A Novel Genetic Algorithm for Lifetime Maximization of Wireless Sensor Networks with Adjustable Sensing Range

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ABSTRACT

Most existing algorithms for optimizing the lifetime of wireless sensor networks (WSNs) are developed assuming that the sensing ranges of sensors are fixed. This paper[1] focuses on adjustable WSNs and proposes a lifetime maximization approach, in which the active periods and sensing ranges of sensors are scheduled simultaneously subject to the constraints of target coverage and power limit. First, the lifetime maximization problem is converted to a problem of finding a set of coverage patterns that can lead to the best schedule when fed into a linear programming model. A genetic algorithm is then developed for coverage pattern finding. With each individual representing a coverage pattern, evolutionary operators and repair strategy are tailored to evolve the pattern set efficiently. Experimental results in a variety conditions show that the proposed approach is advantageous in both terms of computational time and solution quality.

CCS CONCEPTS

• Computing Methodologies → Artificial Intelligence → Search methodologies

KEYWORDS

Wireless Sensor Networks (WSNs); genetic algorithm (GA); lifetime optimization; linear programming (LP)

1 INTRODUCTION

A basic and important function of wireless sensor netorks (WSNs) is to monitor targeted areas or points for a long enough period [1]. Since sensors are often deployed in remote or physically inaccessible environments and spread in an arbitrary manner, it is usually impossible to recharge the batteries. Therefore, a critical issue in WSN applications is the coverage lifetime problem [2]. However, most previous studies investigated the problem assuming that the sensing ranges of all sensors are fixed. Such an assumption gradually becomes outdated as sensing technology progresses. This paper studies the problem of maximizing the lifetime of WSNs with adjustable sensing range and presents a model that using GA and LP methods to generate a schedule that prolong the lifetime of WSNs.

2 PROBLEM DEFINITION

2.1 Premise Settings

Suppose that N sensors $S = \{s_1, s_2, \ldots, s_n\}$ are randomly deployed to cover M targets $T = \{t_1, t_2, \ldots, t_m\}$ in a region R of width W and length L. Each sensor s_i has an initial battery b_i and $(p+1)$ different sensing range options (in ascending order) $r_{i0}, r_{i1}, r_{i2}, \ldots, r_{ip}$ corresponding to energy consumptions $e_{i0}, e_{i1}, e_{i2}, \ldots, e_{ip}$, with $r_{i0} = 0$, $e_{i0} = 0$ denoting inactive. Assume that e_{ij} is a quadratic function of the sensing range r_{ij}, i.e., $e_{ij} = e_{ip}\ (r_{ij}/r_{ip})^2$. For each sensor s_i and for each value e_{ij}, we define a pair (s_i, e_{ij}) referring to a sensor s_i activated at sensing level j and consuming energy e_{ij} per time unit.

A target is covered by a sensor if the Euclidean distance in-between is no greater than the activated sensing range of that sensor. Given a collection of pairs $C = \{(s_i, e_j) \mid s_i \in S, j \in 0, 1, 2, \ldots, p\}$, it is named a *coverage pattern* if the set of targets covered by C equals the target set T. Each coverage pattern C can be written as a vector V of length n, where the ith element v_i is the energy consumption of sensor s_i.

For each sensor s_i, when it is activated with sensing ranges r_j for a time interval τ, the amount of energy it consumes is $e_{ij}\times\tau$. The overall energy consumption of each sensor should not be greater than the initial sensor battery b_i.

2.2 Problem Mathematical Model

Based on the above premise, the lifetime maximization problem of WSNs with adjustable sensing range can be described as follows: find a collection of pairs (C_l, τ_l) $(l = 1, 2, \ldots, \kappa)$, where C_l is a coverage pattern and τ_l is the corresponding activation time, such that the sum of all activated time is maximized under the condition that the power consumption of each sensor does not exceed its battery. That is,

$$\max \sum_{l=1}^{\kappa} \tau_l \tag{1}$$

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$$\text{s.t.}\quad \sum_{l=1}^{\kappa} m_{il}\tau_l \le b_i,\ i=1,2,...,n \qquad (2)$$

$$\tau_l \ge 0,\ l = 1, 2, \ldots, \kappa \qquad (3)$$

where m_{il} is the energy that sensor s_i consumes in a feasible coverage pattern C_l.

