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Energy-Efficient Sensor Activity Scheduling Protocol for Wireless Sensor Networks

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ABSTRACT

The power depletion is one of the critical issues in Wireless Sensor Networks (WSNs) since most sensor nodes are provided with limited power irreplaceable / rechargeable batteries. One fundamental way to minimize the power consumption is to exploit the spatial data correlation among the sensor nodes by reducing the number of active nodes especially in the dense sensor network. In this paper, we propose Energy-efficient Sensor Activity Scheduling (ESAS) protocol for WSNs that periodically choose the best representative set of sensors that will be activated during the sensing phase in the current period. ESAS works into periods. Each period is composed of three phases: data collection, decision, and sensing. ESAS measures the similarity degree among the sensor data that collected in the first phase and makes a decision of which sensors stay active during the sensing phase in each period and put the other nodes into low-power sleep mode with maximum level of accuracy. The simulation results are conducted based on real world datasets provided by Intel Berkeley Research Lab using OMNeT++ network simulator show that the effectiveness of the proposed ESAS protocol in energy saving and extending the network lifetime.

1. INTRODUCTION

Wireless Sensor Network (WSN) composed of hundreds or thousands of nodes, which deployed in high density manner in the area of interest for different purposes such as battle field surveillance, disaster observation, smart homes and many other applications [1]. Sensor nodes data reporting can be divided into two general categories event-based data reporting and continuous data reporting. In event-based data reporting, the sensor nodes send the data to the sink when an event triggered. On the other hand, in continuous data reporting the sensor nodes continuously send their readings to the sink such as humidity and temperature monitoring [2].

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The high density deployment of sensor nodes in area of interest causes the data redundancy at the sink node and leads to an unnecessary power consumption since some nodes remain active whilst they sense redundant data. Therefore, we need a protocol for scheduling the sensor activity by making sleep/active schedule for the sensor nodes that minimize the data redundancy at the sink and eventually save the power since the power is the most important constraint in the sensor nodes that must be considered when design any protocol for the WSN.

The main contributions in this paper are as follow.

i. We propose a protocol, called the Energy-efficient Sensor Activity Scheduling (ESAS) protocol, which exploits the correlation among the sensor nodes for scheduling the sensors to minimize the data redundancy at the sink and maintain the data accuracy and improve the network lifetime. ESAS works into periods. Every period is composed of three stages: data collection, decision and sensing. In data collection stage, all the nodes will be activated and send the data to the cluster head to find the correlation among the sensors reading. The decision stage executes a memetic algorithm at the sink node (or cluster head) to choose the best set of active sensors for the current period and deactivate the other nodes. The active nodes in the sensing stage continue transmitting the sensed data to the sink node until the end of the current period.
ii. A modified optimization model that uses the data correlation among the sensor nodes so as to decide which sensors stay active and which sensors will turn off.
iii. Extensive simulation experiments using OMNeT++ simulator are conducted to demonstrate the efficiency of ESAS protocol. . Simulation results based on multiple criteria (Number of active sensors, energy consumption, data loss ratio, transmitted data ratio) illustrate that the proposed ESAS protocol can minimize the energy consumption and transmitted data with suitable data loss ratio.

The reset of the paper is organized as the follow. Section 2 presents the related works on various scheduling protocols in WSNs. Section 3 describes the proposed ESAS protocol. The results are presented in Section 4. Section 5 demonstrates the conclusion and future works.

2. RELATED WORK

Energy-efficiency is one of the important requirements in WSN protocol design since most of WSN nodes are battery powered. Several scheduling approaches are proposed in the literature. The authors in [3, 4, 5] proposed scheduling algorithm for maintaining the coverage and improving the network lifetime of WSNs. They proposed optimization models based on both primary points and perimeter coverage model to optimize both the coverage and the lifetime of WSNs. Some other existing approaches exploit the spatial correlation among the sensor data in WSN for making sleep/active schedule in order to increase the network lifetime [6, 7, 8].

