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Presenting a Hybrid Method to Increase Lifetime of Wireless Sensor Networks Using Effective Determination of Operating Mode of Sensors in Regional Coverage

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Abstract

In recent years Wireless Sensor Networks have attracted researchers' attention due to vast applications. One of the most prominent issues regarding these networks is coverage which is considered as a quality of Service parameter. In this study, we try to address energy shortage in WSNs through finding a set of optimal coverage nodes in a specific environment. This is performed utilizing effective removal of extra sensors and generating several networks with area coverage. In the first step we use graph based method to classify sensors. The area is divided into several smaller regions in a dynamic manner in such a way that the whole region is covered with sensors. In the next step each set analyzed using genetic algorithm so that optimal or semi-optimal number of active nodes which are necessary to cover the region could be selected. Finally, performance of sensors in coverage of the area is evaluated using Monte Carlo method. Decreasing the number of sensors in each set and generating multiple networks, this method saves more energy which prolongs lifetime of the network.

Keyword: *Wireless Sensor Network, graph based view, genetic algorithm, Monte Carlo*

1. Introduction

Wireless sensor networks are utilized for monitoring and controlling of particular area. These networks consist of large number of cheap sensors which are densely deployed in an area. Information collected by sensors should be transmitted to a base station. Sensor nodes are limited by weight, size and cost constraints which directly affect resource accessibility. Moreover, these nodes use batteries and they have limited computation and communication capabilities. Since replacing batteries is not possible in many applications a paramount requirement of these networks is low energy consumption. Lifetime of each sensor might be effectively increased through optimizing energy consumption [1]. Various methods have been proposed to reduce energy consumption of wireless sensor networks such as clustering and diffusion. Additionally, some approaches are presented based on defining type of coverage in the area. In this article a special kind of coverage is introduced called area coverage. Using this definition and aggregating a few algorithms an approach is proposed which aims to reduce active sensors needed for covering the area. As a result more energy is saved and lifetime of network will increase [2], [3].

In section 2 concepts used in this paper are briefly explained. Related work is presented in section 3. Section 4 includes presentation and evaluation of proposed method. Finally, simulation results are presented in section 5. Section 6 concludes the paper.

2. Some related concepts

In this section some principal concepts utilized in this article are explicated.

Coverage in wireless sensor networks: Because of the variation in the number and types of sensors and various use, interpretation and diverse concepts, for coverage is provided. In general can be said coverage, as one of the parameters of service quality in a wireless network can be defined [4], [5]. However, there are several types of coverage. 3 type: a point coverage, regional coverage and border most of the other coverage is considered. In issue region coverage, main area into a number of smaller regional divided. And Purpose create effective coverage, in the smaller areas created the main area .With Coverage smaller areas, the main area in the whole is covered. As seen in the figure below, a set of sensors, which are arranged randomly, to a smaller area to coverage. And black nodes represent the active sensor nodes and white nodes represent nodes inactive [6], [7].

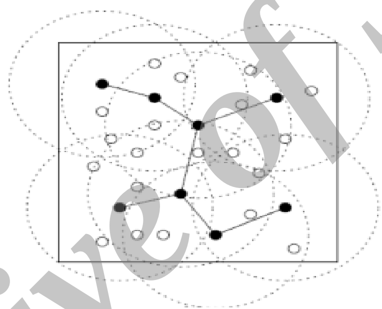

Figure 1: Regional coverage [7]

One of the main concerns in networks, efficient use of energy in networking, storage and increase network lifetime. One way of reducing energy consumption, reducing the number of active sensors in the coverage area. The algorithm reduces the number of sensors, when they can best be implemented optimally, the network is scalable. In the network In addition the network lifetime And reducing the number of active sensors, the following constraints are satisfied:

- Active sensor number should the identification of each target in the area, be guarantee.
- For ensure that data outside to network, all active nodes are connected to the sink.

Each node has two sensing range-R_s & communication range-R_e. The sensing range, sensor nodes the radius of a circular space, is capable of measuring the desired parameters, called the sensing range, and communication range, which defines the range, the sensor node in a circular area the radius of sensor node through with some other nodes or the sink node can communicate. Course connect to the sink, can be connected directly or connected indirectly and through some other node. In addition, the sink node is a node that, data collected by the sensors network receives [8].

