Energy Efficient Protocol for Heterogeneous Wireless Sensor Network using Ant Colony Optimization

Saburi Parvatkar, Deipali Gore

Department of Computer Engineering, PES's MCOE, Pune University
Pune, Maharashtra, India

Abstract— **Wireless Sensor Network (WSN) is a collection of spatially distributed sensor nodes which are used to monitor environmental conditions. These sensor nodes collects information in analytical form, converts it to digital information with the help of ADC converter and routes the converted information to the sink node either directly or with the help of network of nodes. Since sensor nodes are usually mounted in remote and hostile areas and have limited battery life, optimum energy utilization is vital.** Therefore there is a need to limit energy use. The proposed algorithm saves energy consumed during the switching activities of sensor nodes. Conventional scheduling protocols plan the activities of devices in either active state or sleep state. The proposed protocol introduces a new state called Low Power State. If the data packet to be sent is very small, then the energy consumed in switching the nodes from active state to sleep state and vice versa is very high. Low power state keeps nodes in idle mode where in the nodes' radio will be active but will neither send nor receive anything. The proposed protocol satisfies sensing coverage and network connectivity constraints. Ant Colony Optimization (ACO) is a well known metaheuristic. It helps to find out the maximum number of disjoint connected covers that will satisfy both sensing coverage and network connectivity. Pheromone and heuristic information is used to find the coverage set of active sensors. The search experiences and domain knowledge used in ACO helps to accelerate the search process.

Keywords— **Ant Colony Optimization (ACO), Energy Efficiency, Pheromone, Time Division Multiple Access (TDMA), Wireless Sensor Network (WSN).**

I. INTRODUCTION

Sensors have become an important part of our life. They are used in every nook and corner. They are indispensable. A Sensor node is made up of microcontroller, battery source, ADC and the sensor. The sensor senses the region which lies within the sensing range of the sensor node. The analog data sensed by the sensor is converted to digital form by the Analog to Digital converter (ADC) and the information is routed to the sink node. The sensor node is powered by battery. These batteries are usually non rechargeable. And even if they are rechargeable, it becomes difficult to recharge them since the sensor nodes are usually deployed in remote and hostile area. The main sources of energy wastage are collision, overhearing, idle listening and over emitting. Collision results into resending of data package. In overhearing the nodes receives packets that are destined for other nodes. In idle listening the nodes listen to the channel to receive possible data traffic whereas over emitting is caused by the transmission of a message when the destination node is not ready.

Efficient utilization of Energy is a key design objective in Wireless Sensor Networks. Wireless sensor networks can be either homogeneous or heterogeneous. In homogeneous WSN, nodes are identical in terms of battery energy and hardware complexity. A heterogeneous sensor network consists of two or more types of nodes with different battery power and functionality [1].

A number of methods have been proposed for finding the best way to utilize the energy of the sensor nodes. Some of the methods include scheduling algorithms, Genetic Algorithms, Particle swarm optimization algorithms and ant colony optimization algorithm [2][3]. The main aim of the proposed protocol is to maximize the network lifetime, which can be defined as the period that the network satisfies the application requirements.

The outline of the paper is as follows. Section II, covers the literature survey. Section III discusses the proposed approach followed by conclusion.

II. LITERATURE SURVEY

A. Scheduling Protocols

In wireless sensor network, nodes listen to the channel even if no data is placed on the channel, i.e. idle listening. This happens because the nodes do not know when data will be placed on the channel. This issue is solved by TDMA protocols. Scheduling protocols are TDMA protocols. They reduce energy consumption by planning the activities of the devices [6]. Optimization techniques that consider device control approach which includes sleep/wakeup activities are found to be more effective.

TDMA protocols have a fixed time slot for transmitting and receiving data. And therefore, every node after receiving and transmitting data goes in sleep mode or active mode and thus saves battery power. TDMA protocols reduce data transmissions because collision does not occur in TDMA protocols. But most of the TDMA protocols either put the nodes to sleep state or active state. Fixed low power modes involve an inherent trade-off. Deep sleep modes have low current draw and high energy cost and latency for switching the nodes to active mode while light sleep modes have quick and inexpensive switching to active mode with a higher current draw [4][5].

Before designing any protocol for Wireless sensor network, it is important to study how the energy consumption takes place in a node. Energy consumption depends on the nodes' state. At any given time, a node can be in any of the following four states. Transmit, receive, idle and sleep. Transmit and receive states are used for transmitting and receiving data. The default state is idle state where in the nodes simply keep their radio on for possible data traffic. Stemm and Karz have shown that idle: receive: transmit ratios to be 1:1.05:1.4 [7] while Freeny have shown the ratio to be 1:2:2.5 [8]. It is found that the energy consumed during sleep state is very less compared to rest of the state. Hence instead of keeping the nodes in the idle state, the nodes must be put to sleep state.

A further advancement to this can be done. Instead of putting the node to either sleep or active state, the node is put low power state. When to put the nodes to any of these states depends on the length of data transmission. If the length of data to be transmitted is less than the threshold set, the nodes instead of putting to sleep state are put to low power state. In low power state the nodes don't switch of their radio, the way they do in sleep state, instead they stay in idle state. If the length of data is greater than the threshold, the nodes put their radio to sleep state. This advancement is done because if the data packet is very small, then to switch the nodes' radio from sleep to active state and vice versa consumes more amount of energy [10][11][12].

