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Sensor Activity Scheduling Protocol for Lifetime prolongation in Wireless Sensor Networks

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Abstract: ***In Wireless Sensor Network (WSN), the dense sensor nodes deployment in the sensing field can be exploited in conserving the energy of the whole network, where the data of these nodes can be highly correlated. Therefore, it is necessary to turn off the unnecessary nodes that sense similar sensor readings so as to reduce the redundant sensed readings and decrease the communication overhead thus extend the WSN lifetime. This article suggests a Sensor Activity Scheduling (SAS) protocol for lifetime improvement of WSNs. SAS works in a periodic way. It exploits the spatial correlation among sensed sensor data in order to produce the best sensor activities schedule in WSNs. SAS composed of three phases: data collection, decision-based optimization, and sensing. SAS measures the similarity degree among the sensed data that collected in the first phase. It makes a decision of which sensors stay active during the sensing phase in each period and put the other nodes into low power sleep whilst keeping a good accuracy level to the received data at the sink to conserve the power and enhance the lifetime of the WSN. Several experiments based on real sensed data and by using OMNeT++ simulator demonstrate that SAS can save energy and extend the WSN lifetime efficiently compared with the other methods.***

Keywords: WSNs, scheduling, optimization, energy saving, Metaheuristic, spatial correlation.

1. INTRODUCTION

WSNs are one of the most prominent components in the Internet of Things (IoT) future. WSN is composed of a huge number of tiny devices which are capable of sense, process, store, and communicate with limited capabilities. Each sensor node is equipped with a limited battery life. Each node gathers the sensed data from the surrounding environment and then transfers the data to a sink across transmission media [25, 26].

On one hand, the dense nodes deployment in the area of interest can ensure full area coverage and optimal target observation; on the other hand, it increases the volume of data redundancy produced by this tiny sensing devices and aggregated at the sink node. The nearby sensor nodes will send similar readings to the sink. These redundant readings lead to bandwidth exhausting, the congestion in the WSN, increase processing at the sink node, and energy consumption in WSN thus decrease the WSN lifetime. Hence, it is essential to develop protocols which decrease the volume of readings redundancy sensed by these tiny devices before send them to the base station. One important energy saving approach is to produce the sensors activities schedule so as to decrease the number of active nodes by turning off unnecessary nodes whilst keeping the suitable level of data accuracy at the sink node. This approach can decrease the energy consumed by the sensor nodes and improve the WSN lifetime. The principal contributions in this article are outlined as follow:

i. We suggest a new protocol called Sensor Activity Scheduling (SAS) to schedule the activations of sensor nodes (sleep/active) based on the data correlation among them such that the redundant data is reduced and the lifetime of WSN is improved whilst ensuring a good level of data accuracy for the received data at the sink node.
ii. A modified mathematical optimization model is suggested. Rather than attempting to schedule the sensor nodes based on a set of certain targets / points as suggested in the most techniques in the literature, an integer program based on data correlation among the sensor nodes is formulated. The main objective of this model is to decide which sensors stay active and which sensors will turn off based on the correlated sensed data which are received at the sink node.
iii. We propose a metaheuristic memetic algorithm to solve this scheduling problem. The memetic algorithm obtains the suitable sensors set which is responsible for sensing during the sensing phase. The proposed memetic algorithm is a combination between differential evolution algorithm with simulated annealing as a local search algorithm to recombine the results and preventing the local optima.
iv. Extensive simulation experiments using OMNeT++ network simulator, are conducted to demonstrate the efficiency of SAS protocol in comparison with two scheduling methods proposed in [17, 19]. Simulation results based on multiple criteria such as the active sensors nodes ratio, energy saving ratio, energy consumption, data loss ratio, and transmitted data ratio illustrate that the proposed SAS protocol can minimize the energy consumption and transmitted data with a suitable data loss ratio.