The authors in [6] proposed a method in which the base station divides the sensors into n sets by using closeness factor. This method supposes the close nodes can sense the same data. Depending on shift base while the previous set of nodes exhaust its battery the other set of nodes will be activated. The work in [7] is presented structure fidelity data collection (SFDC) framework which consists of two phases: learning and data collection. In the learning phase, the framework utilizes the spatial correlation of the collected data. It

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introduces cluster formation approach that includes cluster head selection and active node selection in each cluster based on similarity index in sensor readings. In data collection phase, all the active nodes continue to send the data to the cluster head. Three algorithms are proposed in [8] for active node selection and less energy consumption. The first algorithm is Cover Sets Balance algorithm (CSB) to select a set of active nodes that have wide data coverage ranges and high energy levels. It depends on the tuple (data coverage range, residual energy) to find an initial active node set and then balance the size of the cover sets in order to replace low-energy nodes. The second algorithm is Correlated Node Set Computing algorithm (CNSC) to calculate the correlated node set with minimum set size and the maximum geometric mean of residual energy of each node in the sensor network to use the correlation results in the next algorithm. The third algorithm is High Residual Energy First algorithm (HREF) to further reduce the number of active nodes selected by CSB algorithm. Xu et al. [9] suggested a data-coverage method in which the active sensor can recover the missing data of sleeping nodes. This method is based on the data correlation between the sensor nodes. A Greedy Reduction Algorithm (GRA) to select the set of active sensors is proposed. The missed data of sleeping nodes can be returned using the sensed data of active nodes as well as the correlation between the sensor nodes.

3. THE PROPOSED ESAS protocol

In this section, we describe the proposed ESAS protocol for minimizing the energy consumption in wireless sensor network, and decreasing the data redundancy at the sink node.

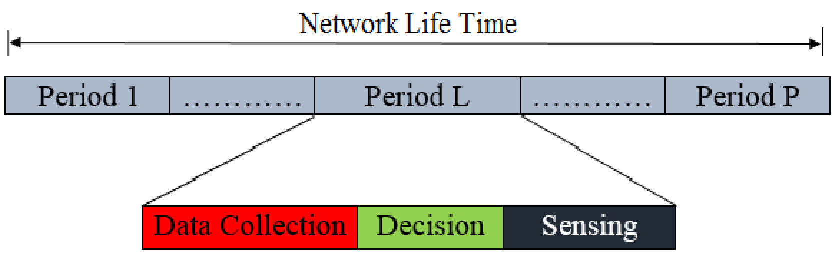

Figure 1. Proposed ESAS Protocol

ESAS protocol mainly divides the network lifetime into P periods. In each period, there are three stages data collection, decision, and sensing as described in the Figure 1. In data collection phase all the sensor nodes wakeup and send their sensed data to the sink for making a decision using a metaheuristic optimization algorithm to provide the best representative set of sensor nodes which are responsible for monitoring during the sensing stage. In the sensing stage the active sensor nodes are responsible for sensing and sensing the sensed data to the sink. ESAS protocol uses two types of packets: DataPacket for sending the sensed data of each sensor node to the sink, and the StatusPacket used by the sink after achieving the optimization for informing the all the sensor nodes with their new status (active or sleep). The DataPacket is 328 bits length (8 bits for header and 320 bits for 10 data reading). The StatusPacket is 16 bits length (8 bits for header and 8 bits for the status of the sensor, 0 is sleep, 1 is active).

In this paper, the main objective of ESAS protocol is to minimize the active sensor nodes and maximize the network lifetime with maintaining an acceptable level of data accuracy.

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Our mathematical optimization model is inspired from [10] with some modifications. Let S = {s_1, s_2, …, s_i, …, s_N} the set of the sensor nodes in the network of size N. Let X_{ij} represents a binary indicator for the correlation between the sensor i and the sensor j. In the decision phase, we exploit the correlation matrix X_{ij} that extracted at the first stage to decide which sensor node will remain active in the next stage of the period (sensing) and which node go to the sleep mode until the next period for saving the power.

$$X_{ij} = \begin{cases} 1 & \text{If the sensed data of the sensor i correlated with sensed data of the sensor j or i=j} \\ 0 & \text{Otherwise.} \end{cases} \quad (1)$$

The data correlation between two sensor nodes is calculated by applying the Jaccard similarity between their two data sets A and B as follow

$$J(A,B) = \frac{|A \cap B|}{|A \cup B|} = \frac{|A \cap B|}{|A| + |B| - |A \cap B|} \quad (2)$$

