A New Approach for Covering Wireless Sensor Networks with Optimum Number of Nodes in Order to Prolonging Network Lifetime

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ABSTRACT

In recent years, wireless sensor networks are in great use in applications like disaster management, combat field reconnaissance, border protection and safe care. Although, much research has been done on wireless sensor networks, but in the quality of service (QoS) field there are not enough researches. Since these networks are widely used in many areas, there are different QoS parameters in contrast with traditional networks such as network coverage, optimal number of active nodes, network lifetime and energy consumption. We have proposed an automata-based scheduling method to improve the QoS parameters of the networks. In this method, each node is equipped with a learning automaton to select its correct status (active or passive) at any given time. Simulation results show that the proposed method in comparison with some existing methods such as: CCP, Lacoverage, PEAS and Ottawa reduce energy consumption and increase network's lifetime. As a result, several QoS parameters are considered in sensor networks, simultaneously.

Keywords

wireless sensor networks; energy consumption; coverage; learning automata.

1. INTRODUCTION

Wireless sensor network is a kind of networks which are composed of many small nodes that each node includes several sensors. The communications between these nodes are wireless. These networks interact strongly with the physical environment, that is, they receive the environment's information via sensors and react by their actuators on the environment.

Each node works independently, without human intervention, and it is physically a very small device. They have some restrictions in their processing power, memory and power supply, etc. These restrictions lead to some problems which they originate new research issues in this field.

It should be noticed that each sensor's radio can be in one of the following four modes: send, receive, wait, and passive. In wait mode, the transceiver will not transmit anything and in passive mode, the radio is turned off and switches to the listening mode. Beside, the receive and wait modes might require the same amount of energy, whereas the passive mode requires the less amount of energy.

Since the nodes have a limited energy in the wireless sensor networks, one of the design challenges is to reduce the energy consumption of the nodes in order to maximize the network's lifetime. Therefore, the proposed method allows the nodes to save their energy by switching between active and passive modes. Changing the mode of each sensor to achieve desired goals is called scheduling mechanism. On the other hand, there must be a certain number of active nodes to ensure coverage at any time. According to the above facts, to prolong the network lifetime, it requires energy-saving mechanisms to manage the radio components of the sensor nodes; such methods are same as the scheduling mechanisms.

A scheduling mechanism plans, so that the sensor nodes are activated just when needed. Provided that they would cover the area that the other active nodes would not cover it simultaneously. Therefore, in such applications, the scheduling mechanism should plan the sensor nodes which the minimum number of active nodes could cover all targets in the network.

2. RELATED WORKS

2.1 Coverage configuration protocol

In this section, one of the best approaches in the coverage area is introduced which is called Coverage Configuration Protocol (CCP). Providing KS degree of coverage for the environment is the main goal of the CCP approach [3.12]. That is, each point in the environment should be covered by minimum number of Ks active nodes.

The more coverage degree of the network leads to higher sensing precision of the environment and higher fault tolerance against nodes corruption. On the other hand, the higher coverage degree causes the more number of nodes to remain active; as a result, it decreases the network life time. In this approach, the following assumptions have been considered:

Each node like v has a sense area, called S(v) that is covered by the node.The sense area of each node is a circle.The sense area of each node like v has a same radius equal to Rs which represents by C(v,Rs). Any two nodes v and u can communicate directly with each other, when they are in communication radius (R_c) of each other ($|uv| \leq R_c$) Each node knows its exact geographic position.

In the CCP approach, each node sends some information to its neighbors such as geographic position and its status. Based on the information that each node receives from the other nodes and the fitness algorithm, it identifies the status of itself (active or passive).

2.1.1 Fitness algorithm for the CCP method

Each node achieves coordinates of its environment and the neighbor nodes. Then, the existence of minimum Ks number of active nodes is inspected for each node repeatedly in its neighborhood area. If there is minimum Ks number of active nodes, then the node will consider as a redundant node, otherwise it should be active.

According to the fitness algorithm, the sensor nodes can be switched between different states. Each node can be in one of the active, passive and listening states. In order to save energy, the node turns off its radio components in the passive state.

Each passive node enters to the listening mode in the specified intervals and receives the messages from its neighbors. Based on the received information, the passive node identifies once again its fitness by the fitness algorithm. In the active state, the node senses its environment and communicates with the other nodes. If density of the nodes increases in the environment, and a node identify itself as a redundant node, it will switch to passive mode.