The reset of the paper is organized as follow. In

Section 2, we discuss the related works on various scheduling protocols in WSNs. In Section 3, we describe the proposed Sensor Activity Scheduling (SAS) protocol. The results are present in section 4. Section 5 demonstrates the conclusion and future works.
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2. LITERATURE REVIEW

In WSN, the high data correlation among the sensor readings especially in the dense sensor network, the correlation can be exploited to maintain the power and prolong the WSN lifetime by making sleep/active schedule. In this section, we explore several approaches that extend the network lifetime by making efficient sleep/active scheduling. The authors in [22, 23, 24] 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 approaches exploit the spatial correlation among the sensor data for making sleep/active schedule in order to increase the network lifetime [5, 6, 7, 8, 9]. In [5] the base station divides the nodes to N sets based on closeness factor. It is supposed that the very close sensor nodes sense the same data. Whereas the earlier group of sensors drain its power, the other set of nodes will be activated. In [6] the structure fidelity data collection (SFDC) framework is proposed which consist of two phases: learning and data collection. In learning phase, the framework utilizes the spatial correlation of the collected data and first introduce cluster formation approach that includes cluster head selection and active node selection in each cluster based on similarity index on the sensor readings. In data collection phase, all the active nodes continue to send the data to the cluster head. The authors in [7] proposed three algorithms for active node selection and least energy consumption. The first algorithm is Cover Sets Balance algorithm (CSB) to select a group of active sensors 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 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. The authors in [9] propose a scheduling method called (SASS). It takes into account the data redundancy for making sleep scheduling approach. It changes adaptively the scheduling scheme when the number of non-sleep neighboring sensors is more than a certain value of threshold or the data loss ratio is greater than the average loss ratio during the test mode when the nodes send to passive mode. Xu et al. [14] suggested a data-coverage method in which the active sensor can retrieve the lacking readings of the sleep sensor nodes. The algorithm depends on the correlation among the sensor nodes data. A Greedy approach called (GRA) is proposed to choose the group of the active sensor nodes. The sleep sensor nodes missed readings can be returned utilizing the active sensor nodes sensed readings and the similarity among the sensor nodes. In [10], the authors propose an iterative heuristic method called (IAND) to find the correlation-dominating set for WSNs and greedy method to obtain the best nodes. In [11] the authors propose a Scheduling method called (CPCSS) that depends on the similarity model for calculating the correlation degree between the data of sensor nodes and partition the nodes into different classes. The redundancy degree among the nodes is calculated according to their sensing area. Then, a centralized method based on the partition of the target area is devised to get the minimum number of nodes.
An improved memetic algorithm is proposed in [18]. It changes the range of sensing of each node by eliminating the intersection in the range of sensing among the sensor nodes and divide the entire sensor nodes into several subsets where each subset monitors the entire target area. It executes the idea of genetic approach and utilizes the local improvement to enhance the optimal solution among the cover sets that can perform full area coverage without blind points (points not covered by any sensor). The work in [20] presents an adaptive clustering method which divides the sensor nodes into clustering groups based on data correlation among the sensor data. The nodes that represent the group send the data to the sink which eventually remove the data redundancy to conserve the energy of the network and improves the network lifetime. In the research paper [21] the authors proposed a technique to determine an efficient schedule for the gathering of data in WSNs. The proposed algorithm adaptively changes these sampling schedules to create dynamic samples based on inter node and temporal data correlation among the sensor data.
Our Proposed protocol reduces the energy consumption by making sleep/active schedule for the sensor nodes by exploiting the correlation among the sensors data and eventually save the energy thus improve the lifetime of WSN. The protocol work into periods where every period is composed of three stages: data collection, decision and sensing. In data collection, all sensor nodes will be activated and send their data to the sink node to extract the correlation among the sensor reading to be used in the decision stage. The sink node executes a memetic algorithm to find the best group of nodes to be turned on in the phase of monitoring of the current period. The active sensors continue to send the data to the sink in the sensing phase until the end of the current period.

