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An Effective Genetic Algorithm for Finding Cover Sets in Directional Sensor Networks

Mohammad Taghi Kheirabadi [1] and Hosein Mohamadi [2]

[1] Department of computer engineering, Gorgan Branch, Islamic Azad University

[2] Department of computer engineering, Azadshar Branch, Islamic Azad University

Abstract. An important challenge facing DSNs is maximizing the network lifetime while covering all of the targets in an area. One effective method to save the sensors' energy and extend the network lifetime is to partition the DSN into several covers, each of which can cover all targets, and then to activate these covers successively. The memetic algorithm proposed in this study addresses the challenge of extending the network lifetime. This algorithm uses both evolutionary scheme and a local enhancement strategy. Due to NP-complete complexity, the minimum subset of directional sensors is approximated using a genetic algorithm. Local enhancement improves the fitness of each individual. In this algorithm, making an upper boundary or any assumption about the maximum number of covers is unnecessary. Our experimental results confirm that the proposed algorithm can contribute to prolonging the network lifetime.

Keywords: Cover set, Directional sensor network and Genetic algorithm.

1. Introduction

Directional sensor networks (DSNs) are formed by the collaboration of many low-cost, low-power directional sensors. These sensors typically have a limited sensing angle and a limited battery life in order to minimize size and cost. Although an individual directional sensor has several directions, it can only sense one direction at a given time. Rotation, a common enhancement, enables cooperation between neighbouring sensors working in distinct directions. Directional sensors, such as video, infrared, and ultrasound sensors, have vast potential applications, particularly for wireless multimedia sensor networks [2].

Since sensors have a limited battery life, an important issue is power conservation in DSNs for the following reasons. First, most sensors are non-rechargeable, with limited power sources, and their batteries are often hard to replace due to operating environments are either hostile or inaccessible to humans. To conserve energy and increase network lifetime, a scheduling algorithm that properly alternates between active and sleep states, for redundant sensors that cover the same area and/or targets, in a specified order is required. Programming each sensor's uptime in an efficient and practical way can thus extend the DSN's lifetime. To accomplish this, the nodes must be divided into subsets, called cover sets, where each of which capable of covering all the monitored targets [1, 3, 4, 5].

In this paper, we propose a novel MA approach to adjust the working direction of sensors in a DSN and to determine when sensors sleep or become active. A local search is used to select a minimum subset of sensors without exceeding the available energy needed to monitor all targets. This algorithm does not require an upper boundary or any assumption about the maximum number of covers. The superiority of the proposed algorithm is demonstrated by simulation results.

The remainder of this paper is organized as follows. Section 2 introduces the multiple directional cover set (MDCS) problem. Section 3 uses the MA to approximate the minimum subset of sensors. Section 4 presents experimental results for the MA. Finally, Section 5 concludes.

2. Definition of the Problem

Consider a DSN which consist of N sensors randomly and uniformly scattered within a two-dimensional Euclidean field. Each sensor has W directions with equal sensing range, and initially faces one of its directions. The sensing region for a direction is a sector of a disk and centred at the sensor. M targets of interest, with known locations are designated in the field. For simplicity, the following notations are used throughout the paper to describe the MDCS problem [7]:

M, the number of targets.

N, the number of sensors.

W, the number of directions per sensor.

a_m, the mth target, $1 \leq m \leq M$.

s_i, the ith sensor, $1 \leq i \leq N$.

D_{ij}, the jth direction of the ith sensor, $1 \leq i \leq N$, $1 \leq j \leq W$.

D, the set of D_{ij}, $1 \leq i \leq N$, $1 \leq j \leq W$.

$A = \{a_1, a_2, \ldots, a_M\}$, the set of targets.

$S = \{s_1, s_2, \ldots, s_N\}$, the set of sensors.

L_i, the lifetime of the sensor s_i.

Problem: To find a minimum subset of directions in the DSN that can cover all targets in A such that each target is covered by at least one direction.

