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Optimizing the Energy Consumption of Wireless Sensor Networks

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ABSTRACT
Wireless sensor networks (WSNs) have great attention and applications in many fields in the recent years. One of the main challenges in using the WSNs is their energy consumptions. Although, many methods have been developed to overcome this problem, there are still some limitations facing the WSNs in this manner. In this paper, the proposed system introduces a new system that uses genetic algorithm (GA) for optimizing the node deployment, their locations and dividing the sensor nodes into two modes of operation that can minimize the energy consumption of the WSN. Suggested system has been applied for a simulated WSN used in the radiation discovering sites as a case of study. Its obtained results have proved its success to be applied in the practical sites.

Keywords
Wireless Sensor Networks (WSNs), Genetic Algorithm, Optimization Systems, and Energy Consumption.

1. INTRODUCTION
In the recent years, there is an increase in the uses of wireless sensor networks (WSNs) in many fields. WSNs are distributed systems consist of low-cost sensor nodes that collaborate together to achieve the goal of its application. They have been applied in many applications such as forest monitoring, disaster management, space exploration, factory automation, secure installation, border protection, radiation detection and battlefield surveillance [1]. A number of the sensor nodes are deployed to operate autonomously in the environments of the applications. Each sensor has the ability to collect the information about its surrounding environments and send them to the base-station either directly or over a multi-hop path. Figure (1) represents typical sensor network architecture [2].

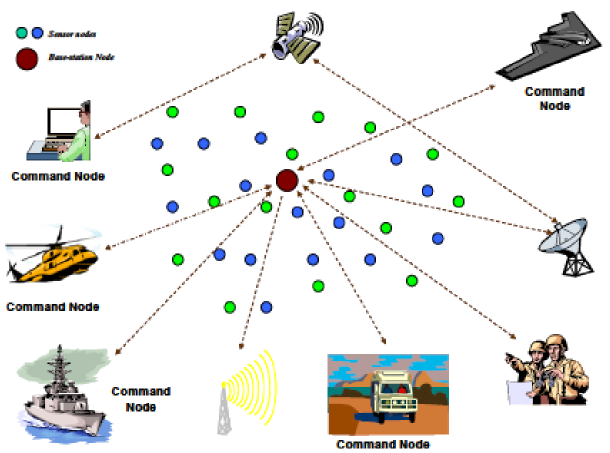

Fig. (1): Typical Sensor Network Architecture

Sensor nodes are usually low battery-powered devices say 100nJ. Any node can dissipate energy during its operation in sensing, processing and communicating tasks. It stops working out when it hasn't enough energy. WSN may be physically damaged if many sensors exhaust their battery power energy [3]. However, the power consumption and the lifetime are considered main limitations for WSNs. Therefore, many energy management systems have been developed to overcome these problems.

From reviewing, it is found that, optimizing the nodes deployment can maximize the total area covered by sensors, decrease the energy consumption and increase the network lifetime [4-6]. Also, the modes of operation of the WSN' sensors can manage its energy-efficiency.

Node deployment or placement is a technique used to locate the nodes effectively in the field area. However, they can use minimum energy to during its operation.

The sensor nodes can be classified mainly into static and mobile. The early work of the sensor deployment strategies used the static nodes. It has deployed a large number of nodes for achieving an accepted coverage level of the network. This method is simple and easy but it can cause a high cost and its coverage is not guarantee. While, more recently, the mobile nodes are used for the WSN [7]. These mobile nodes can move and re-arrange till have the required coverage area of the network. Many methods have been developed to determine the motion path of the mobile nodes [8-9].

One of the important algorithms have been used for the optimization task is a genetic algorithm (GA). GAs are proved their success to find an optimal or near optimal solution for the paths of the mobile sensor nodes' problems [10].

In this research, the proposed system uses GA to improve the energy consumption and the lifetime of the wireless sensor networks. It proposes a new algorithm that optimizes the nodes deployment and their modes of operations.

The reminder of this paper is organized as follows. Section 2 discusses the operation of the GA. Section 3 presents the related work. Section 4 discusses the proposed system. Section 5 presents the applicability of the proposed for wireless sensor network used for discovering the radiation sites, its simulated experiments and results. Section 6 concludes the work.

2. GENETIC ALGORITHM
A genetic algorithm is used to search for near optimal solutions when no deterministic method exists or if it is computationally complex [11]. GA is a population based algorithm. Each solution is represented as a chromosome. Usually a GA starts with random solutions. Then, it chooses the best member solutions to generate new solutions for the next generation. This process is repeated and the generated solutions are improved up and a near optimal solution is achieved [12]. To implement the

GA, developer must concern the representation of chromosomes, GA's operators such as crossover and mutation those used for driving the new solutions from the old ones. The third factor is how to find a fitness function (*i.e.*; a method to evaluate the solutions) in order to accept or reject the solutions, and the selection method applied to select the best members for mating [13].