3. THE SUGGESTED SAS PROTOCOL

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

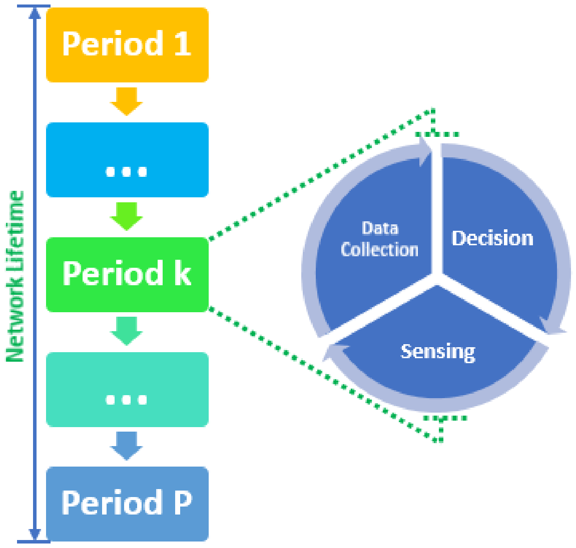

Figure 1 Proposed SAS Protocol

SAS protocol mainly divide the network lifetime into P periods. In each period, there are three stages sensing, decision and data collection described in the Figure 1. In data collection phase, all the sensor nodes wakeup and send their data to the sink for making a decision using a metaheuristic optimization algorithm to provide the best representative set of sensor nodes which are stay active in the sensing stage. In the sensing stage, the active sensor nodes are responsible for sensing and transmitting sensed data to the sink. SAS 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 sensor nodes with their new status (active or sleep). The DataPacket is 328 bits length (one byte for header and 40 bytes for 10 data reading). The StatusPacket is two bytes length (one byte for header and one byte for the status of the sensor, 0 is sleep, 1 is active). In this paper, the principal goal of SAS protocol is to minimize the active sensor nodes and maximize the network lifetime with maintaining an acceptable level of data accuracy. Our mathematical optimization model is inspired from [10] with some modifications. Let S = {s1, s2, …, si, …, sN}, the set of the sensor nodes in the network of size N. Let Xij represents a binary indicator for the correlation between the sensor i and the sensor j. In the decision phase, we exploit the correlation matrix Xij 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 Euclidean score is a way to indicate the percentage of similarity between two things. It produces a value between 0 and 1. The 1 value refer to the 100% similarity percentage. The score can be computed as follows

$$Euclidean\ Score = \frac{1}{(1 + Euclidean\ Distance)} \quad (2)$$

Euclidean distance is the distance between two points in Euclidean space. It can be calculated using the following formula

$$Euclidean\ Distance = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2} \quad (3)$$

We specify the sensor state as follow

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

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

The optimization model can be formulated as follow.

Minimize

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

Subject to:

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

$$S_i \in \{0, 1\}, \forall\, i \in N \quad (8)$$

$$V_d \in \mathbb{R}^{+} \quad (9)$$

In the decision phase, the proposed memetic algorithm is applied to solve the modified optimization model inspired from [10]. This model is based on the correlation matrix X_{ij} so as to produce the optimal (or near optimal) solution vector S which represents nodes states (active/sleep) for the sensing phase in the current period. In the sensing phase, the protocol utilizes the nodes states vector S that found in the previous phase to decide which nodes continue to send their data to the sink and which nodes go to the sleep mode until the next period.

We propose a metaheuristic memetic search algorithm for solving scheduling optimization problem. The memetic algorithm is suggested to find the best sensor set S after applying the optimization model. The proposed memetic algorithm is a combination between DE (Differential Evolution) algorithm and SA (Simulated Annealing) as a local search algorithm to recombine the results and preventing the local optima. Algorithm 1 shows the proposed Memetic Algorithm, whilst Algorithm 2 is a Simulated Annealing which is called inside the Algorithm 1 as a local search.

Algorithm 1: Proposed Memetic Algorithm

Input: X (Correlation Matrix), N, P_m, P_c, P_{Size}

Output: S (Binary vector indicate nodes status (0 means sleep ,1 means active))

1. Initialize the population randomly
2. Calculate fitness value for each individual using our optimization model.
3. Do While (Stopping condition is Not satisfied)
4. For $y \leftarrow 1$ To P_{Size} Do
5. Temp $\leftarrow$ Ind_y;
6. Mutatation (Temp, N, P_m);
7. Crossover (Temp, N, P_c);
8. SimulatedAnnealing (Recombine(Temp));
9. If (Fitness (Temp, X, N) < Fitness (Ind_y, X, N))
10. $Ind_y \leftarrow$ Temp;
11. End If
12. End For
13. End While
14. S $\leftarrow$ Slect the best Ind_z ($z = 1, \ldots, P_{Size}$);
15. Return S;

Algorithm 2: Simulated Annealing Algorithm

Input: Temp, T,CoolingRate, kmax.

