The Coverage Model for the Forest Fire Detection Based on the Wireless Sensor Network

Hiep Xuan Huynh, Tai Tan Phan, Lan Phuong Phan(✉), and Nguyen Tran Trinh

Can Tho University, Can Tho City, Vietnam
{hxhiep, pttai, pplan}@ctu.edu.vn,
pplan@cit.ctu.edu.vn,
trinhnguyen88@gmail.com

Abstract. Wireless sensor networks are being effectively applied in the forest fire detection. Building a model of sensors covering the entire area of the forest is the important problem. This paper proposes the coverage model using the new approach to decrease the number of sensors. With this approach, the sensors are classified into several groups; and those groups work in the alternative way but meet the complete coverage. Experimental results on the map of the forest in Dong Thap province shows that the model works well and meets the complete coverage.

Keywords: Wireless sensor networks · Coverage model · Forest fire detection

1 Introduction

Wireless sensor networks [8] when deployed have to cover the targets (subjects to be observed and tracked), that is the targets must always lie within the scope for monitoring and tracking sensors. Guaranteeing the coverage is the most important requirement for a sensor network [1, 7] and identifying the coverage area is the task to be studied firstly before sensor networks are deployed. The coverage also helps overcome the limitations of a sensor network such as supporting for routing protocol and MAC protocol [4], or addressing the strict requirement of energy and increasing the lifetime of the network [2, 3]. Therefore, the coverage is an important problem for wireless sensor networks and the problem for identifying the coverage has posed many challenges.

Two approaches related to the use of wireless sensor networks for the forest fire detection are interested in [5, 6]. The first approach studies and improves the collected data processing methods in order to make more accurate forecasts. The second approach optimizes the coverage problem of a sensor network. In the first approach, the theory of Type-2 Fuzzy System, the theory of Dempster-Shafer and the threshold method, the probability and the simulated model, and SVM machine learning are used in [9, 10, 11, 12] respectively. All of those methods identify the forest fires based on collected data sets of wireless sensor networks. The second approach builds the algorithms to optimize the coverage problem in a sensor network. The distribution

P.C. Vinh and V. Alagar (Eds.): ICCASA 2015, LNICST 165, pp. 187–197, 2016.
DOI: 10.1007/978-3-319-29236-6_19

algorithm PEAS, the algorithm evaluating the redundant nodes, the Clifford algebra, the coverage algorithm for related multi-targets MTACA, K-coverage algorithm are used in [13–16] respectively. Overall, many algorithms were proposed but there are many problems in the algorithms [5–7], and especially, the research on the complete coverage problem for wireless sensor networks of the forest fire detection has not yet investigated.

In this paper, we propose a new approach in specifying the forest area is covered by a wireless sensor network based on a coverage graph. With this approach, the wireless sensor network is seen as an undirected graph, each sensor is a node of the graph, and the communication connection between sensors is a graph edge. The professional knowledge base is the opinions of experts and the specialized information resources in forestry. The research results provide a basis for building the forest fire detection model using the wireless sensor network, a new method to determine the coverage area and to implement the group to subnets to increase the lifetime of the network.

This paper is divided into four parts. The first section presents the importance of the coverage problem for wireless sensor networks, the recent researches for solving the coverage problem and the new approaches for building the coverage model of a wireless sensor network for the forest fire detection. The second section presents the modeling of the forest coverage problem and the method of specifying the coverage of the built model. The third section describes the experimental data and the tool CGFNET, and describes three scenarios: defining the forest areas that are not covered by the wireless sensor network, defining the forest areas that are covered by the sensor network, and defining the minimum coverage groups. The last section is the conclusion.

2 The Forest Coverage Problem

2.1 Modeling the Coverage Problem

Consider a sensor network consisting of n sensors $s_i, i = 1.., n$. Set r_i and R_i to be the sensing scope and communication scope of a sensor s_i respectively. The sensing area of sensor s_i is the plate where s_i is located at the center and r_i is the radius (similarity to the communication scope). There are some problems as the follows (Figs. 1 and 2).

