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Improvement of Energy Consumption in Wireless Sensor Networks (WSN) by Meta-Heuristic Algorithms

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Abstract— **Sensor networks are composed of the accumulation of a large number of sensor nodes that are dispersed in the environment and each of which seeks a specific goal autonomously with the cooperation of other nodes. The nodes are close to each other and they can communicate with each other to share their information. Finally, the situation of the monitored environment is reported to a central node. In fact, wireless sensor networks consist of the sensor nodes that are distributed in inaccessible sites for data collection. They should continue their activity over the specified time without recharging the battery and moving to another site. The most important point about these networks is to minimize the energy consumption of the sensor nodes while supplying the application necessities. In this paper, wireless sensor network is considered as a graph in a space with the area of 50*50 m. The sensors of the simulation space are randomly distributed in this area. The target node is considered to be fixed in the approximate coordinates of 25 and 25. A normal distribution relation has been used to determine the space between the nodes. The initial energy of the nodes is randomly considered ranging from 2 to 8 J, and an energy consumption model can be defined for default values. The proposed model was compared with SLFA and GA algorithms and it proved to have an acceptable convergence. However, GA algorithm, the convergence border was fluctuating. The use of the proposed algorithm delayed the death time of the sensor node.**

Keywords—Wireless sensor network, clustering, network lifetime

I. Introduction

Wireless sensor network (WSN) refers to a wireless network of self-directed sensors that are distributed in a distance from each other and used for group measurement of some of the physical quantities or environmental conditions such as temperature, sound, vibration, pressure, movement, or pollutants in different sites of an area. Wireless sensor network is a newly emerging technology that has been changed into an important issue in research works and it will become an inseparable part of our future life. Application of wireless sensor networks includes different areas such as the national security, military affairs, health services, environmental monitoring, etc. Regarding the expanded uses of these networks, many researchers have become interested in doing research in this area [1]. Wireless sensor networks consist of a lot of sensor nodes that are distributed in a space. This type of network is an appropriate means for collecting and sending the environmental information or making the central node informed of an incident. These networks have special properties and characteristics that make them distinct from other networks. A sensor network consists of a large number of sensor nodes that are widely distributed in an environment to collect information [2]. The location of sensor nodes is not necessarily already determined. This property provides the possibility of releasing the sensor nodes in inaccessible sites. The recent advances in the technology of building small-sized integrated circuits and the development in wireless communication technology have led to the design of wireless sensor networks.

One of the fundamental functions of these networks is related to the environments where human cannot be present, for example in the oceans or military areas and the environments polluted by chemical and nuclear materials. The smallest instance of hardware implementation of sensor nodes is smart dust that is a node with an area of 1 mm^3. However, it is still tried to make these nodes so small that they can be suspended in the air and float by the airflow to disseminate the sensed incidents for several hours or days. In some military functions, security is a critical issue.

For example, wireless network communication makes security activities more difficult. A WSN consists of a set of nodes whose number can range from a few nodes to several hundreds of nodes. In these networks, each node is connected to another (several other) node(s) [3]. Each of these network sensors consists of several parts: a radio receiver/transmitter with an internal or external antenna. Micro-controller is an electronic circuit for communicating with sensors and power supplies, batteries, or energy storage devices. Introduction of WSN and the recent advances in electronics and wireless telecommunication has provided the possibility of designing and building sensors with low power consumption, small size, proper price, and different functions.

These small sensors can receive different environmental information (based on the sensor type) and process and send the information. So, they have created an idea for expansion of wireless sensor networks (WSN). A sensor network consists of a large number of weak and cheap sensor nodes that are created for sensing the incidents that happen in an environment and collecting information. Each sensor node is equipped with sensory hardware, transmitter, processors, memory, and battery. The location of sensor nodes is not already determined and specified. This property provides the

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possibility of releasing them in dangerous and inaccessible sites. On the other hand, it means that the protocols and algorithms of sensor nodes should have the capacity of self-organization [4].