Since each node checks its state independently and based on the local information, conflicts may occur between the state changes in a neighborhood. As an example, when an active node dies, may be several neighboring passive nodes simultaneously identify themselves worthy to activate and switches to the active state, as a result, too much and unnecessary cover is created. To avoid this problem, two states called “join” and “withdraw” is used.

If a node identifies itself to be active, it won’t activate immediately. Instead, it switches to the join state and remains in that state until a certain period of time. At the end of the period, it runs the fitness algorithm once again. If it finds itself worthy to be active again, it switches to the active state otherwise; it remains in the passive state. Similarly, in order to transmit from active state to the passive state, each node enters to the withdraw state. The state transition cycle of the CCP approach for the sensor nodes, is presented in figure 1.

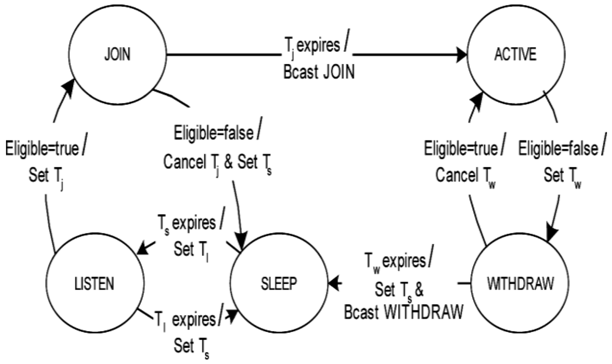

Fig. 1. The state transition cycle of the CCP approach for the sensor nodes.

2.2 Learning automata

Learning automata is a conceptual model that chooses one of its actions, randomly and applies it to the environment. The environment evaluates the applied action and informs its attribute to the learning automata by the specific signal. According to the received signal, the Learning automata rewards or penalizes the applied action and update its situation and then chooses the next appropriate action. Fig. 2 shows the relation between the learning automata and the environment [1].

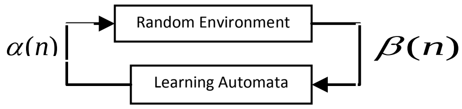

Fig. 2. Relation between the learning automata and the environment

The environment can be shown by three components $E=\{\alpha,\beta,c\}$, where $\alpha=\{\alpha_1,\alpha_2,...\alpha_r\}$ is a set of inputs, $\beta=\{\beta_1,\beta_2,...,\beta_r\}$ is a set of outputs and $c=\{c_1,c_2,...,c_r\}$ is a set of penalty probabilities. The environment has different models based on the kind of responses that it generates. In the P-model environments $\beta=\{0,1\}$ which $\beta_1=1$ and $\beta_2=0$ are considered as penalty and reward, respectively. If β be a finite set of members, the environment will call Q-model; otherwise, it will call S-model. Also c_i is the penalty probability corresponding to α_i. Learner automats have divided into two static and dynamic structures.

3. THE PROPOSED APPROACH

One of the major issues in wireless sensor networks are discussed the sensor coverage problem. This issue is due to the following fundamental question: “How well do the sensors observe the physical space?”

The coverage concept is one of the QoS measures in the area of the wireless sensor networks. The goal is to have each location in the physical space within the sensing range of at least one sensor.

Since the network consists of many nodes then the location of each node cannot be pre-determined and they cannot be placed manually, therefore the nodes are randomly distributed in the space. Thus, the number of distributed sensors may be more than the number of required sensors. In other words, the sensors are densely distributed for the complete coverage of the space.

Energy consumption in the sensors is another major issue which it must be considered here. Since the energy of the sensors is provided through battery, besides, due to the large number of sensors and unavailability of the space, replacing or recharging the batteries is not possible. Discharging a battery leads to finishing a sensor’s life. When some of the sensors have been lost, as a result the network coverage has violated. Thus, the sensor network’s lifetime has ended practically. As mentioned before, sensor network’s lifetime is one of the measures of QoS in sensor networks and it should be prolong as much as possible.