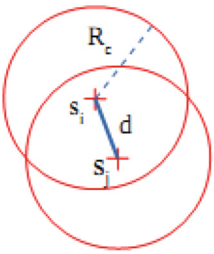

Fig. 1. The connection between the sensor s_i and the sensor s_j.

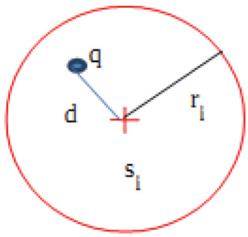

Fig. 2. The target coverage.

The target coverage: for the target q and the sensor s_i, d is called the Euclidean distance between q and s_i. The target q is covered by sensor s_i if and only if $d(q, s_i)r_i$

The coverage (the area coverage): an area A is covered by sensor s_i if and only if the target q is located in the area A with $d(q, s_i)r_i$. From the coverage problem, the area A is covered by a sensor network S if and only if every point q in A must be covered by at least one sensor s_i belonging S. Two sensors s_i, s_j are connected to each other directly when $d(s_i, s_j)R_C$ where d is the Euclidean distance between s_i and s_j; R_C is the communication scope of s_i and s_j, it means each sensor must be within their communication scope.

The communication graph: given a sensor network of n sensors, the communication graph of the network is the undirected graph $G = (V, E)$ in which V is the set of sensors, and E is the set of edges connecting two sensors that can communicate directly.

The coverage connection: given a sensor network of n sensors, and the observed area A, S is called the coverage connection of A if it meets two conditions: (1) the area A is covered by S; (2) the communication graph created by S is connected.

2.2 The Coverage Graph Based on the Wireless Sensor Network

With convention mentioned in Sect. 2.1, the coverage graph of a wireless sensor network for the forest fire detection is created as follows. Given a wireless sensor network of n sensor and the forest area A, if there is at least 01 sensor of S for 01 location in A, then the network S has the undirected graph $G = (V, E)$ in which $V = \{s_1, s_2, \ldots, s_n\}$ is a set of vertices of the sensors, E is a set of edges between two sensors which its Euclidean distance is within their communication scope.

For example, Fig. 3 presents a network of 5 sensors $\{P1, P2, P3, P4, P5\}$ with the communication radius (the communication scope) R_C. The distances $d(P1, P2)$, $d(P1, P3), d(P2, P3), d(P4, P5) < R_C$ and $d(P1, P4), d(P1, P5)$, $d(P2, P4), d(P2, P5)$, $d(P3, P4), d(P3, P5) > R_C$. Therefore, the respective coverage graph of the network consists of 2 sub-networks: $G1 = (V1, E1)$ where $V1 = \{P1, P2, P3\}, E1 = \{P1.P2; P3.P1; P2.P3; P2.P1; P1.P3; P3.P2\}$ and $G2 = (V2, E2)$ where $V1 = \{P4, P5\}$, $E1 = \{P4.P5; P5.P4\}$.

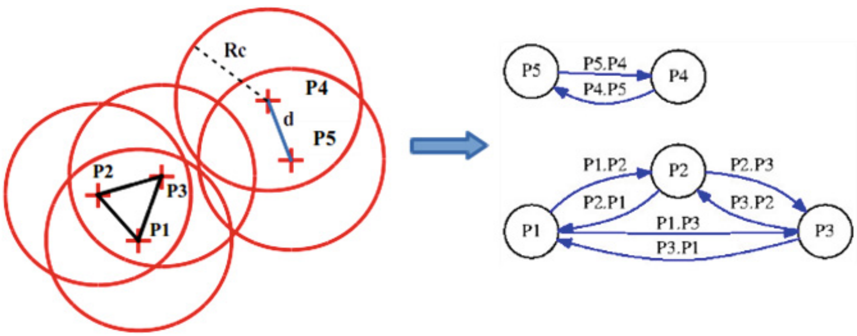

Fig. 3. The coverage graph of the sensor network (5 sensors)

The coverage graph fully reflects the statuses of the deployed sensor network, the cases can occur as follows:

(i) The sensor network for the forest fire detection S if it satisfies the coverage connection, the coverage graph created using S is connected, corresponding to the forest covered by the deployed network.