Various algorithms have been proposed for sending and receiving data in sensor networks. In most of the clustering-based routing algorithms, there are some problems that make the algorithm inefficient. One of these problems is the unawareness of algorithms of the nodes energy, the nodes site, the distance of some of the cluster heads from the target nodes, and the fixed location of the target node in the network [5].

Clustering methods aim to form clustering with an appropriate cluster head based on the location of nodes and placing the target node in the optimal site at any stage. It will lead to the decreased energy consumption of nodes and increased lifetime of cluster head and also balanced energy consumption in the network. In clustering protocols of wireless sensor networks, cluster heads are replaced after every implementation phase, and another node is randomly selected as the cluster head. However, the random selection of the cluster head may lead to the improper distribution of nodes in the network. So, two or more cluster heads may aggregate in the covered area, while no cluster head exists in another area.

The control on the number and place of cluster head and the size of clusters in terms of the number of their members have been always considered a challenge and solving this problem is complex due to its dynamic nature that results from the frequent changes in cluster heads in every period of the network activity, and it cannot be modeled by classic mathematical models. In terms of the nodes population, the network should be partitioned so that the creation of high or low dense clusters is prevented. The primary selection of the cluster heads is significantly effective in the increase or decrease in calculation time. Also, proper balance should exist between the decrease in energy consumption and the increase in the average remained energy of the nodes of the cluster.

Determining the number and place of cluster heads to have the most optimal efficiency and energy consumption is a NP-Hard problem. Common clustering algorithms have mostly used heuristic methods none of which have provided a global solution. On the other hand, heuristic and meta-heuristic algorithms are so flexible in solving dynamic problems [6].

In this paper, node clustering has been proposed based on the frog jumping algorithm in wireless sensor network. Comparing the mentioned algorithm with the optimized particle swarm algorithm is done to determine the algorithm with a more efficient performance in energy consumption optimization. Therefore, it is tried to propose an improved algorithm for reducing the energy consumption in wireless sensor networks by using the capacities of the smart meta-heuristic algorithm. In the following, sections 2 and 3 provide a review of the genetic algorithm. Then, section 4 provides the details of the proposed method. Section 5 includes the evaluation and the results of the proposed method.

II. Genetic algorithm

Genetic algorithm was invented by John Holland in 1967. Later, this method was found its place by efforts of Goldberengin 1989, and nowadays it has appropriate place among other methods in light of its capabilities. Optimization process in the genetic algorithm is based on a directed randomized process. This method has been developed based Darwin’s evolution theory and fundamental ideas. In this method, a set of target parameters are generated firstly for fixed number called as population. After implementing the numerical simulator software representing the standard of deviation and/or fitness of the set of information, we assign it to that member of the mentioned population and we iterate this process for every member of the generated member.

2.1.1. Crossover

To operate the crossover, the arithmetic operator was considered. In this operator, the children are generated from mean weight of two parents.

2.1.3. Mutation

To practice the mutation, there has been used the uniform mutation. In this mutation, the selected gene is replaced by a random uniform amount specified lower and upper limits by the user.

2.1.4. Fitness function

The value of each chromosome is evaluated by the fitness function. The best chromosome would be the chromosome with the minimum error. The number of generations ranges from 50 to 600 for the genetic algorithm, and finally, the best chromosome is selected. After a specific number of generations, the chromosome with the best fitness is selected as a solution for a specific problem. One of the main advantages of using the genetic algorithm (GA) is no need for lots of mathematical calculations during the optimization process. This algorithm only seeks a solution in the evolution process without observing the special internal tasks [7].

III. Frog jumping algorithm

Frog jumping algorithm is used for solving complex optimization and scheduling problems. This algorithm starts from an initial solution in the simplest mode, and then, it jumps to the neighboring solutions in an iteration cycle. If the neighboring solution is better than the current solution, the algorithm considers that as the current solution and jumps towards that. Otherwise, the algorithm accepts that as the current algorithm with a statistical probability. This statistical probability is the difference between the current solution and the neighboring solution, and it is affected by another parameter as the jumping coefficient.

