Expert Systems With Applications 92 (2018) 142–153

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

Optimizing K-coverage of mobile WSNs

Mohamed Elhoseny[a,e,1,*], Alaa Tharwat[b,e,1], Xiaohui Yuan[c], Aboul Ella Hassanien[d,e,1]

[a] Faculty of Computers and Information, Mansoura University, Mansoura, Daqahlia, Egypt
[b] Faculty of Computer Science and Engineering, Frankfurt University of Applied Sciences, Frankfurt am Main, Germany
[c] Department of Computer Science and Engineering, University of North Texas, Denton, Texas, U.S.A
[d] Faculty of Computers and Information, Cairo University, Egypt
[e] Scientific Research Group in Egypt (SRGE), Egypt

ARTICLE INFO

Article history:
Received 16 April 2017
Revised 7 September 2017
Accepted 8 September 2017
Available online 26 September 2017

Keywords:
Wireless Sensor Networks (WSN)
Genetic Algorithm (GA)
K-coverage problem
Mobility sensor networks

ABSTRACT

Recently, Wireless Sensor Networks (WSNs) are widely used for monitoring and tracking applications. Sensor mobility adds extra flexibility and greatly expands the application space. Due to the limited energy and battery lifetime for each sensor, it can remain active only for a limited amount of time. To avoid the drawbacks of the classical coverage model, especially if a sensor died, *K*-coverage model requires at least *k* sensor nodes monitor any target to consider it covered. This paper proposed a new model that uses the Genetic Algorithm (GA) to optimize the coverage requirements in WSNs to provide continuous monitoring of specified targets for longest possible time with limited energy resources. Moreover, we allow sensor nodes to move to appropriate positions to collect environmental information. Our model is based on the continuous and variable speed movement of mobile sensors to keep all targets under their cover all times. To further prove that our proposed model is better than other related work, a set of experiments in different working environments and a comparison with the most related work are conducted. The improvement that our proposed method achieved regarding the network lifetime was in a range of 26%–41.3% using stationary nodes while it was in a range of 29.3%–45.7% using mobile nodes. In addition, the network throughput is improved in a range of 13%–17.6%. Moreover, the running time to form the network structure and switch between nodes' modes is reduced by 12%.

1. Introduction

Wireless Sensor Networks (WSNs) are widely used in many applications such as industry (Elhoseny, Tharwat, Farouk, & Hassanien, 2017; Elsayed, Elhoseny, Riad, & Hassanien, 2017; Tuna, Gungor, Gulez, Hancke, & Gungor, 2013), environmental monitoring (Das & Bruhadeshwar, 2013; Elhoseny, Tharwat, & Hassanien, 2017; Ferentinos, Katsoulas, Tzounis, Bartzanas, & Kittas, 2017), health care (Hackmann et al., 2014; Hassanien, Tharwat, & Own, 2017; Shahin, Tharwat, Gaber, & Hassanien, 2017; Tharwat, Moemen, & Hassanien, 2016; 2017), and agriculture (Gaber, Tharwat, Hassanien, & Snasel, 2016; Srbinovska, Gavrovski, Dimcev, Krkoleva, & Borozan, 2015; Tharwat, Gaber, & Hassanien, 2016). Due to the limited energy, a sensor can remain active only for a finite amount of time. Thus, sensors are organized into different groups, namely sensor cover, in such a way that each cover monitors the targets for a certain duration, and the optimal use of the sensors increases the sensor network lifetime (Cerulli, Donato, & Raiconi, 2012). This motivates the deployment of redundant sensors to cover the area of interest and to organize the sensors to prolong the coverage time after a deployment. This problem is the *K*-coverage problem, which requires a minimum of *k* sensor nodes to monitor one target (Elhoseny, Elminir, Riad, & Yuan, 2016; Elhoseny, Yuan, El-Minir, & Riad, 2014; Elhoseny, Yuan, El-Minir, & Riad, 2016; Yang, He, Li, Chen, & Sun, 2015).