(ii) The communication graph of the unconnected network, i.e. the network is discontinued or there are the isolated nodes. The corresponding coverage graph consists of the sub-graphs, or is the single graph with the number of vertices less than the number of nodes of the sensor network. For example, in Fig. 3, $d(P1, P4), d(P1, P5), d(P2, P4), d(P2, P5), d(P3, P4), d(P3, P5) > R_C$, or $P4$, $P5$ are not communicated to $P1, P2, P3$, therefore, the coverage graph has 2 sub-graphs G_1 and G_2.

(iii) The network that does not satisfy the coverage, i.e. there are areas that have not yet been put sensors.

2.3 Defining the Coverage Area

The distance between 02 points that have coordinates (latitude and longitude) is calculated by the Haversine formula [23].

$$
\begin{aligned}
a &= sin^2(\Delta\varphi/2) + cos\varphi_1\, cos\varphi_2\, sin^2(\Delta\lambda/2) \\
c &= 2.atan2(\sqrt{(a)}, \sqrt{(1-a)})
\end{aligned}
\tag{1}
$$

$$d = R.c$$

where φ is the latitude, λ is the longitude, $\Delta\varphi = \varphi_2 - \varphi_1$, $\Delta\lambda = \lambda_1 - \lambda_1$, and $R = 6.371\,\text{km}$.

According to geographic coordinate system, the adjacent coordinates separates 01 s in latitude or longitude.

For example, Fig. 4 shows the $coordinate(latitude, longitude)$ of x_i $(h_t^0 m_t^{'} s_t^{''}; h_l^0 m_l^{'} s_l^{''})$ where ^{o} is the degree, $'$ is the minute, and $''$ is the second. 4 adjacent coordinates of x_i are: $x_b(h_t^0 m_t^{'}(s_t+1)^{''}; h_l^0 m_l^{'} s_l^{''})$, $x_n(h_t^0 m_t^{'}(s_t-1)^{''}; h_l^0 m_l^{'} s_l^{''})$, $x_d(h_t^0 m_t^{'} s_t^{''}; h_l^0 m_l^{'}(s_l+1)^{''})$, $x_t(h_t^0 m_t^{'} s_t^{''}; h_l^0 m_l^{'}(s_l-1)^{''})$. Using the formula (1), the distance between x_i and x_b is $d(x_i, x_b) \approx 30.9\,\text{m}$, and the distance between x_i and x_d is $d(x_i, x_d) \approx 30.3\,\text{m}$. Therefore, the area of x_i is $S_{x_i} = 30.9x30.3 = 936.27\,\text{m}^2$.

The forest area: given the forest A; Q_A is a set of coordinates x_i, $i = 1, .., n$ $Q_A = \{x_i, i = 1, .., n\}$. S_{x_i} is called the area of x_i, then the area of the forest A is $S_A = \sum_{i=1}^{n} S_{x_i}$ where $x_i Q_A$.

The coverage of a sensor: given a sensor w with the coordinate t (the location where the sensor w is located), and the communication radius R_w. The set Q_w of coordinates x_i, $i = 1, .., n$ is called the coverage of the sensor w if $d(t, x_i)R_w$, or $Q_w = \{x_i | d(t, x_i)R_w, i = 1, .., n\}$.

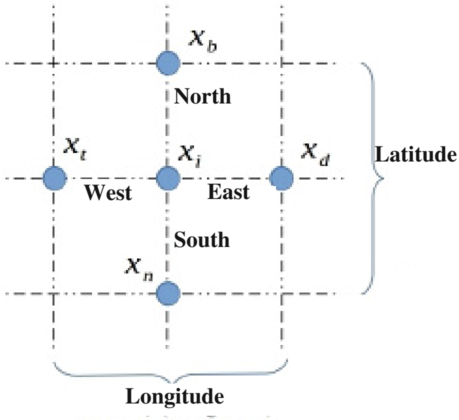

Fig. 4. Locations of the adjacent coordinates

The coverage area of a sensor: given a sensor w with the coverage $Q_w = \{x_i | d(t, x_i) R_w, i = 1, .., n\}$, then the coverage area of the sensor w is calculated as the following. $S_w = \sum_{i=1}^{n} S_{x_i}$ where $x_i Q_w$.