Considering the two issues discussed, the densely distribution and energy consumption of the sensors, a method could be presented for guarantee the network coverage while it reduces the energy consumption in sensors and increases the network’s lifetime. By so doing, the both discussed criteria of QoS will satisfy. The major idea in this method is deactivating some nodes and this action hasn’t any effect on the network coverage; besides, these nodes could be activated, whenever they are needed. This method is described in more details, as follows:

The assumptions

It has been assumed that, number of sensors almost distributed uniformly in a space with specified coordinates; besides, the initial energy of all the sensors is equal, also their covering radius is equal, too. Considering the sensing range of each sensor and the range of their communications correspond to rs and rc, respectively; it has been assumed: rc > = 2rs. This means that each node can be communicated directly to the nodes which the distance between them is twice of their sense range. By existence of the condition, besides if the coverage degree of the space be one, then the network would be connected absolutely [2]. This means that all nodes in the network can communicate with the sink node. This is true in most real sensors; for instance, MICAII [3.12] is a real sensor which it has a communication range of approximately one thousand meters and the sensing range of about one hundred meters. Nodes that are in the communication range of a node are considered as neighboring nodes which it can exchange information directly with them.

The next assumption is that each node knows its position; otherwise it can achieve its position using GPS system (with a little energy consumption) [4.13] or calculating it using positioning methods that are designed for sensor networks in [5-8]. Furthermore, all nodes of the space are identical; it means that the rs and rc of them are the same. Meanwhile, the space has been considered with two dimensions.

Furthermore in this approach, it is assumed that each node can have four states: active, passive, send/receive, and listening. When a node is in passive mode; then, its energy consumption is minimum. The goal of this approach is to maximize the number of passive nodes while network coverage is guaranteed. For this purpose, before deactivating a node, it should be examined whether its sensing area is covered completely by k neighboring active nodes or not. It is assumed that all the nodes are in passive mode, initially.

As mentioned before, if the sensing area of a node is coverable by its k neighboring active nodes, then it is called redundant node; therefore, there should be a mechanism to determine the redundancy of a node and such a mechanism has been proposed, subsequently.

3.1 The proposed mechanism for determining the redundancy of a node

The proposed algorithm performs most of its computations in the sink node. The sink and the other nodes in the network are equipped with Learning Automata (LA) and act as follows:

First, the LA of sink selects a node Si randomly and examines whether the sensing area of this node can cover the entire network or not. If the answer be negative then the sink starts to calculate subscription of coverage area of the Si with every other node. Wherever the subscription result is empty, in order to reduce the search cost, the search action can be cut off; otherwise, the search action can be continued until it finds a node like Sj that has minimum subscription with the Si node. Next, the sink calculates the coverage area's union of the Si and Sj nodes $(S_i \cup S_j)$. Then it evaluates the relation: $NetworkArea \in Area \ldots of\,(S_i \cup S_j)$. If the network can't cover by the area of $(S_i \cup S_j)$; then, the sink node starts to calculate the intersection for the area of $(S_i \cup S_j)$ and the other nodes like Sk; that is: $((S_i \cup S_j) \cap S_k)$. When the result in relation $((S_i \cup S_j) \cap S_k)$ be empty, then the search action will terminate; otherwise, it will continue until it finds a node which its intersection with the area of (Si∪Sj) be minimum. If the sink cannot find such a node, then the new node Sk will be added to the previous set of nodes, and their union will evaluate to have intersection with each of other nodes as illustrated in the following relation: $(S_i \cup S_j \cup ... \cup S_m) \cap S_p$ (Si∪Sj∪…Sm) ∩Sp).

In this process, the nodes are added one by one to the union set until they cover the entire network, which is presented by: $NetworkArea \subseteq (S_i \cup S_j \cup ... \cup S_p)$. After recognizing all the union set nodes for covering the network, the sink node starts to activate these nodes and makes passive the other nodes.

After a working period, because of energy consumption in the active nodes, the LA penalizes them and rewards the passive nodes. Thus, in the next iterations of the algorithm, the probability of choosing the nodes with more energy will be increased by the LA.

In spite of the first iteration of the algorithm, that all the nodes were considered in the calculated intersections, in the next iterations the algorithm chooses the nodes that have more energy and supporting radius (rs), in contrast to the others. The procedure of the proposed algorithm has illustrated in figure 3.

```
LAsink=selects a node like Si
Union=Si
UNION_cover=calculating the space covered by UNION
While(entire area of network is not  subset of union_cover)
begin
  For (all not selected nodes such Sj)
    begin
      Flag=calculating the intersection(Sj, UNION_cover);//flag =false if there is not Sj intersection
      withUnion_cover
      If(flag==false) begin
        Sk=Sj
        exit for()
      Else
        Sk= finding a node with minimum intersection with UNION_cover
      End if
  endFor
union=(union  U  Sk)
UNION_cover=calculating the space covered by UNION
endWhile
```

Fig. 3. the proposed algorithm for determining the redundancy of a node.

