Genetic Algorithm for Sensor Scheduling with Adjustable Sensing Range

D.Arivudainambi [#1], G.Sreekanth [*2], S.Balaji [#3]

[#] Department of Mathematics, Anna University
Chennai, India
[1] arivu@annauniv.edu
[3] skbalaji28@gmail.com
[*] Department of Computer Science Engineering, JNN Institute of Engineering
Chennai, India
[2] sreeranga2002@yahoo.com

Abstract— Sensing, processing and communication can consume energy in wireless sensor network. The lifetime of wireless sensor network can be extended by efficient power management. One efficient method to extend the network lifetime is to divide the set of all deployed sensors into non disjoint subsets or sensor covers so that each sensor cover can monitor the entire targets. Adjusting the sensing range of each sensor can avoid the redundantly covered targets by multiple sensors. This process saves the energy of sensors and maximizes the number of sensor covers. By identifying maximum number of sensor covers and then activating these sensor covers in sequence will improve the network lifetime. This paper, proposes Genetic Algorithm (GA) as a better solution to the Sensor Covers with Adjustable Sensing Range (SC-ASR). The simulation results of the various problem instances confirm that GA improved the lifetime of sensor network compared with fixed sensing range.

Keyword- Genetic Algorithm, Sensor scheduling, Adjustable sensing range

I. INTRODUCTION

Wireless Sensor Network (WSN) consists of large number of sensors and a base station. Sensors are used to monitor the region and the base station is used to collect the data from the sensors to facilitate crucial action. There are many successful applications in wireless sensor network like battle field monitoring, forest fire detection, tsunami detection, nuclear power plant monitoring and so on. Each sensor contains actuator (to sense the environment), processor (to perform certain tasks), transreceiver (to send and receive data from sensors) and battery (to supply energy to perform certain tasks). Each sensor contains limited battery energy and it cannot be replaced or recharged frequently. The entire task has to be performed with the limited battery energy [2, 3, 11]. If the battery runs out of energy then the sensor cannot perform any task. The crucial question is how to prolong the lifetime of the sensor network with the limited energy.

Sensor sensing device can be scheduled to go into sleep mode whenever it does not require to sense the region [5, 14]. The processor can eliminate certain redundant data [18] and identify the shortest path from source to destination [1, 19]. The transreceiver can then send the aggregated data to destination via the shortest path identified by the processor. Another way to prolong the sensor energy would be to schedule the transreceiver to go into sleep mode whenever the sensor does not have a data to transmit to base station [4]. All the concepts discussed above will conserve the sensor energy. This paper deals with scheduling the sensor sensing device in active/sleep mode.

Many sensors are randomly deployed to monitor the given targets. In this random placement, more than one sensor can cover the same targets. However, only one sensor is enough to monitor that particular target. If all the sensors are activated at the same time then the redundant sensors energy will be unnecessarily consumed. To avoid this, the set of sensors with fixed sensing range can be partitioned into non disjoint subset or sensor covers which monitor the entire targets. Then activation of the sensor covers in succession will increase the sensor network lifetime. Many algorithms like greedy [12, 13], genetic algorithm [6], memetic algorithm [7], learning automata [16] are proposed to identify the maximum number of sensor covers. Improvisation would still be required to maximize the lifetime of sensor network.

Adjusting the sensing range of each sensor which does not affect the coverage requirement will increase the lifetime of sensor network. It means that, each active sensor have a minimum sensing range to monitor the given targets. In this paper, two power saving techniques are studied i) scheduling the sensors into active/sleep mode ii) adjusting the sensing range of each sensor. These two techniques are bound to improve the overall lifetime of WSN.

II. RELATED WORKS

Area coverage problem is to monitor the given region by set of randomly deployed sensors. Area coverage problem is modified as target coverage problem by effective partitioning of the given area into subfield and each subfield is treated as targets [17]. Many algorithms were proposed to maximize the lifetime of sensor network in target coverage problem with fixed sensing range. iMA finally improved the quality compared with the existing work in target coverage problem with fixed sensing range [5]. In the meanwhile, adjustable sensing range concept was introduced in area coverage problem and this aided maximizing the lifetime of WSN compared with fixed sensing range [10].