The coverage of a sensor network: given a sensor network W of m sensors, w_1, $w_2, \ldots, w_m$; and $Q_{w_1}, Q_{w_2}, \ldots, Q_{w_m}$ are the coverage of each sensor respectively. Q_C is called the coverage of the sensor network if $Q_C = Q_{w_1} \cup Q_{w_2} \cup \ldots \cup Q_{w_m}$, or $Q_C = \{ x_i | x_i \in Q_{w_i}, i = 1, .., n; j = 1, .., m\}$.

The coverage area of a sensor network: given a sensor network W with the coverage $Q_C = \{x_i | x_i \in Q_{w_i}, i = 1, .., n; j = 1, .., m\}$, then the coverage area of the sensor network Q_C is calculated the follow: $S_c = \sum_{i=1}^{n} S_{x_i}$ where $x_i \in Q_C$.

The complete coverage: given a forest A with the set of coordinates Q_A, and a sensor network W with the coverage Q_C. The forest A is covered completely by the sensor network W if and only if $Q_A \backslash Q_C = \emptyset$, or all coordinates of Q_A have to belong Q_C.

2.4 Defining the Minimum Coverage Groups

The minimum coverage group: given a sensor network W of m sensors w_1 $w_2, \ldots, w_m$, $Q_{w_1}, Q_{w_2}, \ldots, Q_{w_m}$ are the coverage of each sensor respectively. The coverage of that sensor network is $Q_C = \{x_i | x_i \in Q_{w_i}, i = 1, .., n; j = 1, .., m\}$. With a group of k sensors $G = w_1, w_2, \ldots, w_k$ and $k \leq m$, the coverage of that group is called Q_G. G is called the minimum coverage group of the sensor network W if and only if $Q_G \equiv Q_C$, or all coordinates of Q_G and Q_C are the same.

The method for defining the minimum coverage group: given a forest A with n coordinates x_i, $i = 1, .., n$, and a sensor network S with m sensors $s_j, j = 1, .., m$. Q_{w_i} is the coverage of s_j. The following steps are implemented.

Step 1: create a Descartes table m x n where columns are sensors s_j and rows are coordinates x_i, $(x_i, s_j) = 1$ if $x_i \in Q_j$ and $(x_i, s_j) = 0$ if $x_i \notin Q_j$.

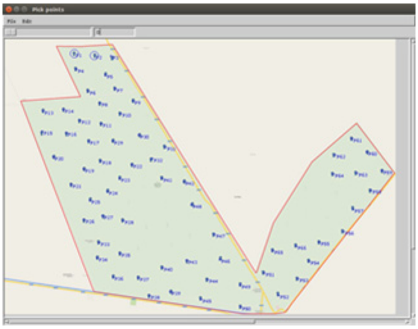

Fig. 5. The representation of 67 sensing locations on the map

Step 2: create a set of equations using the table Descartes. For each equation, its left side equals 1, and its right side is the "collection" of s_j if $(s_j, x_i) = 1$.

Step 3: solve that set of equations; its results are the minimum coverage groups.

For a sensor network of n minimal coverage groups, the lifetime of the network can be increased if the groups work in the alternative way, and the sensors of the groups that do not work at a specific time is in the sleep status [2].

3 Experiments

3.1 Experimental Data

The Forest of Tam Nong district, Dong Thap province was chosen to pilot and assess the empirical results. The input data consists of 02 datasets: the first dataset contains the coordinates (latitude, longitude) of 67 sensors to be deployed; the second dataset contains 81,301 coordinates (latitude, longitude) corresponding to the locations and 7,612 hectares of the forest in Tam Nong. The communication radius of the sensor is 1.2 km. The locations of those sensors are provided by experts (Fig. 5).