3. Proposed Algorithm

In this algorithm, it is assumed that each sensor corresponds to a gene coding; the coding value is represented by a positive integer string ranging from 0 to n. Being inactive is denoted by a gene value of 0, and other values indicate the corresponding working direction within the active status. Random initialization is used to generate the initial population because of its speediness and low complexity. For example, a solution with a structure such as {0,1,3,0,2} means that sensors 1 and 4 are inactive and sensors 2,3, and 5 are active and at work in directions 1,3, and 2, respectively. Figure 1 shows the proposed algorithm for solving the MDCS problem using the same active time t for all cover sets. The objectives of our proposed algorithm are to extend the network lifetime and to minimize the number of active sensors. To achieve these goals, we improve the fitness function, which is introduced in [6], and define a weighted fitness function f as follows:

$$f_1 = \sum_{j=1}^{m} \left(1 - \prod_{i=1}^{n} \lceil A_i / w \rceil . (1 - a_{m,w,n}) \right)$$

$$f_2 = \sum_{i=1}^{n} \lceil A_i / w \rceil$$

$$f = w_1 . f1^{\beta_1} + w_2 . f2^{\beta_2}$$

where f is used to evaluate chromosome X. Chromosome X is represented by an integer string (e.g., "A_1, A_2, ... , A_n"); w is the number of working directions and $a_{m,w,n} = 1$ if the m^{th} target is covered by direction w of sensor n; w_1 and w_2 represent weighting coefficients; and β_1 and β_2 are the exponential factors. In addition, f_1 and f_2 represent the coverage ratio and utility ratio of sensors, respectively. The greater the fitness function, the better the solution in the proposed algorithm.

```
Let N be the number of sensors and the length of each chromosome
Set lifetime of each sensor (L).
Let K =1 and C_K= { }
Initialize the GA
While the targets are completely covered by Sensor
        While the maximum generation is reached
            Calculate_ fit (pop_i);
            Select feasible solutions and preserves those elites
            Apply the crossover operation on multiple pairs of feasible solutions
            Choose some feasible solution and impose mutation on it
            Local search (pop_i)
        End While
        Output C_K
        K = K + 1
            For each sensor ∈C_K do
                L= L−t
                If L≤ 0  then
                S= S−{sx}
                End If
            End For
End While
Return K number of cover sets and the cover sets C_1, C_2, … ,C_K
```

Figure 1: Pseudo code of the proposed algorithm

To generate a new generation while maintaining high quality and diversity of the GA, we apply GA operators such as selection, crossover, and mutation. The proposed algorithm uses tournament selection to look for the optimal fitness of each generation more efficiently and uses the single point crossover operator as a fast and simple technique. In the proposed algorithm, if a gene with a value ranging from 1 to n is selected to mutate, the direction of the active sensor changes. If a gene with a value of 0 is selected to mutate, its value changes to a random integer within the range 1 to n.

The improvement procedure works as follows. In all chromosomes every gene associated with an active sensor is changed to inactive, and this modification is retained when the fitness of the new chromosome is better than that of the original. This algorithm is an extension of the local search addressed in [6], for the case when sensor nodes can be directional. Figure 2 shows the pseudo code of the local search.

```
Input the population pop_i to local  search
For i = 1 to N do
        If Allele A(i) ≥1 in popi then
              fitness1 = calculate_ fit(pop_i)
              Temp = A(i)
              A(i) = 0
              fitness2 = calculate_ fit(pop_i)
              If fitness1 > fitness2 then
                    Ai = Temp
              End If
        End If
End For
```

Figure 2: Pseudo code of the proposed local search

4. Experimental Results

The DSN is configured similar to [7] as follows as follows: N sensors with uniform sensing range r and M targets are scattered randomly and uniformly over a 400 m × 400 m field. Each sensor has W directions and each sensor randomly selects its basic direction. To evaluate the proposed algorithm, we compare our results with theoretical maximum. The rates of crossover and mutation are set at 0.1 and 0.05, respectively. The initial lifetime of all sensors is set to 1.0, and the work time of each cover set is equal to 0.1. The number of iterations for GA for all of the experiments is 300. To accentuate the impact of the coverage ratio on fitness, $(w_1, w_2) = (100, 1)$ and $(B_1, B_2) = (1, 0.5)$. Three parameters (various sensing ranges, various sizes of targets, and various sizes of sensors) were used to evaluate the performance of the proposed algorithm. Each simulated case included 20 runs, from which an average value was computed.

Fig. 3 reveals the performance of the proposed algorithm in extending the network lifetime when the number of sensors vary from 20 to 80 with step 10 to cover 10 targets, and sensing range is set to 100 *m*. Fig. 3 shows that an increase in the number of sensors resulted in a higher network lifetime.