Mihaela cardei et al. used the concept of adjustable sensing range in target coverage problem to improve the lifetime of wireless sensor network [15]. Initially they modeled the target coverage problem in integer programming and Linear Programming (LP) and then designed the LP based heuristic algorithm. Further, authors approached the centralized and distributed greedy algorithm to maximize the solution quality. Finally, author identified that centralized greedy algorithm has higher lifetime than other methods.

Target coverage problem with adjustable sensing range can be a model in linear program with exponential number of variables [8]. Further, garg-konemam algorithm is approached to solve the linear program formulation and identifies four times better results compared to [15]. In [9], author modelled the target coverage problem with adjustable sensing range as mixed integer programming. Moreover, original greedy and greedy randomized adaptive search procedure heuristic is approached to maximize the lifetime of sensor network.

III.FORMULATION OF SENSOR COVERS WITH ADJUSTABLE SENSING RANGE

Let $S=\{S_1,S_2,\cdots,S_n\}$ be the set of sensors with the initial energy E are randomly deployed to monitor the set of targets $T=\{T_1,T_2,\cdots,T_m\}$. Each sensor S_i is placed in the region (x_i,y_i) and targets T_j placed in the region (x_j,y_j). The sensing range of each sensor can be varying from $\{r_1,r_2,\cdots,r_p\}$ and the corresponding energy consumption is $\{e_1,e_2,\cdots,e_p\}$. The sensor S_i with the sensing range r_k is cover the target T_j if it satisfies the following condition

$$(x_i-x_j)^2+(y_i-y_j)^2\le r_k^2 \quad \text{where } 1\le i\le n, 1\le j\le m, 1\le k\le p \tag{1}$$

In this random placement of sensors and targets, a particular target T_j is covered by many sensors. But only one sensor with minimum sensing range is enough to monitor the target. If all the sensors are activated at the same time then the redundant sensor energy will be consumed unnecessarily. So the required sensors are activated to monitor the entire targets. If the sensors are activated with the higher sensing range then it will also reduce the lifetime of sensor network. Therefore, there is a need to adjust the sensing range of each sensor with minimal sensing range and then activate the sensors to monitor the entire target. Identifying the maximum number of sensor cover is modelled as sensor covers with adjustable sensing range. It is as described below

i) Let $C=\{c_1,c_2,\cdots,c_k\}$ where $c_i\subseteq S,\ i=1,2,\cdots,k$ be the cover set. Each covers c_i containing some sensors with different sensing ranges, which cover the entire target set and k should be maximized.

ii) Sensor S_i can be used in any sensor cover c_i up to the energy E.

iii) Activate the sensor cover $c_i,\ i=1,2,\cdots,k$ in succession where $|c_i|$ is the number of sensor activated in the i^{th} schedule.

Figure 1 shows the wireless sensor network of five sensors with sensing range 200 to monitor the four targets. Initial energy of each sensor is five. Each sensor has an adjustable sensing range. The different sensing range for the sensor is {100, 200, 300, 400, 500} and the corresponding energy consumption is {1, 2, 3, 4, 5} for one time unit. First activate all the sensors with sensing range 100. Therefore, the sensor coverage for sensing range 100 is $S_1=S_3=S_4=\phi,\ S_2=\{T_1\}$ and $S_5=\{T_2\}$. No cover can be identified with the sensing range 100. Therefore, the lifetime of WSN with sensing range 100 is zero. Activate all the sensors with sensing range 200. Therefore, the sensor coverage for sensing range 200 is $S_1=S_4=\phi,\ S_2=\{T_1,T_4\},\ S_3=\{T_3\},\ S_5=\{T_2\}$. One cover can be identified for this network. The cover is $c_1=\{S_2,S_3,S_5\}$ and the corresponding energy is two for all the sensors. But the initial energy is five. Therefore, the sensors can be in active mode up to the sensor energy runs out. The lifetime of WSN with sensing range 200 is $1\times 2.5=2.5$.