Many target coverage methods assume that the targets are known, and each target is covered by one sensor (Katsuma, Murata, Shibata, Yasumoto, & Ito, 2009; Liu, 2007; Lu, Li, & Pan, 2015). However, these algorithms have a serious drawback when a sensor runs out of energy. Hence, covering each target with more than one sensor at a time provides a more robust solution (Wan, Wu, & Shen, 2015). In Wan et al. (2015), the flow decomposition algorithm (FDA) was introduced and compared with Fixed Directional Sensor Scheduling Problem (FDSSP) that was proposed in Tang, Zhu, Zhang, and Hincapie (2011). The aim of FDA is to decompose the maximum flow into a set of single flows, and each

* Corresponding author at: Faculty of Computers and Information, Mansoura University, Mansoura, Daqahlia, Egypt.
E-mail addresses: mohamed_elhoseny@mans.edu.eg (M. Elhoseny), aothman@fb2.fra-uas.de (A. Tharwat), xiaohui.yuan@unt.edu (X. Yuan), aboitcairo@gmail.com (A.E. Hassanien).

[1] http://www.egyptscience.net.

http://dx.doi.org/10.1016/j.eswa.2017.09.008
0957-4174/

single flow represents a source to a sink path. The sensors of that path form a cover and the amount of flow passing through this path is equal to the lifetime of this cover. The FDSSP seeks a fixed directional sensor schedule which maximizes the lifetime. Factors such as sensor network topology, sensor activation mode, and sensor role must be taken into consideration for identifying an optimal network management solution (Liu, 2007; Lu et al., 2015; Mnasri, Thaljaoui, Nasri, & Val, 2015; Wan et al., 2015). In FDSSP, given a set of fixed directional sensors which have already been placed. In Tang et al. (2011), two versions of FDSSP were introduced. The first one was the Uniform initial Energy version (FDSSP-UE) in which all the sensor nodes are assumed to have the same initial energy. This version has many problems as reported in Tang et al. (2011). The second version was the Non-Uniform initial Energy version (FDSSP-NUE) in which different nodes may have different initial energy; and this version, i.e., FDSSP-NUE, was used for solving the problems of the FDSSP-UE. The Variable Power Network Lifetime (VP-NL) scheduling scenario was proposed in Yang and Gündüz (2015). In this scenario, it was assumed that each sensor can modulate its sensing range by dynamically varying its operating power, e.g., radar sensors. In VP-NL, A polynomial algorithm was proposed, and many experiments and numerical simulations were conducted to show its effectiveness. With the proliferation of sensors, a wireless sensor network is no longer stationary, which greatly expands the applications such as tracing animal movements applications (Gaber et al., 2016; Han et al., 2016; Wang, Xu, Wei, Gu, & Chen, 2010) and environmental monitoring (Hwang, Shin, & Yoe, 2010), in contrast to the stationary sensor networks. In many cases, monitoring the whole area might be unnecessary, especially if the dynamic nature of the observed processes is taken into account. When sensors are equipped with motion capabilities, monitoring a number of points of interest instead of the whole area increases the network performance and permits time-dependent coverage. In a mobile sensor network, combining target coverage with the connectivity of sensors to the data sink is still an open challenge (Fadel et al., 2015; Rawat, Singh, Chaouchi, & Bonnin, 2014).

Non-stationary K-coverage is often needed when a reliable monitoring capability is desired as in surveillance and military applications. Due to the energy constraint of wireless sensors and often infeasibility of replacement or recharging, it is necessary for the sensors to be densely deployed. Yet, keeping all sensors active will deplete their energy quickly. A typical scenario is multi-agent based corporative field monitoring. Mobile agents collect and transform data to ensure integrity and security in the parameter.