3.2 CGFNET Tool

Tools CGFNET (Coverage Graphs of Wireless Sensor Network for Forest Fire Detection) is created by ourselves. This tool is built on the Smalltalk language [24] and integrated into the platform NetGen [22]. CGFNET contains the following main functions: (i) processing the original data - including the locations of the map, the coordinates, and the sensing radius - refining input data, and storing data in the database. (ii) identifying the set of coordinates of the forest, the set of coordinates in the coverage of the sensor network. (iii) calculating the distance between the coordinates. (iv) defining the forest areas that are covered and not covered by the sensor network. (v) calculating the covered area and non-covered area. (vi) constructing the coverage graph of the sensor network. (vii) defining the minimum coverage groups. (viii) displaying the results on a map (Fig. 6).

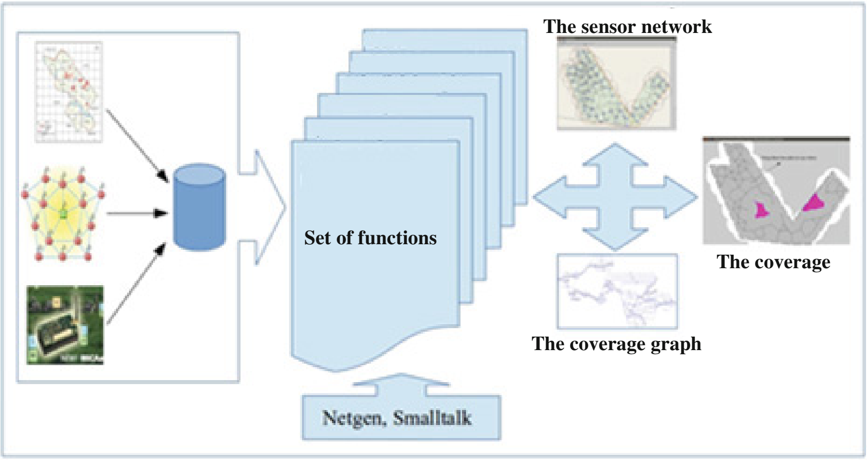

Fig. 6. Tool CGFNET

3.3 Scenarios

Scenario 1: defining the forest areas that are not covered

This scenario must identify the coordinates of all locations that are not covered by the sensor network, and calculate the area that is not covered. The set of identified coordinates are stored in a file.

The sensor network of 67 sensors with the radius 1.2 km deployed in Tam Nong forest is represented as Fig. 7. Figure 8 shows the coverage graph of this network. The constructed graph has 67 nodes, and 197 edges. The result of scenario 1 is displayed in Fig. 9. There are 1,076 locations (with the area 1,007,426.52 m^2) that are not covered by the sensor network. This result is consistent with the opinion of experts, because the locations that have not been covered are lakes, rivers, swamps unnecessary to arrange sensors. The locations - that are not covered by the sensor network - are marked the gray on the map.

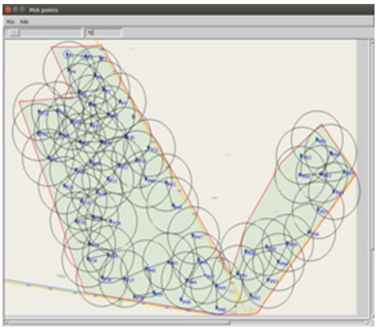

Fig. 7. The network of 67 sensors with the radius 1.2 km

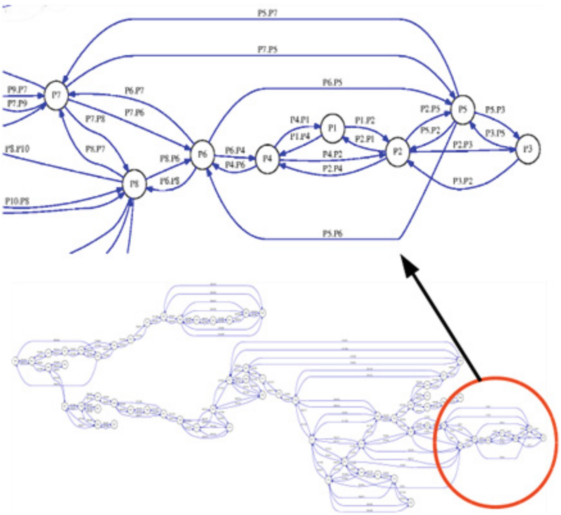

Fig. 8. The representation of the coverage graph (the network of 67 sensors with the radius 1.2 km)

Scenario 2: defining the forest areas that are covered

This scenario must identify the coordinates of all locations that are covered by the sensor network, and calculate the coverage area. The set of identified coordinates are also stored in a file.