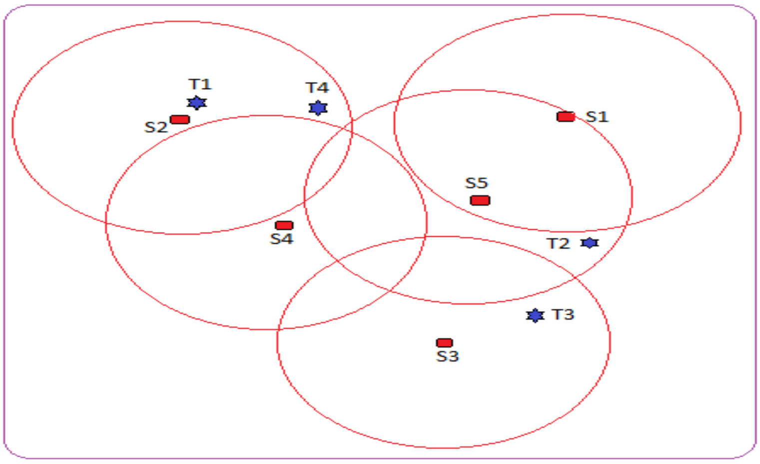

Figure 1: Random placement of sensors with sensing range 200 and targets

Activate all the sensors with sensing range 300. Therefore, the sensor coverage for sensing range 300 is $S_1 = \{T_2, T_4\}$, $S_2 = \{T_1, T_4\}$, $S_3 = \{T_2, T_3\}$, $S_4 = \{T_1, T_4\}$ and $S_5 = \{T_2, T_3, T_4\}$. Two covers can be identified for this network. The covers are $c_1 = \{S_2, S_3\}$ and $c_2 = \{S_4, S_5\}$ the corresponding energy is three for all sensors. Therefore, the lifetime of WSN with sensing range 300 is $2 \times 1.667 = 3.333$.

Activate all the sensors with sensing range 400. Therefore, the sensor coverage for sensing range 400 is $S_1 = \{T_2, T_3, T_4\}$, $S_2 = \{T_1, T_4\}$, $S_3 = \{T_2, T_3\}$, $S_4 = \{T_1, T_2, T_3, T_4\}$ and $S_5 = \{T_1, T_2, T_3, T_4\}$. Three sensor covers can be identified for this network. The covers are $c_1 = \{S_2, S_3\}$, $c_2 = \{S_4\}$, $c_3 = \{S_5\}$ and the corresponding energy is four for all sensors. Therefore, the lifetime of WSN with sensing range 400 is $3 \times 1.25 = 3.75$.

Activate all the sensors with sensing range 500. Therefore, the sensor coverage for sensing range 500 is $S_1 = \{T_1, T_2, T_3, T_4\}$, $S_2 = \{T_1, T_2, T_4\}$, $S_3 = \{T_1, T_2, T_3, T_4\}$, $S_4 = \{T_1, T_2, T_3, T_4\}$ and $S_5 = \{T_1, T_2, T_3, T_4\}$. Four covers can be identified for this network. The covers are $c_1 = \{S_1\}$, $c_2 = \{S_3\}$, $c_3 = \{S_4\}$ and $c_4 = \{S_5\}$ the corresponding energy is five for all the sensors. Therefore, the lifetime of WSN with sensing range 500 is $4 \times 1 = 4$.

For sensing range 200, only one sensor cover is identified and sensor S_1 and S_4 are not used. S_2, S_3 and S_5 with sensing range 200 will cover the entire target but S_2 with sensing range 200, S_3 and S_5 with sensing range 100 will cover the entire targets. Therefore, sensors can be adjusting the sensing range continuously then the higher lifetime can be attained. Five covers can be identified with the adjustable sensing range. The five covers are $c_1 = \{S_{12}, S_{35}\}$, $c_2 = \{S_{22}, S_{33}\}$, $c_3 = \{S_{22}, S_{23}, S_{25}\}$, $c_4 = \{S_{51}\}$ and $c_5 = \{S_{44}\}$. In S_{ij}, i represents the energy and j represents the sensor number. The energy consumed for S_1, S_2, S_3, S_5 is five and S_4 is four. Therefore, the lifetime of WSN with adjustable sensing range is $(4 \times 1) + (1 \times 1.25) = 5.25$. Hence, the sensor with adjustable sensing range have a higher lifetime than the sensor with the fixed sensing range which is shown in the Table I. In this paper, Genetic Algorithm (GA) is proposed to improve the lifetime of sensor network with adjustable sensing range.