The presented model solves the above problem in two steps: firstly, generate a set of coverage patterns M; secondly, use a linear programming (LP) solver to decide the activation time of each coverage pattern in M. Since many LP solvers can get a best solution vector $\tau_1, \tau_2, \ldots, \tau_\kappa$ in polynomial time, the problem is actually reduced to find a set of coverage set that gives the best answer when fed into the LP model.

3 THE PROPOSED GA-LM

A set of coverage patterns can be defined as an n by κ real matrix $M = (m_{il})_{n\times\kappa}$, where each column $\boldsymbol{m}_l = (m_{1l}, m_{2l}, \ldots, m_{nl})$ represents the l-th coverage pattern C_l and $m_{il} = v_i$ is the energy consumed by sensor s_i in C_l.

Each individual in the population of the proposed GA-LM is defined as a N-dimensional vector $V = (v_1, v_2, \ldots, v_N)$ to represent one coverage pattern C. The population of κ individuals forms the matrix M. Then a schedule of sensor activation can be obtained by using M to solve the previous LP problem.

At the beginning of GA-LM, each individual in the population is initialized at random. Then it iterates the following three steps until the termination criterion is met: cover evaluation, survivor selection and reproduction. The cover evaluation step feeds the current population to a LP solver and defines the fitness of each individual as the resulting activation time. Then the survivor selection step only passes individual with positive fitness (i.e., activation time) to the next step. In the reproduction step, GA-LM uses the classic GA to generate additional individuals. In detail, the probabilistic binary tournament is used to select two parents for crossover. Two different crossover operators are used. One is the uniform crossover method, the other one is letting the child inherit the larger value of the two parents for every variable. The mutation operator switches a variable from positive to zero or in reverse. The repair operator consists of two stages. The first stage transforms the child into a feasible coverage pattern by randomly choose sensor around uncovered target to cover that target. The second stage ensures that sensors are used only at their respective minimum power levels necessary for covering all targets by reducing sensing level while ensuring target coverage for every sensor.

4 EXPERIMENT RESULTS

The performance of the proposed GA-LM is evaluated by simulation based on test cases that randomly scatter sensors and targets in a fix region. Three test cases with sensor number N = 100, 150, 200; target number M = 50, 100, 150 respectively are generated. Sensing range options is set to 0, 2, 4, …, 20. The proposed GA-LM is compared with the column generation (CG) method proposed in [3], the heuristic method proposed in [4] and a greedy algorithm. Figure 1 shows the simulation results. The top-left graph shows the final solutions of three different cases. The other three graphs present the iteration processes of the three cases.

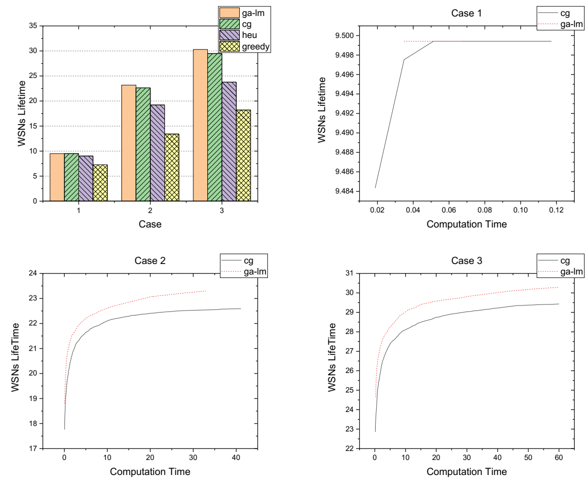

Figure 1: Comparison of GA-LM with other methods

5 CONCLUSION

This paper gives a mathematical model for solving the lifetime maximization in WSN with adjustable sensing ranges and applies a hybrid method using genetic algorithm (GA) and linear programming (LP) to obtain the result. The model addresses the problem into two steps: firstly, use GA to find a collection of coverage patterns; secondly, determine how long each coverage pattern stays active. Each step is identified by the proposed method using GA and LP correspondingly. GA is customized with a repair operator to ensure target coverage after crossover and mutation operators. Additional survivor selection operator is used to discard those coverage patterns that have no activation time. By iterating the above steps, the proposed GA-LM incorporated with the LP technique can approximate the optimal schedule that maximizes the network lifetime. Experiment results confirm the advantage of the proposed approach when compared to the existing methods.

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