Display based on graph: Various sectors of wireless sensor networks should be modeling and simulation, the Network performance is evaluated.

To do this, wireless sensor network which is mapped to a graph, which in this graphs each node represents a sensor node in the network, and each edge represents a link between two nodes the sensor is. If the communication between nodes in the network is bidirectional, undirected graph will be mapped, and if the communication between nodes in the network is asymmetric then the graph-oriented mapping will.The communication model between nodes can be one-to-one or one-to-all.

Genetic Algorithms: Genetic algorithm (GA) based search methods are inspired by the mechanisms of natural genetic leading to the survival of the fittest individuals. Genetic algorithms manipulate a population of potential solutions to an optimization problem. Specifically, they operate on encoded Representations of the solutions, equivalent to the genetic material of individuals in nature, and not directly on the solutions themselves. In the simplest form, solutions in the population are encoded as binary strings. As in nature, the selection mechanism provides the necessary driving force for better solutions to survive. Each solution is associated with a fitness value that reflects how good it is, compared with other solutions in the population. Recombination of genetic material in genetic algorithms is simulated through a crossover mechanism that exchanges portions between strings. Another operation, called mutation, causes sporadic and random alternation of the bits of strings. Mutation also has a direct analog y with nature and plays the role of regenerating lost genetic material [9], [10].

Monte - Carlo simulation: Monte - Carlo approximate solutions to problems in mathematics, statistics, physics, etc. that is used to simulate random quantities and approximate quantification of unknowns, is employed. In fact, any method that tries to solve the problem, by generating random numbers, the Monte - Carlo called.

Monte - Carlo simulation is a method for solving complex problems including random problems or non-random problems uses of random numbers. And the main features, the Monte Carlo method we can refer to the following two cases [11].

- Using Monte-Carlo methods require use of large amounts of random numbers. This combination led to sidestep, and non-proliferation, pseudorandom numbers.
- Using Monte - Carlo, The most commonly used when, compute exact answer, by deterministic algorithms impossible or unjustified is.

Although a single model, the method of Monte - Carlo does not exist, but it can according to their common features are described. That total includes the following steps.

- define a range of possible inputs.
- The range of the random inputs produce.
- Input produced on some specific calculations are performed.
- The results of each run, the final answer to the merger.

3. Related work

In this section some researches regarding area coverage are presented.

Slijepcevic et al in [12] and Cardei et al in [13] proposed similar approaches where nodes are divided into several joint sets. When one set of sensors are active the others should be deactivated. This method aims to find the maximized number of disjoint sets.

In [14] Zang et al proposed a node-scheduling scheme based on probing with efficient energy consumption. Off-duty eligibility rule is planned based on a probing mechanism. The sensor broadcasts a PRB probing message with in a probing range R. each node which receives this message responds with a message. If at least one response is received node goes to sleep state.

Node-scheduling based coverage mechanism is another scheme introduced by D. Tian et al in [15]. It is both localized and distributed. In this protocol one rule is utilized to determine whether sensing coverage of node is included in its neighbors' sensing coverage or not. The method, by which a node discovers whether its neighbors are able to sponsor it or not, is presented for several conditions.

Haung et al have modeled coverage problem as a decision making problem in such a way that a set of sensors are dispersed in target area [16]. The problem is to discover if whole area is covered or not. That is to say, whether each point of target area is covered by k sensors or not where k is a given parameter.

Heinzelman et al presented the most popular hierarchical protocols for clustering wireless sensor networks [17]. In this protocol time is broken into sections called rounds. Each round is divided into two phases. The first one is set-up phase and the second one is clustering phase (steady-state phase). Cluster-heads are selected based on an adaptive probability function. A random number is assigned to each node. If this number is smaller than a threshold, the corresponding node will be selected as cluster-head. In a specific period each node is selected as cluster-head only once. Thus, the energy consumption is distributed on the whole network.