Output: The optimized Temp (0 means sleep ,1 means active)

1. Initialize T with large value.
2. Initialize the CoolingRate with small fraction
3. While (T is not small enough) do
4. For $k = 1$ to kmax do
5. Snew $\leftarrow$ neighbor(Temp) //Generate a New neighbor
6. Calculate ΔS = fitness (Snew) $-$ fitness(S)
7. If ($\Delta S < 0$)
8. Temp $\leftarrow$ Snew
9. Else if ($\Delta S > 0$ And probability (ΔS, T) > Random(0,1))
10. Temp $\leftarrow$ Snew
11. End If
12. End For
13. T $\leftarrow$ T $*$ CoolingRate
14. End While
15. Return Optimized Temp

After the decision step, the sink node transmits a StatusPacket for every sensor node based on the values of vector S that provided by the Memetic optimization algorithm. The active nodes continue transmitting the sensed readings to the sink until the end of the current period. Figure 2 explains the flowchart of the SAS protocol.

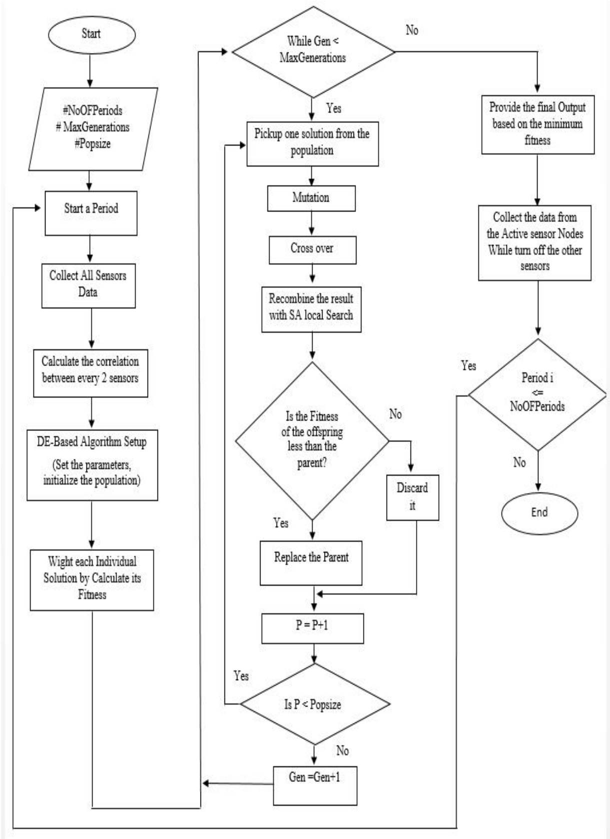

Figure 2 Flowchart for the SAS protocol

4. SIMULATION RESULTS

To show the efficiency of the SAS protocol and validate its powerful in energy saving and extending the network lifetime, this section explains several experiments based on a data set conducted from Intel Berkeley Research Lab [11] and by using OMNeT++ network simulator [12]. Figure 3 shows a Sensor deployment in the Intel Berkeley Research Lab, as shown in this Figure, there is one sink node at the center of the Lab. In order to evaluate our SAS protocol, some performance metrics are used during this simulation such as active sensor nodes Ratio, Data loss ratio, Transmitted data ratio, energy consumption, and energy saving ratio. We compare our work with two existing methods: degree and residual energy (CDRE) strategy presented in [19] and SimilarityMetrics method that proposed in [17] which exploit inter-node similarity metrics to schedule the sensor nodes. SAS protocol applied the energy consumption model that proposed by Heinzelman [13]. Table 1 show the parameters used in our simulation.

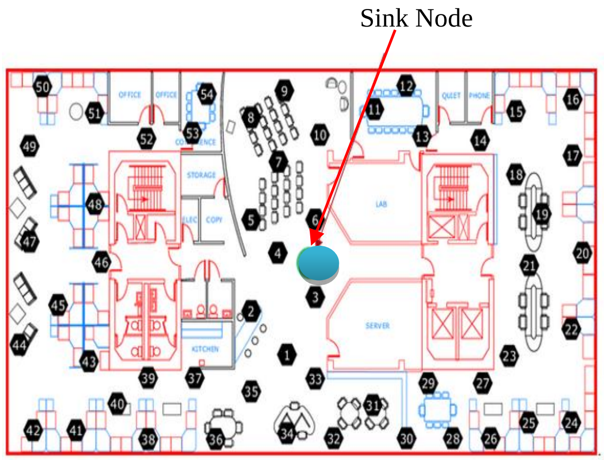

Figure 3 Sensor deployment in the Intel Berkeley Research Lab.