TABLE I
Lifetime of Sensor Network with Fixed and Adjustable Sensing Range

Sensing Range	**100**	**200**	**300**	**400**	**500**	**Adjustable sensing Range**
Lifetime	0	2.5	3.33	3.75	4	5.25

IV. IMPLEMENTATION OF GENETIC ALGORITHM FOR SC-ASR

Genetic algorithm is a stochastic algorithm based on the principles of natural genetics and it is successfully applied in many optimization problems. GA is proposed to adjust the sensing range of each sensor and schedule the sensors in active/sleep mode in order to maximize the network lifetime. GA encodes the candidate solution as chromosome, which is represented in the form of a matrix. An optimal solution can search through the initial population, which is generated with the candidate solution. The quality of candidate solution can be measured by the fitness function. A higher fitness value is the better solution for maximize the network lifetime. Selection operator chooses a chromosome as a parent matrix from initial population. Crossover and mutation is applied to the parent matrix to change some genes and to produce the offspring. Selection, crossover and mutation are repeated to identify the complete offspring. The fittest chromosome is selected for the next generation. This process is continued till the maximum number of generation is reached.

A. Representation

Sensors with different sensing range can be represents in the matrix form. Each column represents a single sensor with different level of energies and the total energy of each sensor cannot exceed the initial energy. First column shows that sensor one with different energy level. S_{11} randomly assigns the energy for sensor one from 0 to initial energy E_1. Sensor one utilizes the S_{11} energy from the initial energy E_1. Therefore, the remaining energy for sensor one is $E_1 = E_1 - S_{11}$. S_{21} randomly assigns the energy for sensor one from 0 to remaining energy of sensor one E_1. So, the remaining energy for sensor one is $E_1 = E_1 - S_{21}$. This process is repeated until the energy of sensor one is fully utilized. The same process can be repeated to all other sensors.

$$R = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & & & \vdots \\ S_{u1} & S_{u2} & \cdots & S_{un} \end{bmatrix}$$

B. Initial Population

Initial population matrix is generated in the same way as is explained in the representation. The set of 100 populations is generated by making a random assignment of initial energy. Therefore, the initial population matrixes are

$$pop_1 = \begin{bmatrix} 5 & 2 & 1 & 2 & 1 \\ 0 & 1 & 1 & 1 & 2 \\ 0 & 2 & 1 & 1 & 2 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} \qquad pop_2 = \begin{bmatrix} 0 & 1 & 3 & 0 & 3 \\ 0 & 2 & 2 & 0 & 2 \\ 3 & 1 & 0 & 3 & 0 \\ 1 & 1 & 0 & 2 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Pop_1 and pop_2 are the two initial population matrix for the network shown in the figure 1. Initial energy for the entire sensor is five. First column of pop_1 is sensor one energy assignment. The first element of first column is five, which is randomly assigned one number from 0 to initial energy 5. The total energy of sensor one is utilized. Therefore, the remaining element in the first column will be zero. Second column of pop_1 is second sensor energy assignment. The first element of second column is two, which is randomly assigned one number from 0 to 5. Second element of second column is one, which is randomly assigned from second sensor remaining energy 0 to 3. Third element of second column is two. Therefore, the total energy of second sensor is five, which is fully utilized and the remaining element is zero. In a similar manner, remaining columns are fixed.