One of the important points in this algorithm is the neighbor search strategy that can be so complex regarding the nature of the problem. How to move from a point to another

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depends on the structure of the designed operators. Detecting the unknown points of the solution space and searching the neighbor points is subject to designing efficient and effective operators. It is difficult in most of the complex optimization problems with various decision variables and different constraints, so that most of meta-heuristic approaches may lose their efficiency. In clustering the wireless sensor networks, first k cluster heads are randomly selected. Then, the distance of each node from the k cluster heads is measured. Each sensor node becomes a member of the cluster with the shortest distance from its cluster. In a cluster, each sensor node sends its data to the cluster head through the shortest distance. Then, a new cluster head is chosen for each cluster, so that the total distance of all the sensor nodes of this cluster from the new cluster head is minimized. This process is iterated until no further change occurs in cluster heads. SFLA is a smart algorithm inspired by the nature organism and it functions based on searching modes [8].

SFLA randomly generates a primary population of F frogs as $P=\{X_1,X_2,...,X_F\}$

For solving the problem in a t-dimensional manner, the place of from i at T is considered as $X=[x_1,x_2,...,x_{it}]$

After generating the frogs population, the efficiency of each frog place (F(xi))is calculated and they are categorized from the maximum value to the minimum value. The frogs are allocated to m groups each of which includes n frogs (F=m*n). Then, local search is applied to each group [9].

The advantages and properties of the frog jumping algorithm include: 1. Memory: frogs have memory and the knowledge of good solutions is preserved by all the agents. 2. Cooperation between frogs in sharing information: in frog jumping algorithm, each member of the group changes its location depending on its own experiences and the experiences of the whole population. Information sharing by the members of a group creates some advantages that are considered as the basis of the optimization algorithm.

There is an efficient cooperation between frogs and they share their information in a group. 3. High convergence speed: in this algorithm, the population members are communicated and solve problems by information exchange. They also have a high convergence speed. 4. Higher flexibility in the face of local optimization problems: there is a higher flexibility in the face of the local optimization problem with the large number of agents.

Since this paper is based on optimization methods, each agent represents for a node. The criterion of finishing the algorithm can be one of the three following: 1. the value of the target cost value is optimal and acceptable. 2. The number of iterations is defined by N. This value is different in problems with different dimensions. 3. No advance or improvement is observed in the value of the target cost function over several subsequent iterations [10].

IV. The Proposed Method

To improve the local search in complexes and acceleration of the convergence of algorithm, a new method has been proposed for frog jumping from poorer solutions to better solutions. Meanwhile, instead of random generation of frogs, a genetic mutation operator has been used for generation of frogs. SFLA is a meta-heuristic memetic algorithm that is designed for finding the globally optimal solution by heuristic search that is done by a heuristic function. This algorithm is based on the evolution of the memes that are carried by interactive agents and global information exchange is done in the population [11]. In SFLA algorithm, frogs change by the memetic evolution. In this algorithm, frogs are considered as the hosts of memes and they are presented as a memetic vector. Every meme includes several memtypes that indicate the properties of the frogs.

SFLA does not change the physical properties of the frogs existing in the population. Rather, it modifies each element of properties [12]. Frogs can exchange their information and modify their memes. As a result of the improvement of memes, mutation of each frog is regulated and in this way, the position of each frog changes. So, the algorithm uses jumping as a tool for local search and competition, and also uses the order for combining the information resulted from local searches and moving toward the global solution [13].