The sensor network of 67 sensors and the coverage graph of this network are presented in Figs. 7 and 8 respectively. The result of scenario 2 - the coverage area is marked by the diagonal lines - is displayed in Fig. 10. There are 80,225 locations (with the area 75,112,260.75 m^2) that are covered by the sensor network. For the sensor network to be deployed, this result is suitable with the requirement of experts.

Fig. 9. The representation of the areas that are not covered by the sensor network (1)

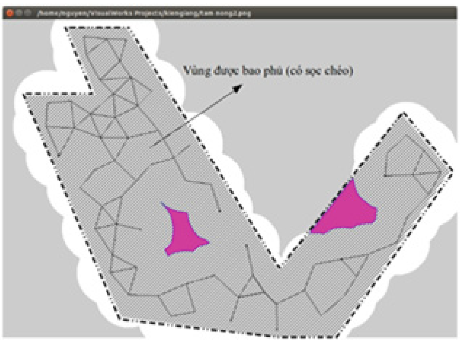

Fig. 10. The representation of the areas that are covered by the sensor network (2)

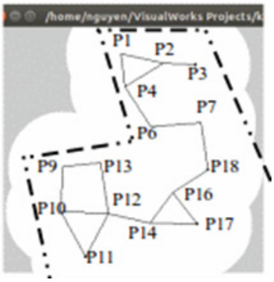

Fig. 11. The coverage of 18 sensors

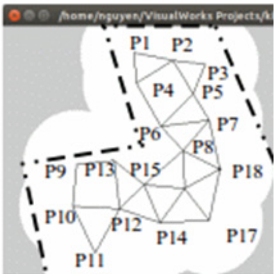

Fig. 12. The minimum coverage group

Scenario 3: defining the minimum coverage groups
This scenario must identify the minimum coverage groups. The return result of scenario 3 is the set of locations of those groups stored in a file, and displays the coverage of groups on the map. With a network of 18 sensors in Fig. 11, we can find 01 minimum coverage group of 15 sensors {P1, P2, P3, P4, P6, P7, P9, P10, P11, P12, P13, P14, P16, P17, P18} as Fig. 12. The group of 15 sensors and the network of 18 sensors have the same coverage.

4 Conclusion

On the basic of the coverage problem for the wireless sensor network and the related issues such as specifying the distance between the coordinates of the geographic coordinate system, finding the minimal coverage, …, the model of the coverage graph is built to define and calculate the coverage area. This model (i) presents a wireless sensor network as a graph; (ii) evaluates the coverage; (iii) develops a method for defining the coverage and calculating the coverage area by using the tool CGFNET.

The coverage problem is modeled to help the experts the support tool in defining and calculating the coverage area. The scenarios - in which the forest area, the locations and the communication radius of the wireless sensor network are provided by experts - are tested. They (i) define the locations and calculate the area that has not been covered; (ii) define the locations and calculate the area that has been covered; (iii) define the minimum coverage groups. The results of those scenarios are verified and validated by the experts.

References

1. Huang, C.F., Tseng, Y.C.: The coverage problem in a wireless sensor networks. In: Proceedings of the ACM International Workshop on Wireless Sensor Networks and Applications, pp. 115–121 (2003)
2. Luqiao, Z., Qinxin, Z., Juan, W.: Adaptive clustering for maximizing network lifetime and maintaining coverage. J. Netw. **8**(3), 616–622 (2013)