The data are sorted in A and B and a difference function is used to compare the similarity between each opposite elements inside A and B. The Difference function can be defined as in (3), where α is a threshold fixed by the application.

$$Difference\ (A_i, B_j) = \begin{cases} 1 & \text{if } |A_i - B_j| \le \alpha \\ 0 & \text{Otherwise.} \end{cases} \quad (3)$$

$$S_i = \begin{cases} 1 & \text{If the sensor i is active} \\ 0 & \text{Otherwise.} \end{cases} \quad (4)$$

$$V_d = \begin{cases} (\sum_{i=1}^{N} X_{id} * S_i) - 1 & \text{The number of correlations with other sensors} \\ 1 & \text{Otherwise.} \end{cases} \quad (5)$$

The optimization problem can be formulated as follow.

Minimize $\sum_{d=1}^{N} V_d$ (6)

Subject to

$\sum_{i=1}^{N} X_{id} * S_i = 1$ (7)

We propose to use a metahuristic search algorithm for solving our optimization problem. A memetic algorithm is suggested to find the best sensor set S after applying the optimization model. The proposed memetic algorithm is a combination between a differential evolution with local search (Hill climbing) to recombine the results and preventing the local optima. Figure 2 shows the pseudo code of the proposed activity scheduling based memetic algorithm.

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Algorithm 1 Activity Scheduling based Memetic Algorithm

Input: X: correlation matrix, NodesNo, Crp, and P.

Output: S: the set of the sensor nodes status (0 sleep, 1 active).

```
popSize = K;
noOfGen=Z;
BestFittness=W;
S[NodesNo] ←—— 0;
Temp[NodesNo]←—— 0;
Initialize the population Randomly;
For i=1:popSize  // Calculate the fitness for the population
Fitness(population[i], X, NodeNo);
End For
For a=1: noOfGen
  For p=1:popSize
    Temp = population[p];
    Mutate (Temp, NodesNo, P);
    Crossover (Temp, NodesNo,Crp);
    localSearch(Recombine(Temp));
    If(Fitness(Temp, X, NodeNo) < Fitness(population[p], X, NodeNo))
      population[(p+1)%popSize]=temp;
    End If
  End For
  For z=1:popSize
    If(Fitness(population[z], X, NodeNo) < BestFittness)
      S= population[z];
      BestFittness= Fitness(population[z], X, NodeNo);
    End If
  End For
End For
```

Figure 2. Proposed activity scheduling based memetic algorithm.

At the end of the decision stage, the sink node transmits a StatusPacket for every sensor node based on the values of vector S that provided by the optimization algorithm based on the memetic approach. The active nodes stay sending the data to the sink until the end of the current period.

4. RESULTS

In this section, we conducted several experiments based on real sensor data from [11] and using OMNeT++ network simulator [12]. In order to evaluate our ESAS protocol, some performance metrics are used during this simulation such as Average of active sensor nodes, Data loss ratio, Transmitted data ratio, and energy consumption. ESAS protocol applied the energy consumption model that proposed by Heinzelman [13].

4.1 Average of Active Sensor Nodes

In this experiment, the average number of active sensor nodes versus α is studied. Figure 3 shows the average number of active nodes for the deployed nodes in Intel Berkeley Research Lab. As shown in Figure 3, when the value of the threshold α of the Difference

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function increases, the number of active sensor nodes decreases. This is due to the high correlation between the data sets of the sensor nodes when the value of α increased.