Table 1 Simulation parameters

Parameter	Description	Value
NodesNO	Number of nodes in the network	10, 20, 30, 40, 50
K	Similarity threshold for Euclidian score	0.9
Sr	Sensor sensing range	15 m
Csp	Spatial correlation threshold	$2 \times Sr$
Ctp	Temporal correlation threshold	0.45
Tcs	Threshold cosine similarity	0.999999
Tpc	Threshold Pearson coefficient	0.99
minEnergy	Minimum energy level for each node	0.000216441
P_c	Crossover probability	0.5
P_m	Mutation probability	0.2
T	Initial temperature for SA algorithm	600
Tthreshold	Temperature threshold for SA algorithm	0.02
coolingRate	Cooling rate for SA algorithm	0.2
P_{Size}	Population size in DE algorithm	100
MaxGen	Maximum number of generations in DE Algorithm	63

4.1. Active Sensor Nodes Ratio

It is essential to minimize the active sensors number in each period to preserve the power and then extend the life of the sensor battery. Figure 4 exhibits the ratio of active sensors to 50 deployed nodes and for the proposed SAS protocol compared with two other scheduling methods (CDRE and SimilarityMetrics). The experiment clearly shows that our SAS protocol significantly decreases the active sensor nodes number over the periods which eventually led to decrease the energy consumption and extend the network lifetime.

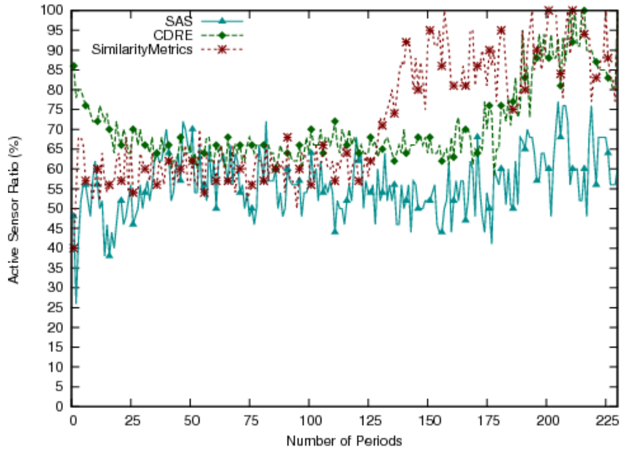

Figure 4 The active sensors ratio.

4.2 Data Sent Ratio

In this experiment, we study the ratio of the send data from the active sensor nodes to the sink node in all three scheduling methods for several sizes of WSNs as shown in Figure 5. We notice from the figure that the SAS protocol provides better performance when the network size increases. The CDRE method provides better results for small network sizes (less than 30 nodes). Due to activating as less number as possible of sensor nodes using SAS protocol, this leads to minimize the data transmitted to the sink node thus increase the network lifetime.

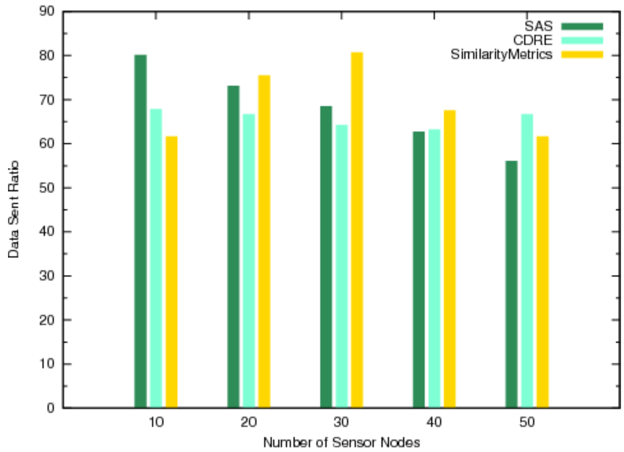

Figure 5 Data sent ratio.

4.3 Data Loss Ratio

In this section, we study the effect of the number of missed readings at the sink node for different network sizes ranging from 10 to 50 sensor nodes. As shown in Figure 6, when the network size increases, the data loss ratio increases for our proposed SAS protocol. Our protocol has lost the least number of readings for different network sizes compared with other methods. This can improve the data accuracy that received at the sink node.