In [18] Lee et al and Rosmark et al in 2005 [19] introduced a query-based scheme. In these methods sink node generates and broadcasts a query in the network. Receiving this query each node process it and transmit the query to its neighbors. When the query is completely analyzed the result is returned to sink node. In this scenario some nodes just process the query and others broadcast it and obtain detailed results, aggregate them and return them to sink node.

In some of the work done by, Bontempi et al in [20], Virrankoski et al in [21] and Soro et al in [22], the network is first clustered and then cluster heads, data from each aggregation are separate cluster.

4. Proposed scheme and evaluation cases

In this section we present proposed scheme and evaluation cases.

4.1. Classifying sensors and generating smaller regions in the main area

Each sensor has sensing range Rs and communication range Rc. Sensing area is a disk whose center and radius are sensor and sensing range, respectively. Similarly, each sensor has a communication area which is a disk centered at the sensor and its radius is communication range. Most of problems in this field are classified in this way [23].

In this paper wireless networks are demonstrated by a graph. Each node in the graph represents a sensor and each edge illustrates that two sensors are neighbors or located in a specific area around each other. In other words, if two sensors are inside their communication range an edge whose weight is 1 connects those sensors. Afterwards, for each sensor number of adjacent nodes (weight of sensor) is derived from degree of centrality; the equation shown below.

Centrality degree nodes $K^{th} = \frac{\sum_{i=0}^{n} a(Pi, Pk)}{n-1}$ (1)

- $a(p_i, p_k)$ is one if there is a direct link between two i and k nodes and zero otherwise.
- n is the total number of nodes.

Subsequent to calculating adjacent nodes for each sensor (weight of sensor), all nodes broadcast a message including the number of adjacent nodes (nodes with direct link) to their neighbors. When the degree of each node is calculated, nodes are sorted based on their degree. The node with highest degree will be selected as the first central node. If there are several nodes with the same degree one of them is randomly selected as central node. Selected node and all of its adjacent nodes are categorized in one class called first class. Then, between the rests of nodes the node with highest degree is considered as the second central node and together with its adjacent sensors it forms the second class. This process is continued till there is no unclassified node. Using this method it is even possible to have classes with merely one sensor. Now all sensors in the whole area belong to one class. The overall sensing range is the sum of sensing ranges of all sensors in that class.

Obviously, coverage area of sensors in each class might overlap with other classes. According to location of each sensor it is even possible that some sensors cover an area outside the L*L area. Hence, the overall sensing range of each class is less than sum of sensing range of individual sensors.

When classes are specified, sensing area of each class should be determined. To do so, center of each class is firstly calculated. In order to derive center of each class x coordinates (y coordinates) of all sensors inside that class are added and divided by number of sensors. Resulted number is x coordinate (y coordinate) of central point of the class. We draw a circle with center of this point which shows sensing range of the class. Various methods are proposed for calculating sensing range of a class; nevertheless, in this study, equation 2 is exploited. This equation is based on density of sensors in each class.

Sensing area size category $M^{Th} = \frac{N}{2} * \pi * Rs^2$ (2)

- π : is 3.14
- N: is the number of sensors in each class
- Rs: is sensing range of sensors.

Notice: It should be noticed that during implementation there are two constraints for equation 2. First, if the number of sensors in a class is one, its sensing area is not calculated. Second, to achieve a proper sensing area for classes with more than one sensor, a constant number is added to N/2 during implementation.

4.2. Genetic algorithm

In this step genetic algorithm is utilized to obtain optimal or close to optimal solution in each small area. By solution we mean choosing minimal number of sensor nodes for effective coverage of each small area. This is performed so that effective coverage for main area is acquired.

4.2.1. Formulation

In this section we use equation 3 as fitness function for coverage problem where goal function is defined as follows.

Min [Z= g_i3*(pc_i + AE_i +(Nc_i* h_{ij}))] (3)

Parameters of fitness function are presented as follows.

- PC_i: is sum of distances between each sensor and other sensors inside a class.
- AE_i: The amount of energy needed to turn on a sensor which is randomly selected in determined range.

- g_i: it is design variable. If i^{th} sensor of desired class is active it equals to 1; otherwise it equals to zero.
- Nc_i: Assuming two sensors i and j, if distance between these two sensors is less than determined threshold, i^{th} sensor is fined NC units (constant value).