3. Yulong, X., Fang, J.-A., Zhu, W.: Cui W (2013) Differential evolution for lifetime maximization of heterogeneous wireless sensor networks. Math. Probl. Eng. **172783**, 1–12 (2013)
4. He, T.C., Cao, W.M., Xie, W.-X.: Coverage analyses of plane target in sensor networks based on Clifford algebra. Acta Electron. Sin. **37**(8), 1681–1685 (2009)
5. Liang, J., Liu, M., Kui, X.: A survey of coverage problems in wireless sensor networks. Sens. Transducers **163**(1), 240–246 (2014)
6. Dagar, A., Saroha, V.: An efficient coverage scheme for wireless sensor network. Int. J. Adv. Res. Comput. Sci. Softw. Eng. **3**(4), 557–563 (2013)
7. Thai, M.T., Wang, F., Du, D.-Z.: Coverage problems in wireless sensor networks: designs and analysis. Int. J. Sens. Netw. Arch. **3**(3), 191–200 (2008)
8. Li, Y., Thai, M.T., Wu, W.: Wireless Sensor Networks and Applications. Signals and Communication Technology. Springer, Heidelberg (2008)
9. Singh, A.K., Singh, H.: Forest fire detection through wireless sensor network using type-2 fuzzy system. Int. J. Comput. Appl. **52**, 19 (2012)
10. Arnoldo, D.-R., et al.: Wireless sensor networks and fusion information methods for forest fire detection. In: The 2012 Iberoamerican Conference on Electronics Engineering and Computer Science, Procedia Technology, vol. 3, pp. 69–79 (2012)
11. Elleuch, M., et al.: Formal probabilistic analysis of a wireless sensor network for forest fire detection. In: Symbolic Computation in Software Science 2012 (SCSS2012), EPTCS 122, pp. 1–9 (2013)
12. Sathik, M.M., Mohamed, M.S., Balasubramanian, A.: Fire detection using support vector machine in wireless sensor network and rescue using pervasive devices. Int. J. Adv. Netw. Appl. **2**(2), 636 (2010)
13. Ye, F., Zhong, G., Lu, S., Zhang, L.: PEAS: a robust energy conserving protocol for long lived sensor networks. In: Proceedings of 10 th IEEE International Conference on Network Protocols (ICNP 2002), Paris, France, pp. 200–201 (2002)
14. Tian, D., Georganas, N.D.: A node scheduling scheme for energy conservation in large wireless sensor networks. Wireless Commun. Mobile Comput. **3**(2), 271–290 (2003)
15. Ping, L.L., Qiang, Z., Sun, Y.-G.: Multiple targets associated coverage algorithm in wireless sensor network. J. Tianjin Univ. **32**(6), 483–489 (2002)
16. Wang, X., Xing, G., Zhang, Y., Lu, C., Pless, R., Gill, C.D.: Integrated coverage and connectivity configuration in wireless sensor networks. In: 1st ACM Conference on Embedded Networked Sensor Systems (2003)
17. Zhou, Z., Das, S., Gupta, H.: Connected k-coverage problem in sensor networks. In: ICCCN (2004)
18. Bai, X., et al.: Optimal patterns for four-connectivity and full coverage in wireless sensor networks. IEEE Trans. Mob. Comput. **9**(3), 435–448 (2010)
19. Ostovari, P., Dehghan, M., Wu, J.: Connected point coverage in wireless sensor networks using robust spanning trees. In: 2011 31st International Conference on Distributed Computing Systems Workshops (ICDCSW), pp. 287–293 (2011)
20. Han, K., Xiang, L., Luo, J., Liu, Y.: Minimum-energy connected coverage in wireless sensor networks with omni-directional and directional features. In: Proceedings of the Thirteenth ACM International Symposium on Mobile Ad Hoc Networking and Computing, pp. 85–94 (2012)
21. Mini, S., Udgata, S.K., Sabat, S.L.: M-connected coverage problem in wireless sensor networks. Int. Sch. Res. Netw. ISRN Sens. Netw. **2012**(858021), 1–9 (2012)

22. NetGen website, a generator of concurrent systems. http://wsn.univ-brest.fr/NetGen/
23. Sinnott, R.W.: Virtues of the haversine. Sky Telescope **68**(2), 159 (1984)
24. Goldberg, A., David, R.: Smalltalk-80 the Language, pp. 31–75. Addison Wesley, Reading (1989)