C. Fitness Function

Lifetime of sensor network is assigned as the fitness value. If one sensor covers all targets or combination of various sensor covers all targets with different sensing range then it forms one sensor cover. The total number of sensor cover for each matrix can be identified and set as a lifetime of sensor network. The higher fitness value will move on to the next generation. Union operation is used to identify the sensor cover. In pop_1, S_{11} is 5 it means that sensor one utilizing energy 5 and the corresponding sensing range is 500. Therefore, first sensor with sensing range 500 can cover all targets. So, it forms one cover. The next element S_{12} is 2. It means that second sensor utilizing energy two and the corresponding sensing range is 200. Therefore, sensor two with sensing range 200 can cover $\{T_1, T_4\}$. It does not cover all targets so next sensor is choosen to form the cover. The next element S_{13} is one. It means that sensor three using energy one and the corresponding sensing range is 100. Therefore, sensor three with sensing range 100 can cover $\{T_3\}$. Union of $S_{12} \cup S_{13}$ can cover $\{T_1, T_3, T_4\}$ still the cover was not found. Therefore next element was chosen to form the sensor cover. Finally, $S_{12} \cup S_{13} \cup S_{14} \cup S_{15}$ covered all targets $\{T_1, T_2, \mathrm{T}_3, T_4\}$. Therefore, another cover was identified. The same process can be repeated until the last element of the matrix. The total cover for pop_1 is two. Therefore, the lifetime of sensor network is two for pop_1 matrix. The same process was used to identify the fitness value for the entire matrix.

D. Selection

Parent selection and survival selection are used in the GA. 50 populations are selected from the initial population to form the mating pool based on the higher fitness value. Parent selection can be done randomly from the mating pool to reproduce the child matrix. Survival selection applies the principle of survivor of the fittest. Child matrix is compared with the parent matrix and the fittest one based on the network lifetime is selected. If the child has maximum lifetime compared with parent matrix then parent matrix is replaced by child matrix in the mating pool.

E. Crossover

Genetic algorithm used one point crossover to produce the offspring chromosome. Two chromosomes are chosen from the mating pool and the crossover point is randomly generated. Then two chromosomes changing the genes to produce the offspring. pop_1 and pop_2 are chosen from the mating pool and the crossover point is two. Therefore third, fourth and fifth column of pop_1 and pop_2 are interchanged to produce the $offspring_1$ and $offspring_2$.

$$offspring_1 = \begin{bmatrix} 5 & 2 & 3 & 0 & 3 \\ 0 & 1 & 2 & 0 & 2 \\ 0 & 2 & 0 & 3 & 0 \\ 0 & 0 & 0 & 2 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \qquad offspring_2 = \begin{bmatrix} 0 & 1 & 1 & 2 & 1 \\ 0 & 2 & 1 & 1 & 2 \\ 3 & 1 & 1 & 1 & 2 \\ 1 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 \end{bmatrix}$$

F. Mutation

Creep mutation is used to modify the offspring value with the mutation rate. Genetic algorithm randomly chooses one sensor from offspring matrix and re-generates the energy level. Fourth sensor is chosen from $offspring_1$ and it re-generates the energy level of sensor four. Finally this offspring matrix after the mutation identified the maximum number of sensor cover and its lifetime is 5.25. When the fitness value of offspring is higher than the population matrix then population matrix can be replaced by offspring matrix.

$$offspring_1 = \begin{bmatrix} 5 & 2 & 3 & 4 & 3 \\ 0 & 1 & 2 & 0 & 2 \\ 0 & 2 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \qquad offspring_2 = \begin{bmatrix} 0 & 1 & 1 & 2 & 1 \\ 0 & 2 & 1 & 1 & 2 \\ 3 & 1 & 1 & 1 & 2 \\ 1 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 \end{bmatrix}$$

V. PERFORMANCE EVALUATION

The proposed genetic algorithm has been implemented to maximize the lifetime of wireless sensor network with adjustable sensing range and results obtained by GA are compared with lifetime of fixed sensing range. Sensors and targets are randomly deployed in the 500×500 region. Sensing ranges of each sensor varied from 50 to 200 with the incremental of 50. Results generated for each fixed sensing ranges were compared with continuously adjustable sensing range. Population size 100, mating pool 50, generation limit 1000 and mutation rate 0.5 were considered in this simulation. The series of simulation was implemented in the matlab. Each result shown in the tables are averages of 10 runs. Simulation results consist of two sections. First section consists of simulation results with varying different number of targets. Second section consists of simulation results with different number of sensors.