- h_{ij}: When it is set to one it means that distance between i^{th} and j^{th} sensors is less than threshold and ith sensor must be fined.

4.2.2. Chromosome coding

In this section binary codes are utilized for variables. Chromosome length is T which is variable and equals to number of sensor nodes in each class. One value for a bit in chromosome string means that the corresponding sensor node is active; whereas, a zero denotes inactive state. For instance if a class includes 20 sensors and nodes number 2,4,9,13,14,18 are active, the corresponding chromosome string should include 1s in bits corresponding to mentioned numbers and the other bits should be set to 0.

Thus, in this step optimal number of sensors required for covering sensing area of each class, is calculated using genetic algorithm and based on mentioned goal function. In this section it is probable to select more than one sensor for each class to fulfill suitable coverage. It is worth to mention that selected sensors are the only ones which are active for each class and the rest of them stay in idle state.

4.3. Monte-Carlo simulation

In this section ratio of area covered by selected sensors to area covered by whole sensors deployed in the area should be derived. For this purpose we utilize Monte-Carlo simulation. In the following procedure of calculating percentage of coverage provided by sensors selected in previous step is explicated. A few points are randomly generated in desired area. The number of points is chosen so that we could ensure that whole area is covered. Then, number of generated points which are included in sensing range of active sensors in each step is derived.

Considering variations in the size of area and number of sensors, correct estimation of these points is problematic and there is always a probability of incorrect estimation of coverage percentage. In this study, the plain is considered as a set of points (The area is considered as a set of points with coordinates between (0,0) and (L,L). Now all points in the plain are investigated to determine percentage of coverage. Subsequently, number of points covered by sensing range of sensors, which are selected by proposed method, is calculated. If coverage percentage provided by selected sensors is more than specified threshold (which is calculated considering coverage percentage of sensors in primary state), it might be stated that selected sensors offer optimal and efficient coverage for whole area.

In proposed method, network is created in two levels. In each level at the end of data transmission round, area coverage percentage is derived. If the amount of coverage is less than defined threshold, the network is immediately deactivated. Then, sensors which were not selected in genetic step and active sensors remained from first level, constitute new network. These new sensors continue data transmission as far as they have effective coverage.

4.4. Evaluation cases

To validate our proposed method some evaluation cases are investigated which are briefly explained in this section.

4.3.1. Number of selected sensors

In this study an optimal or close to optimal solution is presented where minimum number of sensors are selected for effective and efficient coverage among all dispersed sensors. To demonstrate efficiency of selected sensors in proposed method Monte-Carlo simulation is employed.

4.3.2. Energy consumption

It is assumed that all sensors in each round transmit k bits data to base station. The energy consumption of the network in each round for all k bits data which is transmitted to base station is reported. To calculate consumed energy per round in each sensor, equation 4 which is known as Heizelman equation is exploited. This equation is stated bellow.

$$TX = \varepsilon_{elec} * K + \varepsilon_{amp} * K * d^2 \quad (4)$$

- K: number of bits transmitted from each sensor to base station per round. K is constant for all sensor nodes.
- d: distance between each sensor node and base station.

- Additionally ε_{amp} and ε_{elec} parameters are energy consumption of internal circuits of each sensor during data transmission. These are constant values as well 100Pj/bit*m^2 and 50nj/ bit are respectively equal to $100*10^{-12}$j and $50*10^{-9}$j.

4.3.3. Lifetime increase

In this study, remained energy of each selected sensor is obtained in each round of data transmission. These values are examined. If remained energy of a sensor is less than e determined threshold, it cannot transmit data anymore and it is deactivated. Moreover, in each round area coverage is evaluated. In other words, it is investigated that how many selected sensors are deactivated. If the coverage is less than 60% of desired area, the sensors which were not selected in genetic algorithm step will be activated and added to sensors remained in the network. Hence, effective lifetime of the network is increased from two aspects: 1) proper coverage with minimum number of sensors; 2) instead of one network using all sensors, multiple networks are generated with suitable coverage by efficiently selecting sensors (When all sensors are utilized simultaneously a large portion of data is common between neighboring sensors).