According to figure 1, the hybrid proposed solution has been designed for better solving the simultaneous optimization problem. For this purpose, a hybrid two-level model has been proposed by using the genetic meta-heuristic algorithm and frog jumping algorithm. In this way, a set of nodes are selected by GA at the first level and the selected nodes are used for designing the network by frog jumping algorithm at the second level. So, location and routing are simultaneously done in the best way. As a result, in the cost function, the probability of getting involved in the location optimal site is minimized due to the properties of the used heuristic algorithms and the probability of convergence is accelerated. For possibility of solving the problem, the routing problem is solved as a concurrent two-stage problem. The heuristic method is proposed as the following:

1. The shortest distance of the candidate node from all the network nodes is determined by calculating the cost function and the nearest node head to each node is identified.
2. Global search is allocated to the shortest designed routes.
3. The bonds whose allocated demand is less than a specific level are omitted.
4. Omission of the bonds continues as far as none of the network nodes become discrete.
5. The cost function is once again calculated for the new network and the shortest distance from each node to the selected nodes is calculated and the nearest cluster head to each node is identified. Also, the average energy of the network is calculated.
6. After the convergence of the solutions or the end of iterations of GA, the selected cluster heads are specified.

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7. The network routes are constructed regarding the selected nodes by frog jumping algorithm.

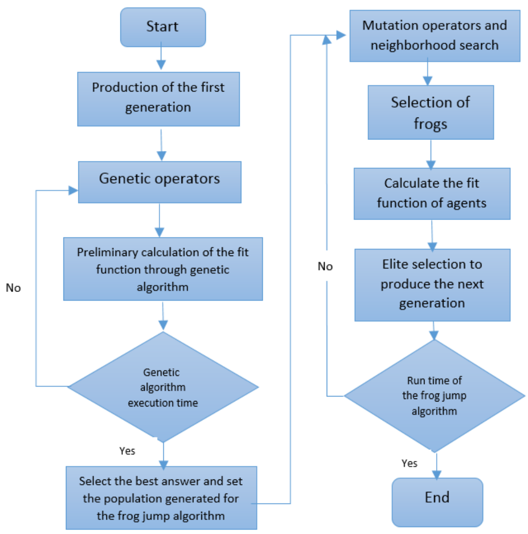

Figure 1. Flowchart of the proposed algorithm

5.1. The evaluation criteria and the parameters

In this research, it is tried to use a standard method for evaluation of the system. This method is usually one of the most common methods of evaluating a system, and it is tried to customize the meta-heuristic frog jumping algorithm for routing the wireless sensor networks [14]. Since the fitness function of the algorithm is based on the energy consumption over the route and regardless of the average remained energy of sensor nodes, the algorithm functions as the shortest route algorithm and detects the shortest distance between the origin and target nodes. The fitness function is based on equation (1), and Table 1 presents the combined parameters of GA and frog jumping algorithms. Equation (1) Fitness function = the energy consumption over the route/1

Table 1. Combination parameters of genetic and frog algorithms

Amounts	Description	Parameter
50*50	Problem space area	M * M
200	Number of sensor nodes	N
10	Data packet size (bits)	Packet Size
4	Number of cost matrix dimensions for chromosomes	dim
-1	Hypothetical number to start ranking	maxmin
-5.12	Score floor channel	Lb
5.12	Rating ceiling channel	ub
200	Maximum number of smart agents	Max popsize
500	Most generation of algorithm generation	Maxgen
50	minimum optimal amount	localmin
1e-16	Hypothetical function of the end of the algorithm	tolfun

V. SIMULATION RESULTS

The wireless sensor network is considered as a graph in a space with the area of 50*50 m. The simulation space sensors are randomly distributed in this environment. The target node is considered to be fixed in the approximate coordinates of 25 and 25. A normal distribution relation has been used to determine the space between the nodes. Meanwhile, MATLAB tools have been used for this purpose. The data of the distance between the nodes is stored in a matrix. This matrix can be also used as the connection matrix for making sure of the connection between every two nodes.