The limitation of scheduling methods is it need the devices to be densely deployed in an interest area. To achieve a longer lifetime, it is important to find the maximum number of disjoint subsets of devices in the scheduling methods.

B. Particle Swarm Optimization Algorithm

The Particle swarm optimization (PSO) is a population based optimization technique. In this technique, first the population is initialized with random solutions and after every iteration the population is updated. Throughout the process, the search is made for better optima. The PSO technique use several particles, each represents a solution, and finds the best solution with respect to a given fitness function.

PSO is based on the social behaviour of bird flocking. Each single solution is a bird in the search space. It is called a particle. All particles have fitness values that are evaluated by the fitness function to be optimized. In every generation, each particle is updated by following two 'best' values. The first one is the best solution achieved so far by the particle. The other best solution is the best solution obtained so far by any particle in the population [14].

C. Ant Colony Optimization (ACO) Algorithm

Ant Colony optimization (ACO) is a probabilistic technique for solving computational problems. ACO is proposed by Marco Dorigo. ACO utilizes search experiences and domain knowledge to accelerate the search experiences. Search experience is represented by the 'pheromone' and the domain knowledge is represented by the heuristic information. Ants are the stochastic constructive procedures that build solutions while walking on a graph. Ants act concurrently and independently and thus helps to get high quality solution via global co-operation [15]. ACO uses probabilistic sensor detection model. Sensors detect the event being monitored. The intensity of the data sensed attenuates exponentially with the distance between the PoI and the sensor. The probabilistic sensor model considers the uncertainty of event detection. The detection probability exponentially decreases. The main aim of ACO is to minimize cost of sensor nodes. The EEC problem can be stated as an integer programming problem and is described as follows:

$$minimize \sum_{i=1}^{N} c_i x_i$$

subject to coverage constraint and connectivity constraint. c_i is the cost of the sensor node i and x_i take value 1 or 0 depending on whether the sensor node i is selected or not respectively. The above constraint ensures that the sensors form a complete coverage to the target; all monitoring results obtained are transmitted to the sink node.

ACO has following advantages over Scheduling protocols [13]:
1. ACO utilizes search experiences and domain knowledge to accelerate the search process.
2. In ACO, ants are stochastic constructive procedures that build solutions while walking on a graph.
3. Ant act concurrently and independently.
4. High quality solution emerges via global co-operation.
5. Indirect communication via interaction with environment (stigmergy).
6. Decreases direct communication.
7. Pheromone evaporates. Thus helps to avoid being trapped in local optima.
8. Distributed computation avoids premature convergence.

III. PROPOSED APPROACH

To achieve longer lifetime it is important to find the maximum number of disjoint connected covers [9]. Connected covers are disjoint subset of devices which will satisfy the coverage constraint and network connectivity. Coverage constraint ensures that every Point of Interest (PoI) will be covered by at least one sensor and network connectivity ensures that the sensed data will be routed to the destination following a network of sensor nodes. That is, no sensor node will be left stranded. The proposed algorithm works as follows:

At the beginning of the TDMA frame a function is called to find the disjoint connected covers. After getting the optimal disjoint cover, the transmission process starts. Whenever a node wants to send a data packet, the packet size is calculated. This packet size is compared with the threshold set. If the data packet size is lesser than the threshold then all the sensor nodes, not present in the connected cover, are put to lower power state. If the data packet is big, then the non participating sensor nodes are put to sleep state. It has been found that the energy

consumed during low power state is less compared to energy consumed during switching from active state to sleep state and vice versa when the data packet to be sent is very small.

To find disjoint connected covers, ACO algorithm is used. Three pheromones are used to store heuristic information. The connected covers are found by following below two stages.

In the first stage, all sensor information (eg. Position, sensing range, characteristic values, residual energy, current cost), Point of Interest (PoI) information are collected. Adjustable parameters are set. And the global pheromones are initialized. One global pheromone stores the number of required active sensors per PoI. The second global pheromone is used to form a sensor set with fewest active sensors.

In the second stage, each ant starts a travel and while the termination condition is not satisfied, it tries to find out the connected cover using local pheromone and roulette wheel method. At the completion of each PoI, the ant updates its local pheromone with a predefined pheromone value ρ. When one connected cover is found out the global pheromones are updated.

Termination conditions are the connectivity and sensing constraints. In the end, sensor and PoI information are updated and the process stops.

Thus, introducing low power state and ACO concept in the scheduling protocol helps to utilize the sensor nodes' energy in a better way. And thus increase network lifetime.

IV. CONCLUSIONS

In this paper, a novel approach for efficient use of sensors' energy is proposed. Basic scheduling methods optimize the protocol by putting the sensors' radio to sleep state when not in use. When a sensor node is used to carry out a transmission, its radio stays in active state. The proposed algorithm introduces a new state called low power state. When data packet to be sent is very small, the energy consumed to put the nodes' radio from active to sleep state and vice versa is very high compared to energy saved by sleep state. Low power state keeps the nodes' radio in idle state and consumes less power than switching the states. ACO helps to find the disjoint connected covers. ACO algorithm uses three types of pheromones. One local pheromone helps to find the coverage set with fewer sensors. And two global pheromones help to optimize the number of active sensors per PoI. The simulation is carried out using OMNet++ simulator.

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