4.3.4. Comparison and evaluation of proposed method

To demonstrate efficiency of proposed method, it is benchmarked against a network which uses all sensors of the area which normally transmits data to sink node. The operating conditions are considered the same (regarding sensors coordinates, initial energy and so on).

5. Simulation

For our simulations C# language in Visual Studio environment is exploited. In this section simulation results are presented. First off, some defined constant parameters needed for implementation of proposed method are introduced. These parameters are similar in both samples of networks.

- It is assumed that deployed sensors are fixed and covered area is a L*L square.
- Initial population in genetic algorithm for each class is 100 chromosomes. These

chromosomes are randomly generated in terms of bit strings. Lengths of chromosomes are different and dependent on number of sensors in each class.

- Selection operation is of sort type.
- Forming new generations in genetic algorithm continues till there are 50 generations without modifications (stop criterion).
- Percentage of crossover operation is 0.8 which is single point crossover. The percentage of mutation is 0.01.
- Initial energy of each sensor is 1 J and it is deactivated as soon as its energy drops under 0.05 J.
- All sensors are capable of direct transmission of data to sink node. Effective network coverage is considered to be 60%.
- In this study networks are merely generated in two levels due to small number of sensors and size of network area.

5.1. Implementation and simulation results

In this section implementation and simulation results for three samples of experiments performed by proposed method are presented. Conditions where initial coverage of all sensors in primary shape of the network is between 90-100% are considered. Black nodes are inactive sensor nodes. Red nodes denote active sensors and the yellow nodes are center of classes. Sensing area of each sensor is demonstrated using a green circle while connecting edges of sensors are shown by blue. Sensing area of each class is also illustrated by red circles.

Results obtained from evaluation of first experiment: In this section, Proposed method is applied to a 170*170 square which includes 45 distributed sensors and simulation results are provided in this section. Sensing radius of each sensor is considered 30 while communication range between sensors is 60. sink node is located in the center of the plain.

Remained energy of sensors are calculated to 3 decimal places so remained energy is rounded. Some nodes close to sink node behave such that their energy consumption is zero. This happens due to lack of precision and rounding remained energy. Two levels of network are utilized in this study. The first level includes 29 sensors which attempt to transmit data in 953 rounds with coverage higher than 59%. The second level consisting of 23 sensors continues to 1904 rounds with coverage higher than 59%. The results are presented in table 2.a and 2.b. It should be mentioned that inactive sensors are included when remained energy is computed.

Table 1. Initial coordinates

The size of area	Number of Sensors
170*170	45

Table 1.a. Results of proposed method in first level

The first level				
The number of selected sensors	Percent coverage	Number of times Effective Executive	The remaining number of active sensors	The total remaining energy
29	96%	953	7	20.075

Table 1.b. Results of proposed method in second level

The second level					
The number of live sensors	Percent coverage	Number of times sending data the total	The number of remaining sensor live	remaining energy	Percent coverage
23	79%	1904	12	10.607	39%

Results obtained from evaluation of second experiment: In this section, proposed method is applied to a 150*150 square which includes 35 distributed sensors and simulation results are provided in this section. Sensing radius of each sensor is considered 30 while communication range between sensors is 60. Sink node is located in the center of the plain.

Remained energy of sensors are calculated to 4 decimal places so remained energy is rounded. Two levels of network are utilized in this study. The first level includes 24 sensors which attempt to transmit data in 1024 rounds with coverage higher than 59%. The second level consisting of 16 sensors continues to 1756 rounds with coverage higher than 59%. The results are presented in table 2.a and 2.b. It should be mentioned that inactive sensors are included when remained energy is computed.

Table 2.Initial coordinates

The size of area	Number of Sensors
150*150	35

Table2.a. Results of proposed method in first level

The first level				
The number of selected sensors	Percent coverage	Number of times Effective Executive	The remaining number of active sensors	The total remaining energy
24	96%	1024	5	15.8151

Table 2.b. Results of proposed method in second level

The second level					
The number of live sensors	Percent coverage	Number of times sending data the total	The number of remaining sensor live	remaining energy	Percent coverage
16	76%	1756	10	9.7643	44%

Results obtained from evaluation of three experiment: Proposed method is applied to a 100*100 square which includes 25 distributed sensors and simulation results are provided in this section. Sensing radius of each sensor is considered 25 while communication range between sensors is 50.