A widely used representation for genes is bits where each gene is represented by a bit. In this case, mutation is done by flipping a bit randomly in the chromosome. After crossover and mutation, two new chromosomes are reproduced. The final step is accepting or rejecting these chromosomes to be in the new population. Typically, the new chromosomes are accepted if they are better than their parents.

Termination is the last step in the genetic algorithm. Usually, the iteration of the genetic algorithm is stopped when a certain criterion is met. The most widely used stopping criterion is achieving a certain predefined number of iterations. When this number of iterations is satisfied, the genetic algorithm is terminated [14].

3. RELATED WORK

Researchers have introduced the node deployment as a solution for the energy consumption problem in WSN. They have used the random node deployment for the mobile sensor node networks or the mixed networks [15-17].

More recently, the optimization approaches are used to improve the performance of the node deployment techniques. Their obtained optimum solutions provided better deployment in the coverage area [18]. Particle swarm optimization is used to optimize the virtual force algorithm [19-20]. While, a biogeography-based optimization algorithm was proposed to maximize the coverage area of the network [21].

Also, genetic algorithms have been used to solve the problem of optimizing the static node deployment. On the other hand, a little work has been developed to deal with the random node deployment for the mobile nodes or for coupling both the static and mobile nodes. Traditional GA, a force-based GA, and a multi-objective GA are applied for random deployment to determine near optimal positions for additional mobile nodes to maximize the coverage. Also, a genetic algorithm was used to find the best positions for the cluster heads that cover the maximum number of nodes and hence maximizing the area coverage of WSN [22-26].

The proposed system introduces the using of the genetic algorithm for two main tasks: (1) optimizing the number of additional mobile nodes and their best path to maximize the overall coverage. (2) optimizing the number and locations of dividing the environment of the application field area into group of sub-areas. This enables the system to concern the operation in only one subarea that contains active nodes. While, all the reminder subareas have becoming in a sleep mode. This can decrease its nodes' power consumptions, increase the lifetime and improve the performance of the wireless sensor networks.

4. PROPOSED SYSTEM

Although the great wide spread of using the sensor wireless networks in many applications, their energy consumptions still cause main challenges for their designing and management processes.

It is found that, using unsuitable node placement strategy and the sensor nodes' modes of operation represent main parameters for increasing the power consumptions and having bad effects on the network's performance. Besides, these limitations have been proven to be NP-Hard problems for most of the formulations of sensor deployment. Many methods have been developed to overcome these limitations. But, these problems are very difficult to be solved by the traditional methods.

The proposed system introduces a new algorithm to achieve an energy-efficient design of the sensor wireless networks. It concerns the uses of the genetic algorithm optimization technique for optimizing the sensor nodes deployment and dividing them into two main modes of operation: the active and the sleeping ones.

The operation of the proposed system is divided into two main phases. Each phase uses a separate genetic algorithm to deal with an optimization task in the sensor wireless network.

Suggested system uses GA in order to determine the optimum number and location of mobile nodes that should be used in addition to the previously deployed static (fixed) nodes and the optimum locations for decomposing the large field area into subareas. Then, the system concerns only the motion of the sensor nodes found in the subarea of the monitoring. While, the other nodes are in the sleep mode that used minimum level of energy. However, the energy consumption of the WSN is minimized.

4.1 Phase one

The first phase of operation concerns the sensor nodes deployment strategy. The proposed system uses the mixed deployment strategy. It starts with some essential static (stationary) nodes and added only mobile nodes to complete the communications. This deployment strategy enables the system to have the advantages of both the static and mobile sensor nodes and overcome their disadvantages. Thus, using the static nodes can decrease the complexity of the network by avoiding using all nodes as mobile ones. In many cases there are unnecessary task that required moving every sensor till achieve the coverage requirements. On the other hand, using the mobile nodes can decrease the network's cost by decreasing the great number of the static nodes required to deal with the complex networks. In this case, suggested system has used the random sensor nodes deployment and the base station node position is stationary.

Assume that S_i static sensor nodes are deployed randomly over a sensing field. All the static sensor nodes have the same sensing range represented as a circle with radius r. The proposed system gathers the information about the locations of the static sensor nodes. Then, it uses the GA to determine the number and locations of the required mobile sensor nodes using the first GA as follow:

1. Chromosomes Representation

Each chromosome of the first proposed GA represents the location of a mobile sensor node in the sensing area as (X, Y) point in a binary digit form. While, the number of the ones in the chromosome represents the number of its mobile nodes in this solution. The size of the proposed population is 20 chromosomes.

2. Selection methodology

The roulette-wheel selection scheme is used by our proposed genetic algorithm for this task.

3. Crossover

Proposed GA uses a single point crossover. Its rate=0.6.