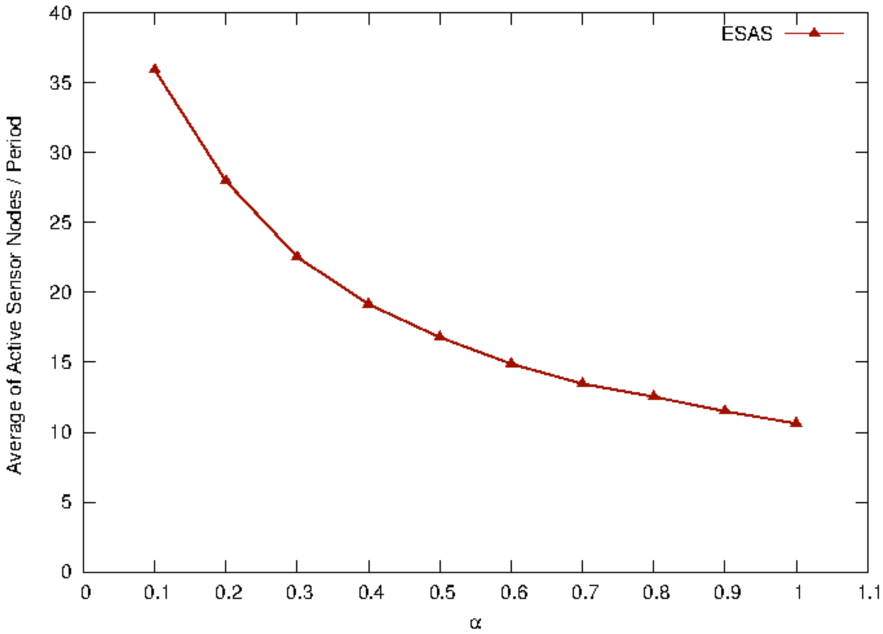

Figure 3. Average number of active nodes for the deployed nodes in Intel Berkeley Research Lab..

4.2 Transmitted Data Ratio to Sink

In this section, the percentage of the transmitted data to the sink node is investigated. Figure 4 shows the transmitted data ratio to the sink node. The results show that the sink node receives as less number of data as possible when the threshold α increases. This is due to the small number of active nodes provided by the ESAS protocol after performing the memetic optimization algorithm based on the correlated data of the sensor nodes.

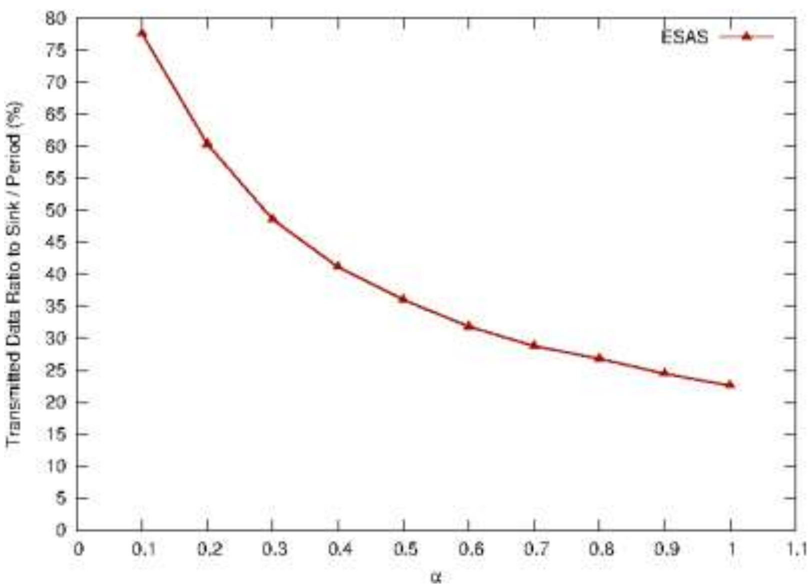

Figure 4. Transmitted data ratio to the sink node.

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4.3 Data Loss Ratio

This experiment studies data loss ratio after applying the scheduling algorithm in the network. Figure 5. Shows the data loss ratio after receiving the data at the sink node. As shown in this figure, ESAS protocol loses a lot of data when the threshold α increases because it activates a smaller number of sensor nodes due to the high correlation between the sensor nodes.

