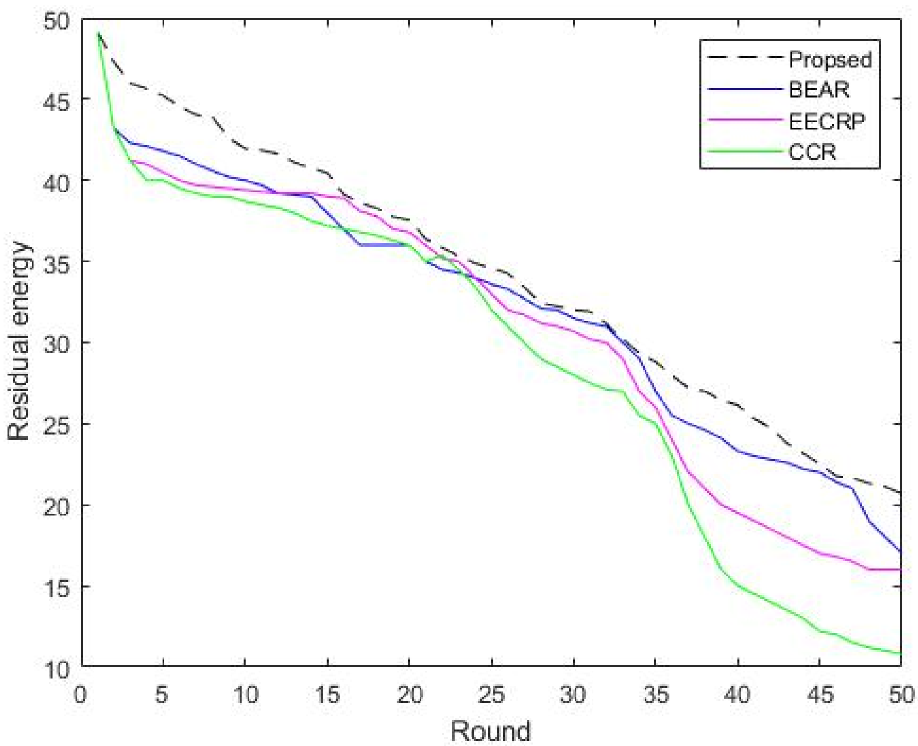

Figure 5: Comparing the remaining energy of various algorithms with the proposed method

In Figure 6, the comparison results of these algorithms are provided. To do so, the 4 algorithms with specified energy values in 50 rounds are simulated, and the percentages of primary energy and remaining energy are presented. According to this figure, the proposed method, using the WOA, shows a higher optimization percentage than the other 3 algorithms.

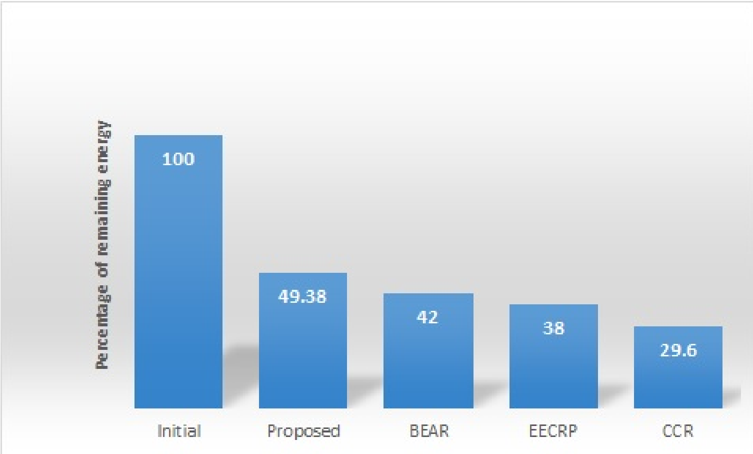

Figure 6: Comparing the percentage of remaining energy in 50 rounds of iterations for different algorithms

For further comparison, the frequencies of dead nodes in 50 rounds of simulation were compared. Figure 7 shows the comparison of dead nodes. According to the obtained results, the proposed method, with the WOA, generally revealed a better performance than the other methods. The percentage of improvement was slightly lower in the early iterations than the subsequent ones due to the nature of the WOA.

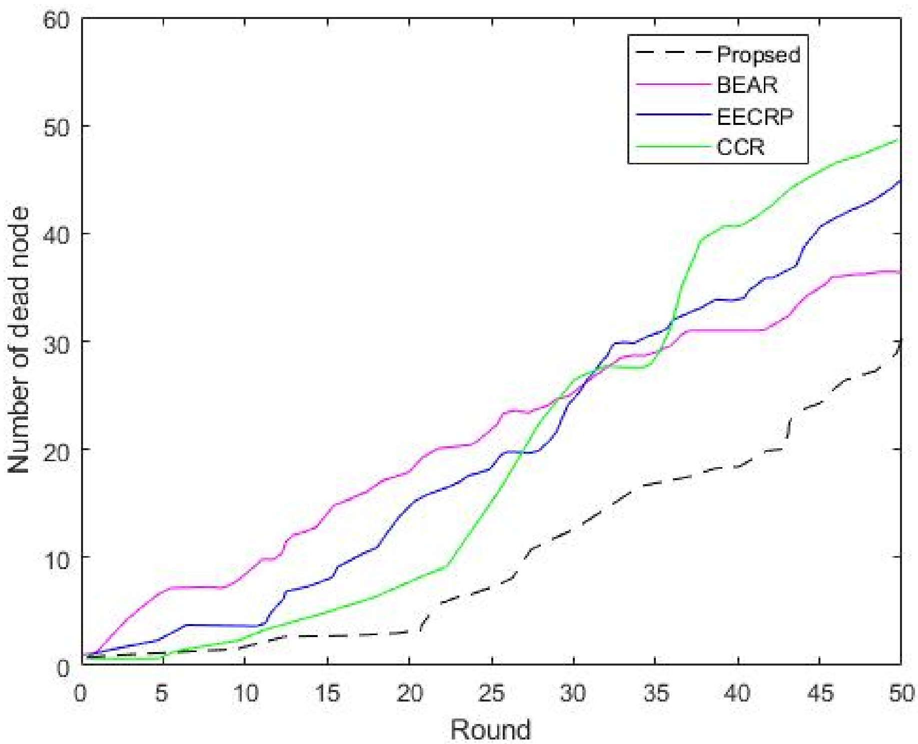

Figure 7: Comparing the number of dead nodes in the proposed method with other methods

6. Conclusion

In this paper, a new clustering and routing method based on the whale optimization algorithm is presented. Due to the ability of meta-heuristic algorithms in optimizing cost functions, we tried to reduce energy consumption in the Internet of Things. In order to reduce the lost nodes and control the energy consumption of the sensor nodes used in the Internet of Things, clustering was performed using the whale optimization algorithm. Then the optimal path from the clusters to the base station was selected by the whale optimization algorithm. The efficiency of the proposed method was evaluated and confirmed using energy consumption criteria and the number of surviving nodes. Comparisons showed that the proposed algorithm was improved compared to other methods. For future work, other meta-heuristic optimization algorithms can be used in IoT clustering and routing. Other parameters can also be used in the fitness functions defined in the article. We assume the sensor nodes are fixed. The proposed method can also be used for a network with a mobile sensor.

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