4. Mutation
Inversion mutation is applied to the offspring. The mutation rate is: 0.02.

5. Fitness function
The fitness function is defined to evaluate the fitness of each chromosome (solution) in the population. GA uses these chromosomes for the reproduction of the next generated solutions. The fitness function calculates the maximum number of the targets that each mobile node can detect. The proposed system concerns that these targets must be uncovered by other mobile or static nodes. This can avoid the overlapping redundancy among the coverage areas of the deployed mobile nodes. Also, each mobile node can cover only a distinct region. The fitness function is given by:

$$\boldsymbol{F(i)} = \frac{\mathbf{F}(\boldsymbol{N_{Si}})}{\sum \boldsymbol{O_j}} \quad (1)$$

As:

$$\mathbf{F}(\boldsymbol{N_i}) = \begin{cases} \mathbf{F}(\boldsymbol{N_{Si}}) + \mathbf{1}, \boldsymbol{D}(\boldsymbol{N_{Si}}, \boldsymbol{O_j}) \leq \boldsymbol{r} \\ \textbf{and } \boldsymbol{O_j} \notin \left\{\boldsymbol{S_c}, \boldsymbol{F}\left(\boldsymbol{N_{\frac{S}{i}}}\right)\right\} \\ \boldsymbol{F}(\boldsymbol{N_{Si}}), \textbf{otherwise} \end{cases} \quad (2)$$

where F(i) is the fitness function of the mobile node (i), $F(N_{Si})$ is the objective function of mobile node i (N_{Si}). It determines the coverage as a function of the targets it covered when the target object O_j is not covered by any static node or other mobile nodes. In Equation (2), S_c is the coverage of initially deployed static nodes and $F(N_{S/i})$ is the coverage of any mobile node except mobile node i.

6. Termination
The GA can be terminated either by reaching the required solution or by having 50 iterations.

However, the proposed system can optimize the number and the locations of the sensor nodes used in the communication process.

4.2 Phase Two

The goal of this phase is to have energy-efficient sensor nodes that are classified into two modes of operation as: active and sleep nodes. The proposed system can divide the sensor nodes into group of disjoint sets. Each set can individually concern a region of the monitoring area. These sets are activated successively. During the system's operation, the nodes of certain sensor set are in active mode and all the other node sets are in a sleep mode that uses low-energy. So, the energy consumption can be minimized.

The goal of this phase of the research is to optimize a maximum number of disjoint sets that can increase the number of sleeping nodes and so minimize the energy consumption and increase the lifetime of the network. It uses the GA to optimize the number and locations of dividing the field area into the subareas (regions) of the network as follow:

1. Chromosomes Representation
The chromosomes of the second suggested GA represent the number and locations of the regions of the sensing area. It uses a binary representation form. The size of its population is 30 chromosomes.

2. Selection methodology
The tournament selection scheme is used in our algorithm for this task.

3. Crossover
Proposed GA uses a single point crossover. Its rate=0.7.

4. Mutation
Inversion mutation is applied to the offspring. The mutation rate is: 0.025.

5. Fitness function
The fitness function of this GA is represented as:

$$F(y) = \sum_{i=1}^{N} C_i \frac{x_i}{X} L_i \quad (3)$$

Where x= instant of regions in the sensing area, N=total no. of regions of sensing area, C=the cost of dividing the sensing area into the present instant of regions. X=total sensing area of the network. L is the location of the instant region in the sensing area.

6. Termination
The GA terminated either by achieving the solution or by having 50 iterations.

However, the proposed system can optimize the diving areas of the sensor nodes used in the network. This enables the system to determine the unused nodes in sleep mode in order to decrease the power consumption.

5. APPLICABILITY OF THE PROPOSED SYSTEM AND ITS RESULTS

To evaluate the proposed system, simulation for a wireless sensor network that communicates between a dosimeter for discovering the radiation sites and the tested sources in certain area. Then, a comparison between the proposed system, another system that uses a particle swarm optimization technique [19], another one uses traditional GA for node deployment only [26], and a fourth system uses multi-objective GA [27].

From the obtained results, the network lifetime increases while the total power consumption decreases of the network. It is found that, the lifetime of the network using the proposed system increases 1.60% longer than the system used traditional GA for node deployment only. While, the lifetime of the network increases by 1.422% longer than the system using multi-objective GA for node deployment by using the proposed system. Finally, the proposed system can increase the lifetime of the network by 1.28% longer than the system uses PSO for node deployment.

Furthermore, the proposed system can decrease the power consumption to 0.25 times rather than the power losses by the system uses the traditional GA. Also, it can decrease the power consumption of the network to 0.40 times rather than that one for multi-objective GA system. Besides, the power consumption of the network is decreased to 0.286 times rather than the power losses for the PSO system for the node deployment.