4. SIMULATION RESULTS

In this section, performance of the proposed algorithm is evaluated using variety of experiments. In order to perform the experiments, the network simulator of MATLAB has been used.

In the experiments, the achieved results from executing the proposed coverage algorithm is compared with some of the best previous approaches include: CCP [3.12], Ottawa [10], and PEAS [11]. It should be noted that the Ottawa and PEAS approaches are able to solve only the problems with coverage degree of one. It is worth noting, the coverage degree of one means that each area of the network be covered by at least one sensor.

To compare the performance of the algorithm, two measures are considered: 1) number of active nodes in each iteration, 2) network lifetime.

In the first experiment, it is obtained the appropriate value of MaxIteration for full coverage of the network. In the second experiment, it will be shown that the proposed method by a minimum number of active nodes can solve the coverage problem with different degrees (i.e, different values of k). In the third experiment, the network lifetime is evaluated in the proposed method compared with the other methods.

4.1 Conditions of simulation

In the simulations, a fixed sensor network is considered that the sensors are distributed randomly and uniformly in a 100m * 100m region. Communication and sensing range of the sensors are considered 20 m and 10 m, respectively. Meanwhile, the initial energy of each sensor node is selected randomly from the range of [1.8 .. 2]. In the experiments, size of the data and control packets are considered 526 and 8 bytes, respectively. The number of sensor nodes which is considered in the experiments include: 100, 200, 300, 400 and 500 nodes. Each experiment has been executed 5 times for each number of nodes. In this section, the obtained results are the average of 5 times executions.

4.2 First experiment

Science keeping active the optimal number of nodes as well as ensuring complete coverage of the network is the major idea in the proposed algorithm; therefore, one of the important issues in algorithm is the maximum number of times that each node can iterate the learning algorithm to achieve a proper situation (MaxIteration). The lowness of the MaxIteration leads to perform the learning phase incorrectly; besides, the network coverage will not complete. Furthermore, the great amount of the MaxIteration results in high energy consumption during the learning phase.

As mentioned above, the proper amount of MaxIteration is determined in this experiment which its results are presented in figure 4. Based on the figure 4, the network coverage reaches 100 percent when the MaxIteration is considered 50; so, this value has been used in the experiments of this paper. It should be noted that, the results obtained in this experiment are the same with the results obtained in [9].

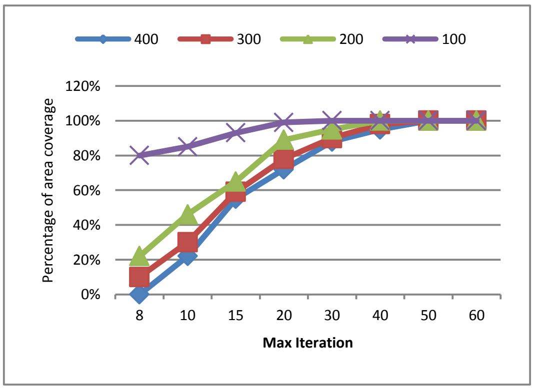

Fig. 4. Evaluating the proper MaxIteration in order to achieve complete network coverage for different number of sensors.

4.3 Second experiment

In this experiment, the performance of the proposed algorithm has been evaluated. In this study, the evaluated measures include: the number of active nodes at any coverage degree, and the average ratio of energy in the active nodes to the passive nodes. As noted before, the Ottawa and PEAS approaches are able to solve only the problems with coverage degree of one.

The ratio of the active nodes number to the entire deployed nodes achieved by different approaches has been illustrated in figure 5; as it can be seen, the proposed approach outperforms the other methods.

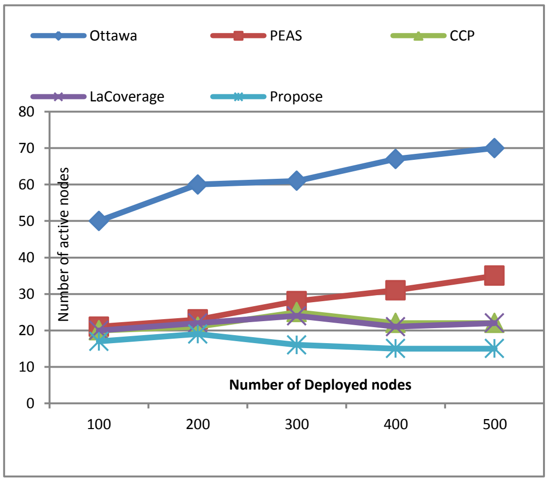

Fig. 5. Comparing the number of active nodes in different coverage approaches.