A. *Simulation Results for Different Number of Targets*

This section shows the simulation results to validate the lifetime of WSN with different number of targets. Table II shows the results for 50 sensors and different number of targets. Table III shows the results for 100 sensors and different number of targets. Third column shows the number of maximum possible cover can be generated by all the sensors with sensing range 50. Similarly fourth, fifth and sixth columns show the number of maximum possible cover can be generated by all the sensors with sensing range 100, 150 and 200 respectively. Seventh column shows the number of cover generated by GA with each sensor having different sensing ranges. Adjustable Sensing Range (ASR) generated higher lifetime compared with fixed sensing range.

TABLE II
Results Generated for Fixed and Adjustable Sensing Range with 50 Sensors and Different Number of Targets

Sensor	Target	SR-50	SR-100	SR-150	SR-200	ASR
50	30	0	5.50	12.33	19.25	22
	60	0	3.5	8.33	14	19.4
	120	0	3	8.33	12	19.2
	250	0	0.5	6.33	11	16.5
	500	0	2	8.67	12.75	16.5

TABLE III
Results Generated for Fixed and Adjustable Sensing Range with 100 Sensors and Different Number of Targets

Sensor	Target	SR-50	SR-100	SR-150	SR-200	ASR
100	30	0	19	31.67	41.5	42.1
	60	1	13.5	24.33	33	37.6
	120	0	12.5	18.67	29.5	33.8
	250	0	11	23.67	30.75	32.1
	500	0	8	20.33	26.75	31.6

B. *Simulation Results for Different Number of Sensors*

This section shows the simulation results of WSN lifetime with different number of sensors. Table IV shows the results for 100 targets with different number of sensors. Table V shows the results for 500 targets with different number of sensors. Third column shows the results generated by sensors with sensing range 50 and generated results is zero. It means that some of the targets are not covered by any sensors with sensing range 50. Adjustable sensing range attain maximum lifetime compared with the fixed sensing range. When the number of sensors is less, then the search space is reduced and adjustable sensing range improves the large amount of solution quality compared with fixed sensing range. This result validates the hypothesis that the adjustable sensing range attain maximum lifetime compared with fixed sensing range.

TABLE IV
Results Generated for Fixed and Adjustable Sensing Range with 100 Targets and Different Number of Sensors

Target	Sensor	SR-50	SR-100	SR-150	SR-200	ASR
100	20	0	0	2.67	4	8.6
	40	0	1.5	7.67	11.25	15.2
	60	0	6.5	15	21	22.1
	80	0	9.5	18	22	28.4
	100	0	9.5	23	31.5	34.9

TABLE V
Results Generated for Fixed and Adjustable Sensing Range with 500 Targets and Different Number of Sensors

Target	Sensor	SR-50	SR-100	SR-150	SR-200	ASR
500	20	0	0	0	2.25	7.2
	40	0	0.5	3.33	6.25	13.5
	60	0	1.5	8	13	19.2
	80	0	6.5	14.67	19.25	24.9
	100	0	8	20.33	26.75	31.6

VI. CONCLUSION

Energy efficiency is an important issue in a wireless sensor network. Genetic algorithm improves the lifetime of sensor network by adopting two techniques. The techniques involve adjusting the sensing range of each sensor and scheduling the sensors in active\sleep mode. This method improves the wireless sensor network lifetime. Simulation results shows that GA increases WSN lifetime with adjustable sensing range to a large extent compared with fixed sensing range. The results validate the effectiveness and efficiency of GA to give a better solution.

ACKNOWLEDGMENT

One of the authors S. Balaji gratefully acknowledges the financial support received from Anna University under Anna Centenary Research Fellowship to carry out this research work.