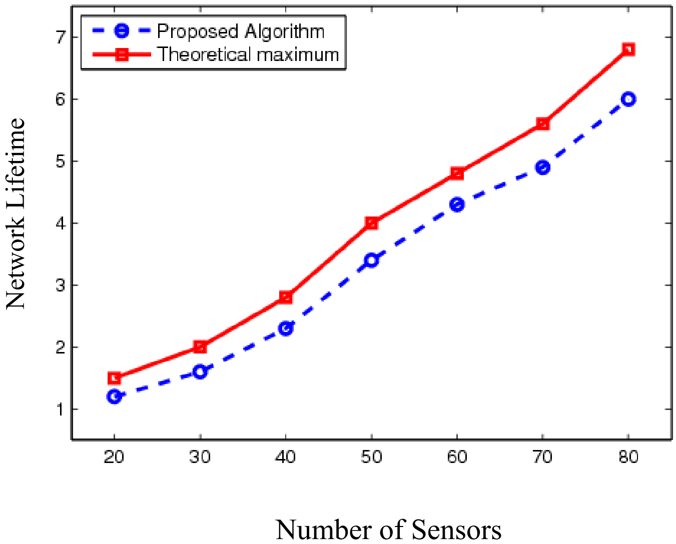

Figure 3: Effect of the number of sensors on the network lifetime.

Fig. 4 reveals the relationship between the network lifetime and the number of targets when 50 sensors are deployed, and *r* is fixed at 100 *m*. We can see that network lifetime decreased when the number of targets increased. This is because coverage of more targets would require a greater number of sensors, thereby consuming more energy.

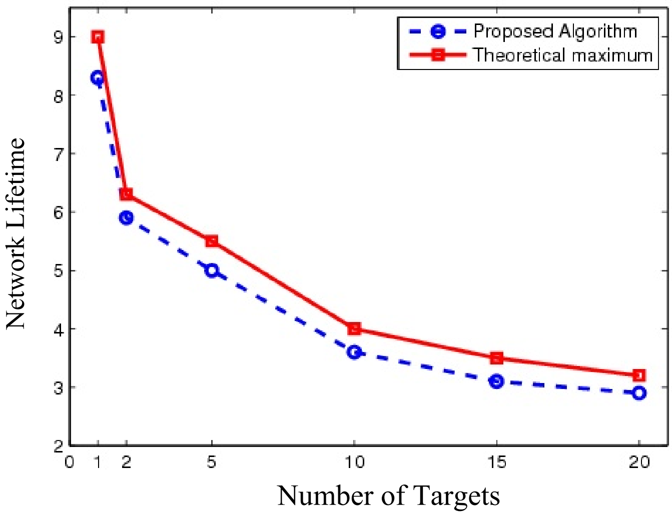

Figure 4: Effect of the number of targets on the network lifetime.

Fig. 5 reveals the impact of different sensing ranges from 75 *m* to 200 *m* with step 25 *m* on the network lifetime when number of sensors and targets are set to 50 and 10 respectively. We can see that as the sensing range increases, the network lifetime also increases. This is because more targets can be covered when sensors have a longer range.

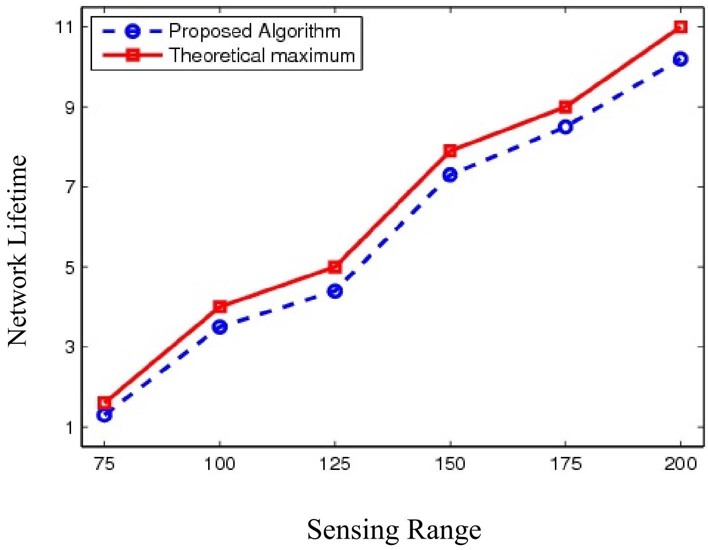

Figure 5: Effect of sensing ranges on the network lifetime.

5. Conclusion

Here in we propose a MA for extending DSN lifetime. The algorithm solves the MDCS problem, which is known to be NP-complete. To save energy and thus prolong the network lifetime, the proposed algorithm organizes directional sensors into a group of non-disjoint cover sets. This algorithm eliminates the need for an upper boundary or assumptions about the maximum number of covers, and it uses a local search strategy that improves fitness and increases the number of covers. Our experimental results confirm that the proposed method can extend network lifetime in a DSN.

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