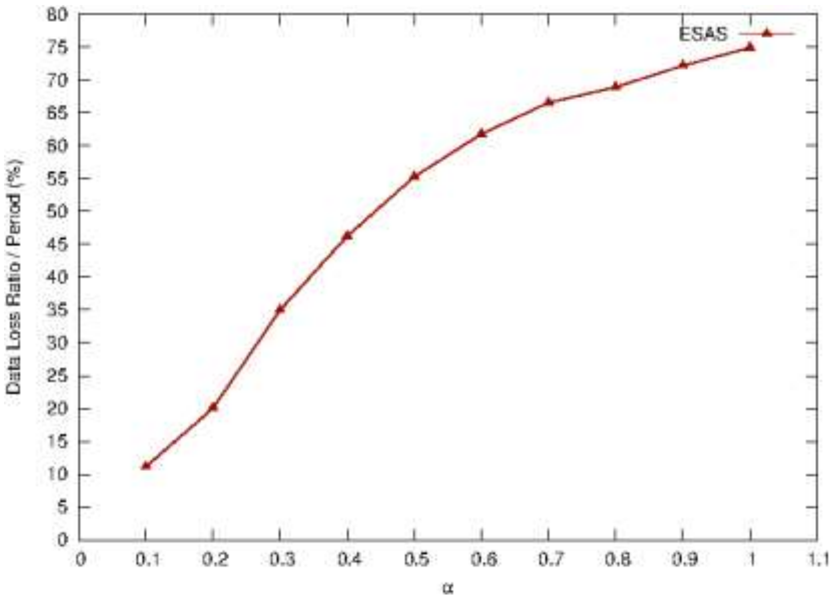

Figure 5. Data loss ratio.

4.4. Energy Consumption

In this study, the performance of the ESAS protocol from the energy consumption point of view is investigated. Figure 5 illustrates the consumed energy by the sensor nodes during applying our ESAS protocol. The results show that ESAS protocol can consume less energy when the value of α increases due to increase the correlation between the sensor nodes and thus decreases the number of active sensor nodes.

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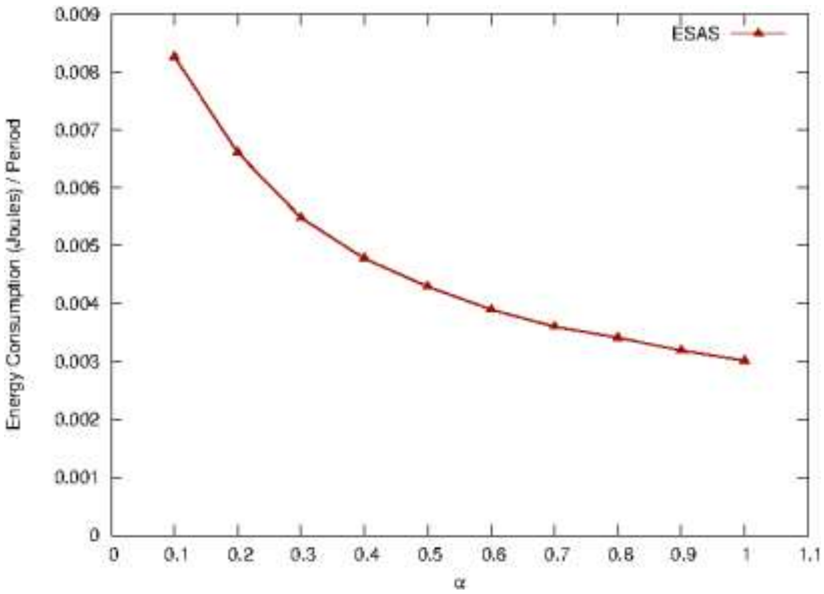

Figure 5. Energy consumption.

5. CONCLUSIONS AND FUTURE WORKS

One of the essential problems in WSNs is to provide a best sensor activity schedule that save the energy of the sensor node while ensuring a suitable level of accuracy for the received data at the sink. One solution is to exploit the data correlation between the sensor nodes so as to decrease the energy consumption in the WSN. In this paper, we propose Energy-efficient Sensor Activity Scheduling (ESAS) protocol for WSNs. It is periodic and it chooses the best representative set of sensor nodes which are activated during the sensing phase in the period. Each period in ESAS is composed of three phases: data collection, decision, and sensing. Experimental results demonstrate the effectiveness of ESAS protocol in terms energy efficiency, data loss ratio, number of active nodes, and the transmitted data ratio to the sink.

In the future, we will include the energy inside the optimization model in order to prevent selecting the low power nodes and to improve the balancing in selecting the sensor nodes in each period. In addition, we plan to compare our protocol with some recent existing method to show the superiority of our protocol.

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