REFERENCES

[1] Adamu Murtala Zungeru, Li-Minn Ang and Kah Phooi Seng, “Classical and swarm intelligence based routing protocols for wireless sensor networks: A survey and comparsion,” Journal of Network and Computer Applications, vol. 35, pp. 1508-1536, 2012.
[2] Akyildiz I.F., Su W., Sankarasubramaniam Y. and Cayirci E., “Wireless sensor networks: a survey,” Computer Networks, vol. 38, pp. 393-422, 2002.
[3] Akyildiz I.F., Tommaso Melodia and Chowdury K.R., “Wireless multimedia sensor networks: a survey,” IEEE Wireless Communications, vol. 14 (6), pp. 32-39, 2007.
[4] Anar A. Hady, Sherine M. Abd El-kader and Hussein S. Eissa, “Intelligent sleeping mechanism for wireless sensor networks,” Egyptian Informatics Journal, vol. 14, pp. 109-115, 2013.
[5] Arivudainambi D., Balaji S., Rekha D., “Improved memetic algorithm for energy efficient target coverage in wireless sensor networks,” The Eleventh IEEE International Conference on Networking, Sensing and Control, pp. 261-266, 2014.
[6] Chih-Chung Lai, Chuan-Kang Ting and Ren-Song Ko, “An effective genetic algorithm to improve wireless sensor network lifetime for large-scale surveillance applications,” in:proceedings of the 2007 Congress on Evolutionary Computation, pp. 3531-3538, 2007.
[7] Chuan-Kang Ting and Chien-Chih Liao, “A memetic algorithm for extending wireless sensor network lifetime,” Information Sciences, vol. 180 (24), pp. 4818-4833, 2010.
[8] Dhawan A., Vu C.T., Zelikovsky A. Li Y. and Prasad S.K., “Maximum lifetime of sensor networks with adjustable sensing range,” Seventh ACIS International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/ Distributed Computing, pp. 285-289, 2006.
[9] Fang Zhou, “Energy efficient coverage using sensors with continuously adjustable sensing ranges,” Seventh International Conference on Natural Computation, vol. 1, pp. 109-113, 2011.
[10] Jie Wu and Shuhui Yang, “Coverage issue in sensor networks with adjustable ranges,” International Conference on Parallel Processing Workshops, pp. 61-68, 2004.
[11] Luigi Alfredo Grieco, Gennaro Boggia, Sabrina Sicari and Pietro Colombo, “Secure wireless multimedia sensor networks: a survey,” Third International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies, pp. 194-201, 2009.
[12] Mihaela Cardei and Ding-Zhu Du, “Improving wireless sensor network lifetime through power aware organization,” Wireless Networks, vol. 11(3), pp. 333-340, 2005.
[13] Mihaela Cardei, Thai M.T., Yingshu Li and Weili Wu, “Energy efficient target coverage in wireless sensor networks,” IEEE INFOCOM, vol. 3, pp. 1976-1984, 2005.
[14] Mihaela Cardei and Jie Wu, “Energy efficient coverage problems in wireless ad-hoc sensor networks,” Computer Communications, vol. 29 (4), pp. 413-420, 2006.
[15] Mihaela Cardei, Jie Wu, Mingming Lu and Mohammad O. Pervaiz, “Maximum network lifetime in wireless sensor networks with adjustable sensing ranges,” IEEE International Conference on Wireless and Mobile Computing, Networking and Communications, vol. 3, pp. 438-445, 2005.
[16] Mostafaei H. and Meybodi M.R., “Maximizing lifetime of target coverage in wireless sensor networks using learning automata,” Wireless Personal Communications, Vol. 71 (2), pp. 1461-1477, 2013.
[17] Sasa Slijepcevic and Miodrag Potkonjak, “Power efficient organization of wireless sensor networks,” IEEE International Conference on Wireless Communications, vol. 2, pp. 472-476, 2001.
[18] Shouling Ji, Jing He, Yi Pan, Yingshu Li, “Continuous data aggregation and capacity in probabilistic wireless sensor networks,” Journal of Parallel and Distributed Computing, vol. 73, pp. 729-745, 2013.
[19] Wang Ke, Wang Qianping, Jiang Dong and Xu Qin, “A routing and positioning algorithm based on a k-barrier for use in an underground wireless sensor network,” Mining Science and Technology, vol. 21, pp. 773-779, 2011.