In all simulations, a single graph with 100 nodes and also a matrix have been used for storing the energy consumption of nodes. After every period of routing, the information is updated. The initial energy of the nodes is randomly considered ranging from 2 to 8 J, and an energy consumption model can be defined for default values. Figure presents the location of nodes in the sample graph and the origin node has been considered to be located at 20,20.

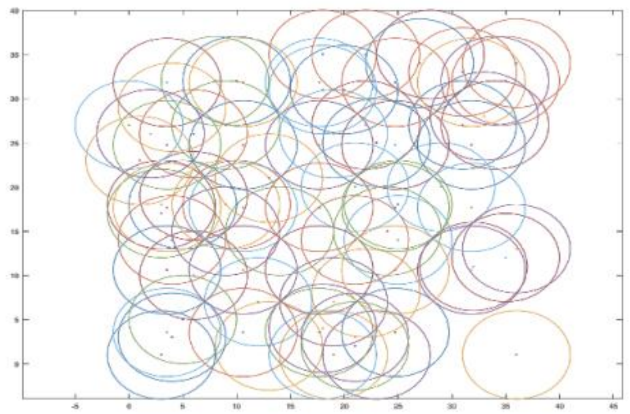

Figure 2. Graph of the location of the nodes in the problem space with the area covered in the starting position

Regarding the fitness function, only the energy consumption and proper distribution of energy consumption that is significantly effective in the increase of the network lifetime have been observed. As already stated, the network lifetime refers to the period of time starting from the beginning of the network operation and ending to the finished energy of the first node. Table 2 presents the criteria of the proposed algorithm and the frog jumping algorithm.

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Table 2. Criteria of the proposed method algorithm and frog jump algorithm

Frog Jump Algorithm	Hybrid algorithm	
700 rounds	1003 rounds	Network life
8.0000	2.0000	Average energy consumption
0.3	0.0800	Average residual energy of the covered area after 1003 routing rounds

As seen in Table 2, three criteria have been considered for comparing the proposed algorithm with frog jumping algorithm. These three criteria include the network lifetime, the average energy consumption, and the average remained energy of the whole sensor nodes after the death of the first node. Analysis of the results shows that the better is the energy consumption distribution between the sensor nodes, the lower is the average remained energy of the nodes. It is observed that the average energy has increased under the second condition. So, the balance between the energy consumption and proper distribution of energy consumption will eventually lead to the increased lifetime of the network. Based on this test, the efficiency of the fitness function in energy consumption distribution is observed, and the proposed algorithm can well detect the optimal route based on this fitness function. Figure 3 presents the efficiency of the fitness function.

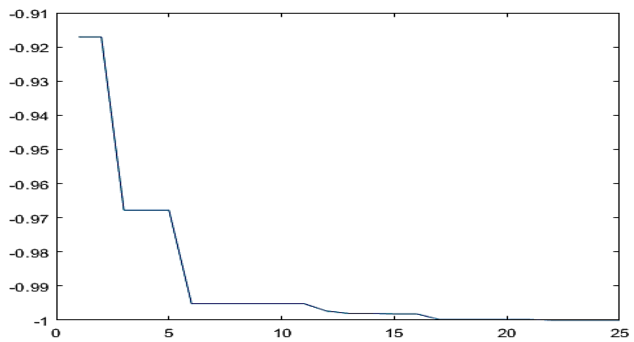

Figure 3. Performance of the fit function for the proposed hybrid algorithm

As seen in Figure 3, x axis presents the generation and y axis presents the fitness function for each cycle of the heuristic algorithm. The descending flow of this diagram shows that scores of the agents are converging to zero, and finally, it reaches close to zero at the 25^{th} stage. It should be mentioned that the scores are not acceptable regarding the descending flow.