Remained energy of sensors are calculated to six decimal places. Sink node is out of area and located in the top left corner. Two levels of network are utilized in this study. The first level includes 15 sensors which attempt to transmit data in 864 rounds with coverage higher than 59%. The second level consisting of 23 sensors continues to 1359 rounds with coverage higher than 59%. The results are presented in table 3.a and 3.b. It should be mentioned that inactive sensors are included when remained energy is computed.

Table 3. Initial coordinates

The size of area	Number of Sensors
100*100	25

Table 3.a. Results of proposed method in first level

The first level				
The number of selected sensors	Percent coverage	Number of times Effective Executive	The remaining number of active sensors	The total remaining energy
17	98%	856	8	11.015329

Table 3.b. Results of proposed method in second level

The second level					
The number of live sensors	Percent coverage	Number of times sending data the total	The number of remaining sensor live	remaining energy	Percent coverage
16	72%	1574	10	5.959647	52%

5.2. Comparison and evaluations

Number of alive nodes and operation rounds of proposed method are compared to the condition where all sensors are engaged with data transmission to sink node. This comparison may illustrate influence of our proposed method on reduction of energy consumption and increase in network lifetime.

One must pay attention to difference between alive and active nodes. Alive nodes in first level are referred to all active nodes together with inactive ones which are not selected in genetic algorithm step; however, number of alive nodes in second level equals to number of active nodes in the network.

Figure 2 depicts number of alive sensors in different operational rounds of two networks one of them is based on proposed method and the other is a normal network, nodes normally transmit data to sink node. The area is a 170*170 square with 45 sensors. As can be seen owing to calculation of energy consumption to 3 decimal places, at the end of some data transmission rounds, energy of several sensors drops lower than 0.05 J. This leads to simultaneous deactivation of these sensors.

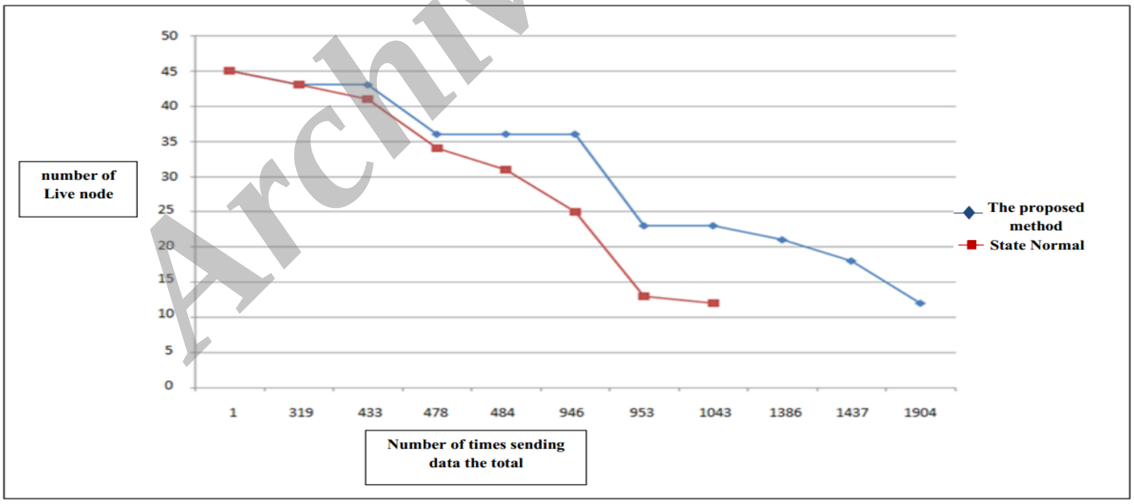

*Figure 2: Comparison of alive sensor for 170*170 area and 45 sensors*

Figure 3 illustrates number of alive sensors in different operational rounds of two networks. One of them is based on proposed method and the other is a normal network, nodes normally transmit data to sink node. The area is a 150*150 square with 35 sensors. As can be seen owing to calculation of energy consumption to 4 decimal places, at the end of some data transmission rounds, energy of several sensors drops lower than 0.05 J. This leads to simultaneous deactivation of these sensors.