In contrast to the CCP approach, the main advantage of the proposed method is to use the Learning Automata for keeping active the high-energy nodes. Furthermore, the PEAS, Ottawa, and CCP methods don't consider energy of the nodes.

In these methods, the average amount of energy in the active nodes is lower than the passive nodes. In the examined methods, since the active nodes are kept active for a longer period of time, also they endure a lot of load, and then these lead to lose them in the network; as a result, the network lifetime decreases. Figure 6 illustrates the results of comparing the average ratio of active nodes' energy to the passive nodes' energy in the CCP, LaCoverage, and the proposed approaches with different coverage degrees. As it can be seen, in the proposed method the mean energy level of the active nodes is significantly higher than the passive nodes which lead to great increase in the network lifetime.

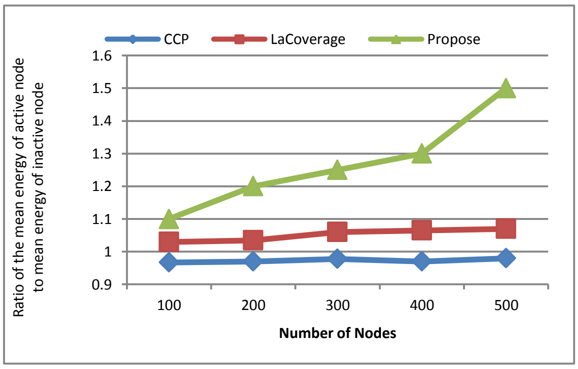

Fig. 6. comparing the average ratio of energy level in active nodes to the passive nodes in different methods.

4.4 Third experiment

In this experiment it is illustrated that the proposed method can lead to increase the network lifetime. In these experiments, the end of network's lifetime has been considered when the whole living nodes (nodes that their battery has not been finished yet) couldn't cover the entire network altogether. The network lifetime has been compared in three methods: CCP, LA-based method, and without use of any coverage algorithms. In the later one, all nodes of the network had been active and the network lifetime had been the least amount. In these experiments, the active nodes send the information to the sink in several steps. In the CCP algorithm, since the energy of nodes doesn't considered, then in each execution of the algorithm some specific nodes are selected for keeping active which leads to rapid loss of the nodes. However, the idea of the proposed method is to prolong the network lifetime by selecting the nodes with maximum energy to keep active. The experiments results have shown in figure 7.

5. CONCLUSION

In this paper, the coverage problem of the wireless sensor networks was studied. In this area, the coverage problem is important because if it does not use optimized algorithms for network coverage, its lifetime will be reduced dramatically.

In this paper, a new mechanism based on learning automata has been introduced which every node has equipped with an automated learning machine. The proposed method affects the amount of energy consumption. Each automated learning machine determines that whether the related node is needed for covering the network or not. Therefore, the extra nodes will be disabled; as a result the number of active nodes will be less than other approaches in each cycle. In this way the energy of the passive nodes will save for the future use.

According to the computer simulations, it has been shown that by applying the new algorithm, the results have been improved significantly in terms of: covering the environment, energy consumption in each node, the number of active nodes, and the network lifetime. The results show that in terms of above metrics, the proposed algorithm outperforms the other evaluated approaches.

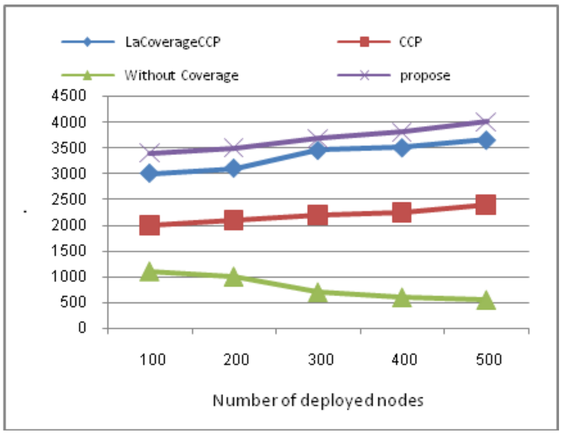

Fig. 7. Comparing the network lifetime in three methods: CCP, LA-based method, and without use of any coverage algorithms

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