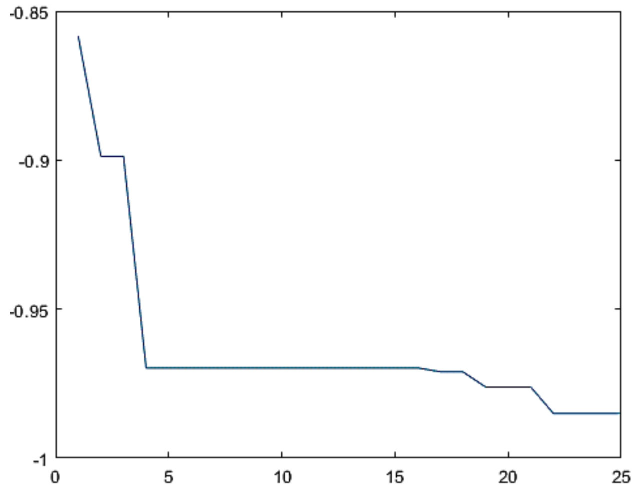

Figure 4, Convergence function during generation generation, without using the hybrid algorithm with the GA algorithm

Figure 4 presents the result of the convergent function in generation production without the use of the hybrid algorithm and only using GA. As seen in Figure 4, convergence of GA has presented without using the proposed method to compare the results of the problem solving period. Axis x presents the generation production and axis y presents the fitness function of GA. The score of the cost function of GA is involved in the 4^{th} to 15^{th} stages of generation production and its score has suddenly increased in the 16^{th} stage. It indicates the poor performance of the algorithm in the face of local optimal points and the high convergence speed of GA.

Based on the test results, it can be concluded that with the increase in the number of properties, the proposed method is more accurate than other algorithms. Figure 5 indicates the descending low of the score of cost function in the proposed algorithm for reduction of energy consumption.

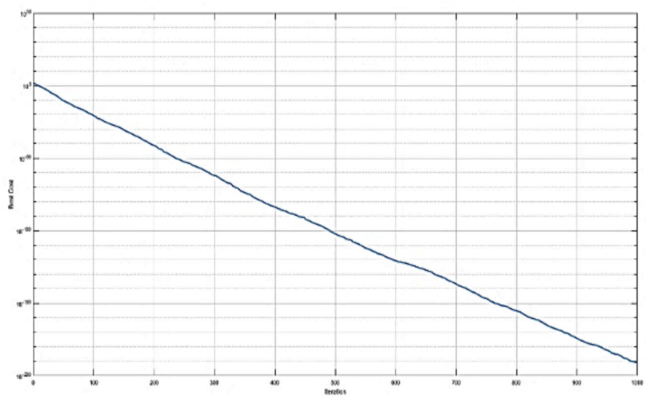

Figure (5) shows the downward trend chart of the best cost per round of the GA-SFLA algorithm

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VI. CONCLUSION AND FUTURE WORKS

Evolutionary algorithms such as GA and frog jumping algorithm are considered as population-based random search tools. Their most important strength is that they are innately parallel and they can investigate the search space in different directions. Parallel investigation of the sub-spaces leads the searching process to the areas with high means of objective function and high probability of existence of absolute optimal point. Unlike single-route methods, the solution space is comprehensively searched in these methods and there is a lower probability of getting involved in a local optimal point. Evolutionary algorithms are route-independent methods, and it makes them distinct from the old methods. So, they can effectively search the whole search space. Meanwhile, evolutionary algorithms do not depend on the function continuity or its derivatives, the searching process only requires the value of the objective function in different points. These algorithms only need some information about the quality of the solutions created by every set of variables. However, precise methods require the full recognition of the problem structure and the variables. In future works, we aim to increase the efficiency of this method by further studies about the fitness function and improvement of operators. Also, future studies will investigate the following issues:

1. The possibility of using the smart particle swarm optimization algorithm (PSO)
2. Observing other costs besides the network lifetime and reducing the cost to minimize that and also determining the hybrid updating period
3. Using meta-heuristic algorithms or other optimizers in addition to the mentioned algorithms such as neural network and fuzzy logic algorithms.

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