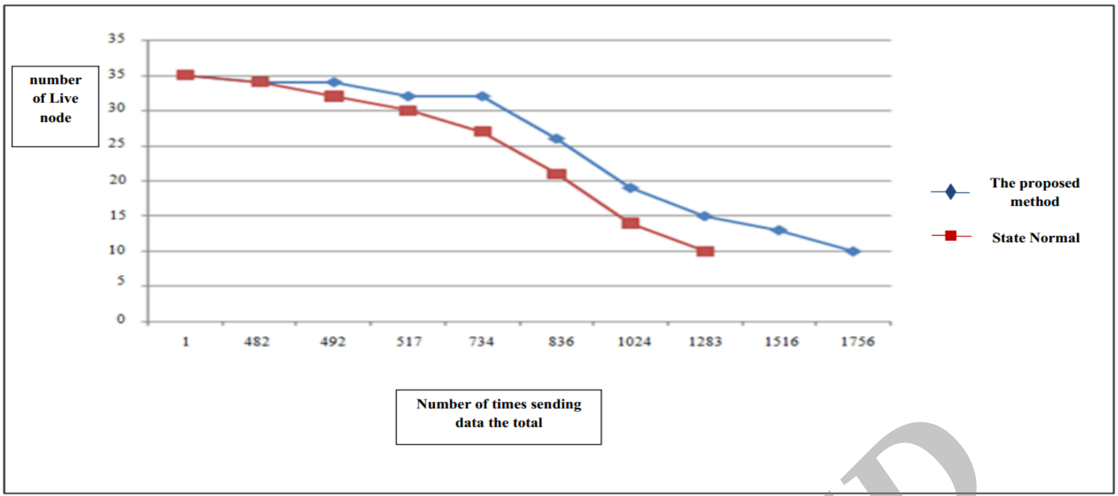

*Figure 3: Comparison of alive sensor for 150*150 area and 35 sensors*

Figure 4 illustrates number of alive sensors in different operational rounds of two networks. One of them is based on proposed method and the other is a normal network, nodes normally transmit data to sink node. The area is a 100*100 square with 25 sensors. As can be seen owing to calculation of energy consumption to 6 decimal places, at the end of some data transmission rounds, energy of several sensors drops lower than 0.05 J. This leads to simultaneous deactivation of these sensors.