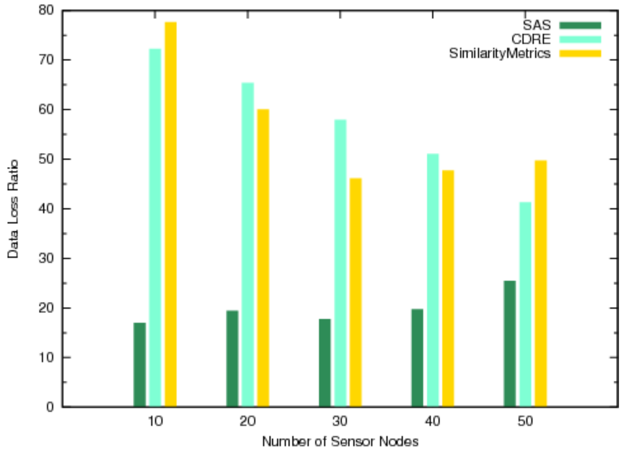

Figure 6 Data loss ratio.

4.4 Energy Consumption

The consumed power of the sensor network is studied for several sizes of WSNs, and the three methods are compared. Figure 7 exhibits the consumed power for several sizes of WSNs. The experimental results confirm that the SAS is the best protocol from the standpoint of consumed energy. As shown in Figure 7, SAS protocol consumes much less power than the other techniques. Indeed, the Memetic optimization algorithm permits to the active nodes number and consumed energy to be decreased significantly whilst maintaining a good accuracy level compared with other approaches. When the WSN size increases, the energy consumption is the lowest with SAS protocol.

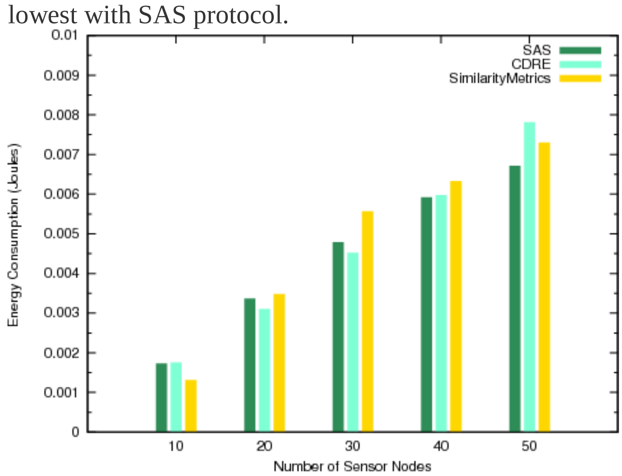

Figure 7 Energy Consumption.

5. CONCLUSIONS AND FUTURE WORK

The energy conservation in WSNs represents a big challenge that must be taken into account during design any protocol for these networks. Since the nodes in the network are provided with limited power batteries and the depletion of nodes' energy will limit the lifetime of the whole network, therefore, it is necessary to consider the energy consumption of the sensor nodes during any protocol design for WSNs. In this paper, we propose sensor activity scheduling protocol (SAS) that produces a sleep/active schedule for the sensor nodes depending on the correlation among the sensor data sensed from the surrounding environment. Our protocol measures the similarity degree among the sensors data and then makes a decision to provide the active/sleep schedule for the sensor nodes in the network. SAS protocol works in a periodic way. Each period composed of three stages: data collection, decision-based optimization, and sensing. SAS protocol uses proposed a memetic optimization algorithm to solve our improved optimization model to choose the best set of sensors to be activated in the sensing phase in each period. Several experiments have been performed to assess the suggested SAS. The experimental results confirm that SAS is the more energy saving compared with the other methods, with respect to active sensor ratio, energy saving ratio, data transmitted ratio, data loss ratio, and energy consumption. In future, we plan to expand our optimization model to produce schedules are prepared for several periods of sensing and based on the data of heterogeneous sensor nodes.

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Biography

Dr. Ali Kadhum IDREES is currently an assistant professor in Computer Science at the University of Babylon, Iraq. He received his Ph.D. degree in Wireless Networks in 2015 from the University of Franche-Comte (UFC), France. He has several research papers in Wireless Sensor Networks (WSNs) and computer networks. His research interests include Wireless Networks, WSNs, SDN, IoT, Distributed Computing, Data Mining, and Optimization in Communication Networks.

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