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Research Article

An Ant Colony Optimization Algorithm for maximizing the lifetime of Heterogeneous Wireless Sensor Network

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Abstract

Wireless Sensor Network is made up of numerous tiny sensor nodes. These sensor nodes are battery powered. Maximizing the lifetime of wireless sensor network is very important. Inspired by the noval approach followed by Ant Colony Optimization algorithm to solve combinatorial problems, this paper proposes an ACO-based approach to solve the energy efficient coverage problem of wireless sensor network. The algorithm finds maximum number of disjoint sensor node sets that satisfies sensing coverage and network connectivity. Probabilistic sensor detection model is used to get the intensity of sensed data. The approach is effective and efficient in increasing the lifetime of wireless sensor network.

Keywords: *Ant Colony Optimization (ACO), pheromone, network lifetime, Wireless Sensor Network (WSN).*

1. Introduction

A Wireless Sensor Network (WSN) can be defined as a network of small embedded devices, called sensors, which communicate wirelessly following an ad hoc configuration. These networks are designed to handle very low data throughput (as low as few bits/day), exchanging lower throughput and higher message latency for longer node battery life, lower cost, and self-organization. Applications include Industrial control and monitoring, Home automation and consumer electronics, Security and military sensing, asset tracking and supply chain management, Intelligent agriculture ,environmental sensing, Health monitoring. The sensor nodes are generally unattended after their deployment in hazardous, hostile or remote areas. These nodes have to work with their limited and non replenish able energy resources hence Communication protocols for WSNs, including routing and MAC layer protocols, should be designed energy-efficiently. Traditional wireless MAC protocols such as IEEE 802.11 are not available for this purpose; since in these protocols, nodes are required to keep awake to listen to the medium even when the network becomes idle. This inefficient idle-listening mechanism wastes substantial energy.

The major causes of energy wastage at MAC layer are *collision*, *idle-listening*, *over-hearing* and *control packet overhead*. Collision occurs when the transmission packets are corrupted partially or fully. *Collision* causes retransmission thus increases the latency and power consumption. Listening to an idle channel for possible traffic is called *idle-listening.* In order to conserve energy most of the energy efficient protocols put their network interface in sleep state rather than in idle state. Receiving packets which are meant for other nodes is called *over-hearing*. *Control packet overhead* occurs when more number of control packets are used. Use of more numbers of control packets not only increase, the energy consumption but also decrease, the utilization of limited bandwidth. Carrier sensing is another major cause of energy waste due to collision of data packets and hidden and exposed terminal problems.

Optimization techniques that consider device control approach which includes sleep/wakeup activities are found to be more effective. The main aim of the proposed algorithm is to maximize the network lifetime, which can be defined as the period that the network satisfies the application requirements.

The paper is organized as follows. Section II covers the literature survey. Section III is dedicated to Ant Colony Optimization. Section IV discusses the proposed approach. Section V covers the simulation bits. Section VI draws conclusion.

2. Literature Survey

Many protocols are proposed to minimize energy consumption of sensor nodes. Scheduling protocols if used directly has the following problem. These protocols want the sensor nodes to be densely deployed in the interest area. At every time slot a part of these devices will be used to carry out the WSN functionality. Therefore to achieve a longer lifetime, it is important to find the maximum number of disjoint subsets of devices in the scheduling method. The disjoint subsets should satisfy the sensing coverage and network connectivity constraints. There are

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many optimization techniques including Genetic Algorithms (GA), Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) algorithms. ACO is based on swarm intelligence.

2.1 Scheduling Protocols

In wireless sensor networks, nodes listen to the channel even if data is not placed on the channel, i.e. idle listening. This happens because the nodes do not know when data will come. This issue is solved by TDMA protocols. Scheduling protocols are TDMA protocols. They reduce energy consumption by planning the activities of the devices.

TDMA protocols have a fixed slot for transmitting and receiving data. And therefore, every node after receiving and transmitting data goes in sleep mode or active mode and thus this technique saves battery power. TDMA protocols reduce unnecessary data transmissions because collision does not occur. But most of the TDMA protocols either try to 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 M. (N. Rahman, 2011; M. N. Rahman, 2011).

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. 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 idle state, the nodes must be put to sleep state.

2.2 Particle Swarm Optimizations (PSO)

Particle Swarm Optimization (PSO) is a population based optimization technique. In this technique, first the population is initialized with random solutions and after each iteration the population is updated. Throughout the process, the search is made for the 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 behavior 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 (J. Lee, 2011).

2.3 Ant Colony Optimization

In computer science and operations research, the ant colony optimization algorithm is a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs. ACO concept was initially proposed by Marco Dorigo in 1991. ACO is a population based metaheuristic that can be used to find approximate solutions to difficult optimization problems. Metaheuristic algorithms are algorithms which, in order to escape from local optima, drive some basic heuristic: either a constructive starting from null solution and adding elements to build a good complete one, or a local search heuristic starting from a complete solution and iteratively modifying some of its elements in order to achieve a better one. In ACO, a set of artificial agents called artificial ants search for good solutions to a given optimization problems. The solution construction process is stochastic and is biased by a pheromone model (M. Dorigo and T. Stutzle, 2004).

Ant Colony Optimization: Ant Colony optimization (ACO) is a probabilistic technique for solving computational problems (M. Dorigo and T. Stutzle, 2004). 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 help to get high quality solution via global co-operation. ACO utilize 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 ensure that the sensors form a complete coverage to the target, all monitoring results obtained are transmitted to the sinks and the sinks compose a connected wireless network (Y. Lin, 2012).

ACO has following advantages over Scheduling protocols

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.

3. Proposed Approach

To achieve longer lifetime it is important to find the maximum number of disjoint connected covers. 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 (S. Parvatkar, 2012).

To find disjoint connected covers, ACO algorithm is used (J. Lee, 2011). 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.

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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