However, the proposed system has proved significant improvement for the WSN's performance. It has decreased the power consumption and increase the lifetime of the network. Also, it can increase the accuracy of the system.

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Table (1): A comparison between the proposed system, Traditional GA system, Multi-objective GA system, and PSO system

System	Lifetime of the network	Power Consumption	Accuracy %
Proposed System	70.4 H.	70 W	98.7
System using traditional the genetic algorithm for node deployment only	44.0 H.	280 W	95.2
System uses multi-objective GA	49.5 H.	175 W	93.6
System using the practical swarm algorithm	55.0 H.	245 W	92.1

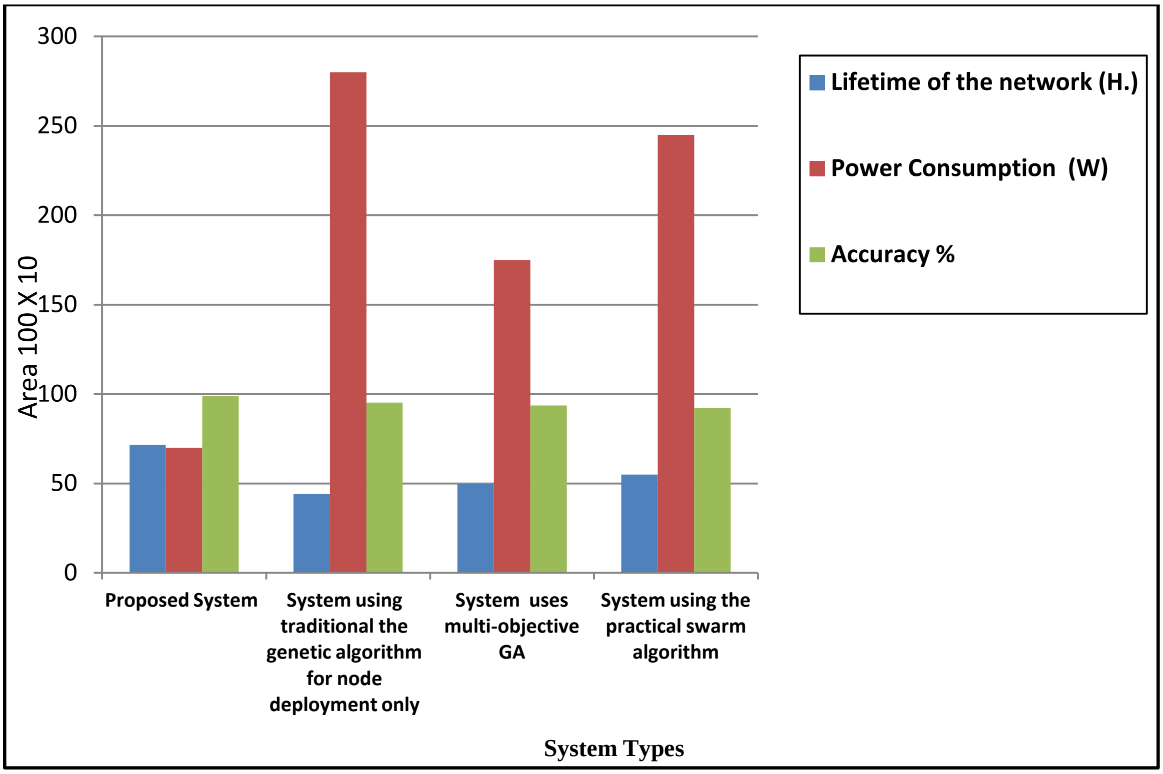

Fig. (2): Comparison between the proposed system and the other three tested systems for WSN at Area 100 X 10 m^2

It is found that, the proposed system has proved its goodness by increasing the lifetime of a WSN used in detecting the radiation sites. Also, the proposed system decreases its power consumption. Therefore, the suggested system can improve the performance of Wireless Sensor Networks those are applied in real time applications.

6. CONCLUSION

Although the wide spread of the wireless sensor networks in our daily life, there still some challenges faces them to be applied in many other applications. It is found that, the energy-efficiency of a WSN is very important issue till now.

Proposed system has suggested new algorithm that uses two genetic algorithm modules to optimize the number of the mobile sensor node deployed besides the original static one, their optimum locations and to decompose the nodes into two main types. The first one concerns the active area for sensing. While, the other nodes are considered in a sleep mode that use minimum energy. Therefore, the energy consumption can be decreased.

Proposed system has been applied for evaluate a simulated wireless sensor network used in discovering the radiation sites. It has compared for three other optimization systems used for the energy consumption of the WSNs when applied for the same simulated WSN. The proposed system has proved a significant decreasing in the energy consumption, increasing the WSN's lifetime and increasing the network's accuracy. Its obtained results have proved its goodness to be applied for real time WSN applications.

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