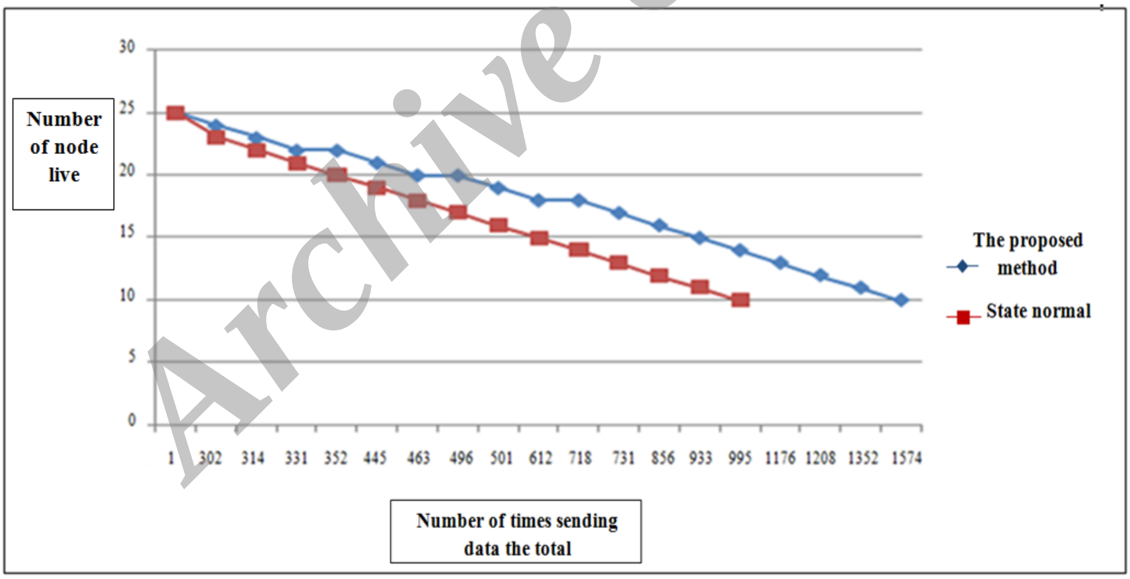

*Figure 4: Comparison of alive sensor for 100*100 area and 25 sensors*

Figure 5 demonstrates comparison between numbers of operational rounds of two previously mentioned networks where area coverage is at least 60%. These operational rounds are calculated and compared for three mentioned experiments.

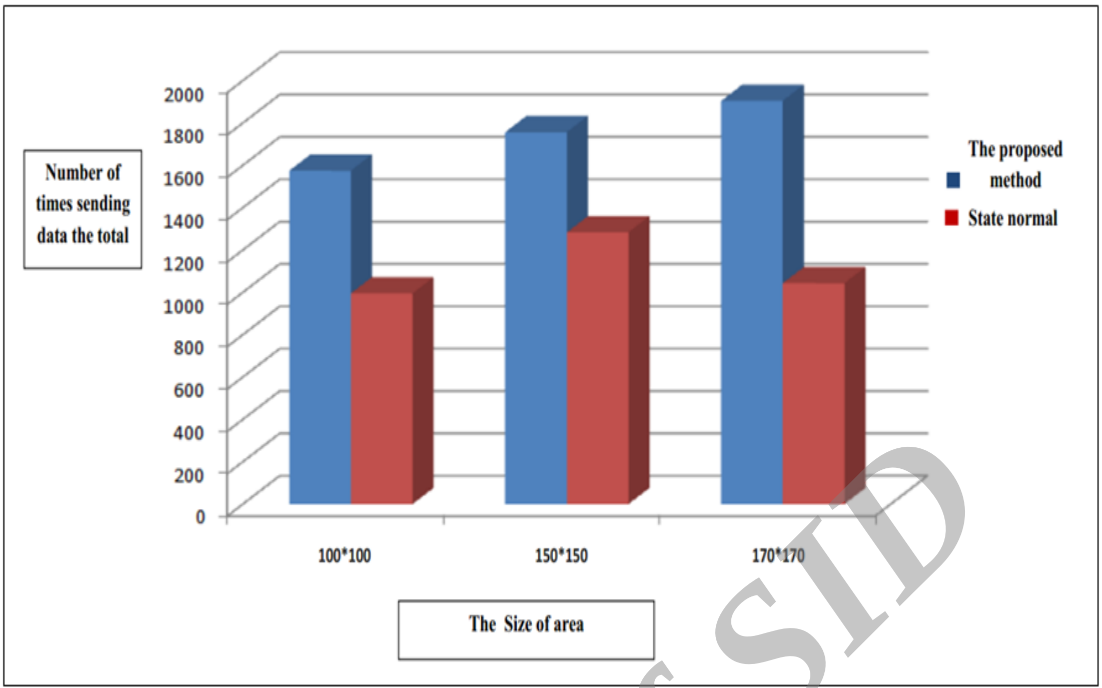

Figure 5: Comparison between operational rounds of the networks

6. Conclusion

Simulation results revealed that proposed hybrid method provides fast and feasible solution for optimization of wireless sensor networks. Furthermore, interpretability, effective decrease of energy consumption, increasing lifetime of network and effective estimation of coverage percentage (which is needed to estimate network lifetime) might be mentioned as other advantages of this method.

The following might be named as benefits of this scheme.

- Despite most of other methods where scheduling parameters are emphasized, this method uses percentage of coverage as a measure to calculate effective lifetime of network.
- Regions generated in the area are not constant. The size of smaller regions depends on density of sensors in that region.
- The length of chromosomes in genetic coding is not constant. It depends on number of sensors in each class which leads to generating optimal or close to optimal solutions.
- It is possible to determine percentage of coverage provided by selected sensors in each data transmission round.
- The interpretability of our method is another advantage which is indebted to capability of being simulated.

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