Different bio-inspired optimization algorithms have been employed in WSNs. For example, Particle Swarm Optimization (PSO) was used to optimize the fuzzy membership function to achieve the best results regarding the battery life of sensor nodes (Collotta, Pau, & Maniscalco, 2017). Due to the importance of clustering approach to achieve energy efficiency in wireless sensor networks, a hybrid swarm intelligence algorithm was utilized to optimize fuzzy rule table, and the proposed algorithm was utilized to cluster all sensor nodes into balanced clusters (Zahedi, Akbari, Shokouhifar, Safaei, & Jalali, 2016). In another research, Ant Colony Optimization (ACO) algorithm was used to achieve a complete coverage of the service region which maximizes the lifetime of the network (Liao, Kao, & Wu, 2011). Glowworm Swarm Optimization (GSO) was also employed to enhance the coverage as reported in Liao, Kao, and Li (2011). However, as reported in Yang (2014), some of the nature-inspired optimization algorithm have no explicit crossover such as in ACO (Liao, Kao, & Wu, 2011), and Ant Bee Colony (Karaboga, Okdem, & Ozturk, 2012), GSO (Liao, Kao, & Li, 2011), and PSO (Collotta et al., 2017). This may reduce the searching capabilities for these algorithms. On the other hand, Genetic Algorithm (GA) consists of three key genetic operations, namely, *crossover*, mutation, and selection, and both crossover and mutation operations provide the diversity for the new solutions, where the crossover provides limited diversity within the subspace, while the mutation operations can provide better diversity by exploring far-away subspaces (Metawa, Hassan, & Elhoseny, 2017; Tharwat, Gaber, Hassanien, & Elnaghi, 2017; Yamany et al., 2015).

We propose a GA based method to optimize the coverage in WSNs to monitor specified targets for the longest possible time with limited energy. The sensor nodes are non-stationary and can move in the field to collect data. We make no assumption of the mobility speed of the sensors that can be at continuous or variable speed. GA has been applied to WSN (Ebrahimian, Sheramin, Navin, & Foruzandeh, 2010; Elhoseny et al., 2017; 2015; Shieh et al., 2016; Yuan, Elhoseny, El-Minir, & Riad, 2017). In our problem, the data transmission round is a time period that the data of targets are collected and transmitted to the base station. A GA-based method was proposed to optimize the sensor covers with a goal of maximizing the network lifetime by determining the mode of sensor covers. Based on a set of factors such as the coverage range of each sensor, expected consumed energy, the distance to the base station, and targets positions, the GA forms the covers after determining the optimum cover heads that are responsible for transferring the data to the base station. Thus, the proposed model ensures that the monitored area is fully covered by a minimum number of sensors.

This study has two main contributions. Firstly, GA-based cover forming method that creates all possible sensor covers. Secondly, a WSN covers management method that switches between different sensor covers to maximize the network lifetime. To form the sensor covers, the proposed model assumes that:

- The positions of the targets are known, which are stationary,
- All nodes are capable of transmitting data to the base station,
- All sensor nodes have the same amount of initial energy,
- Sensor network is adjusted after each data transmission round,
- The field has one base station, which, after each round, constructs the network for the next round, and
- The data transmission round starts when a sensor cover changes its mode (active/sleep).

The remainder of this paper is organized as follows: Section 2 summarizes the related work of the target covering problem. Section 3 explains the proposed model in details. It discusses the mathematical model, data representation, and the proposed GA algorithm for the target coverage problem. Section 4 summarizes the experimental results and discussions of our experiments. Finally, conclusions and future work are presented in Section 5.

2. Related work

Target covering problem has been attracting significant attention in WSNs (Berman, Calinescu, Shah, & Zelikovsky, 2004; Cardei & Du, 2005; Slijepcevic & Potkonjak, 2001). In Slijepcevic and Potkonjak (2001), a heuristic algorithm that selects mutually exclusive sets of sensor nodes was proposed. The members of a set cover the whole area completely, and only one of the sets is active at any time. This algorithm achieved a significant energy saving while fully preserving coverage. Cardi et al. proposed a method to extend the lifetime of the sensor network by reorganizing the sensors into a maximal number of disjoint set covers (Cardei & Du, 2005). Moreover, the sensors from the current active set are utilized for (1) monitoring all targets and (2) transmitting the collected information, while the nodes from all the other sets are in