Optimizing Coverage in a K-Covered and Connected Sensor Network Using Genetic Algorithms

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Agenda

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Wireless Sensor Networks

- Sensor networks are dense wireless networks of small, low-cost sensors, which collect and disseminate environmental data.
- Wireless sensor networks facilitate monitoring and controlling of physical environments from remote locations with better accuracy.
- They have applications in a variety of fields such as environmental monitoring, military purposes and gathering sensing information in inhospitable locations

Important Aspects of WSN

- Coverage:
  - Sensing coverage characterizes the monitoring quality provided by a sensor network on a designated region and reflects how well a sensor network is monitored or tracked by sensors.
  - Can be considered as the measure of quality of the service of a sensor network
- Connectivity: Connectivity is being defined as the ability of any active node to communicate directly or indirectly with any other active node [4]
  - Without connectivity, nodes may not be able to coordinate effectively or transmit data back to base stations.
- Hotspots: Some areas in the network which are more important than other areas and need to be covered by more sensors.
  - K-Covered property holds sensor count of hotspot area

Genetic Algorithms

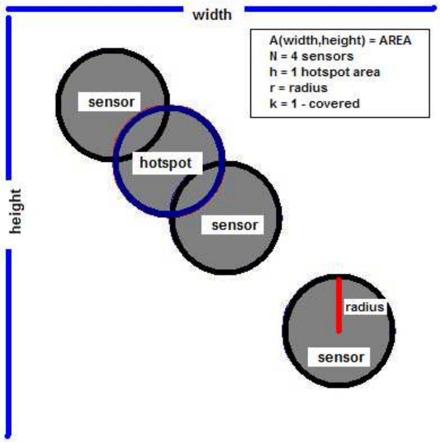
- A genetic algorithm (GA) is a search technique used in computer science to find approximate solutions to combinatorial optimization problems.
- It does not require detailed knowledge about the problem, it can search globally, and it can adapt to the changing conditions in the problem

What we have done?

- The main contribution of this paper to be the first application employing genetic algorithms that satisfies three conditions for finding an optimal sensor placement :
  - maximizes the coverage area of a sensor node distribution
  - all of the given hotspot areas are covered by at least k sensors (k-covered)
  - maintains connectivity between sensor nodes

Problem Definition

- Obstacle-free 2D area $A(width, height)$
- N sensors (sensing radius r_s) (communication radius $r_c = 2 * r_s$)
- h hotspot areas
- K-Covered k value



Problem Definition

- We are requested to maximize total covered area of sensor network under the following constraints:
  - All sensors can communicate with each other (connectivity)
  - h hotpot areas must be covered by at least k sensors ($k - covered$)
  - Centers of sensors must reside in the limited area A
  - We assumed that the sensing and communication ranges of all sensors are identical

Definition (Problem Definition)

Given parameters A, N, r_s, r_c, k; try to increase coverage area of the sensor network without breaking the property that all hotspot areas are k-covered and all sensors are connected

Evolutionary Approach for Solving the Problem

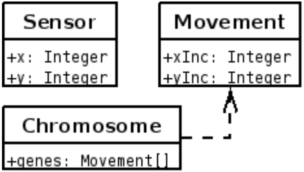
- GA requires some important parameters:
  - T Population size
  - P_m Mutation probability
  - P_c Crossover probability
  - G Generation count
- GA Outline:
  - **Start** Generate a random population of chromosomes
  - **Loop** Repeat until termination criteria is reached
    - **Fitness** Calculate fitness and sort individuals
    - **New Population** Crossover and mutation are applied to current population to form a new population
    - **Elitism** The best individual is selected and applied to current sensor deployment
  - **Solution** Return optimal solution

Chromosome Encoding

Sensors are represented using 2D coordinates ($S(x,y)$) on a 2D plane ($A(width, height)$) of the form

$$\{S(x,y) : 0 \leq x \leq width, 0 \leq y \leq height\} \quad (1)$$

$$C_0 = \{M_{S_0}, M_{S_1}, M_{S_2}, M_{S_3}, \ldots.., M_{S_N}\}$$
$$C_1 = \{M_{S_0}, M_{S_1}, M_{S_2}, M_{S_3}, \ldots.., M_{S_N}\}$$
$$C_2 = \{M_{S_0}, M_{S_1}, M_{S_2}, M_{S_3}, \ldots.., M_{S_N}\}$$
$$C_i = \{M_{S_0}, M_{S_1}, M_{S_2}, M_{S_3}, \ldots.., M_{S_N}\} \quad (2)$$
$$C_T = \{M_{S_0}, M_{S_1}, M_{S_2}, M_{S_3}, \ldots.., M_{S_N}\}$$



$$M_{S_i}(x_{inc}, y_{inc}) : \{-r_s * 0.01 \leq x_{inc}, y_{inc} \leq r_s * 0.01\} \quad (3)$$

GA Operators

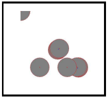
- One Point Crossover (P_c)
- Random mutation (P_m)
- Elitism

Coverage Area & Fitness Function

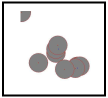
$$A_c = \sum_{i=0}^{width} \sum_{j=0}^{height} \begin{cases} 0, & \text{if } Color_{ij} \text{ is White} \\ 1, & \text{else} \end{cases} \tag{4}$$

$$F(C_i) = \begin{cases} -INFINITY, Q_0 \\ -(D_{cc} * N_{cc}), Q_1 \\ A_c, Q_2 \end{cases} \tag{5}$$

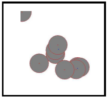
Q_0=not k-covered (not feasible)
Q_1=k-covered, not connected (not feasible)
Q_2=k-covered, connected (feasible)



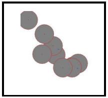
(a) $N_{cc} = 4$ (F=-5428)



(b) $N_{cc} = 3$ (F=-1926)

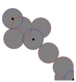


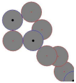
(c) $N_{cc} = 2$ (F=-510)

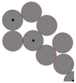


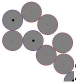
(d) $N_{cc} = 2$ (F=-224)

Elite individuals and increase in coverage during GA run (k=2, h=3, N=12, $A(400, 400)$)

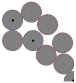

(e) G=100 (F=51116)

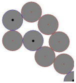

(f) G=200 (F=58627)

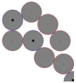

(g) G=500 (F=65322)

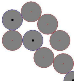

Szeged

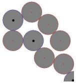
(h) G=1000 (F=65331)

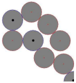

(i) G=1500 (F=65349)


(j) G=2000 (F=65453)

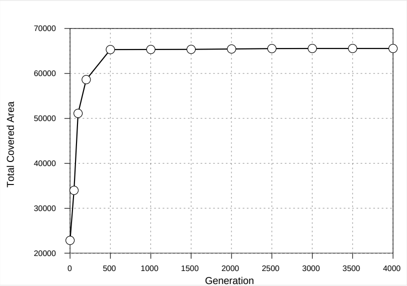

(k) G=2500 (F=65546)


(l) G=3000 (F=65546)


(m) G=3500 (F=65546)


(n) G=4000 (F=65546)

Total covered area change during GA run



Implemented using Java programming language. For all our experiments, we assigned the population size, the number of generation, the crossover rate and mutation rate to be 100, 4000, 0.7, and 0.2 respectively. Experiments are executed on Ubuntu GNU/Linux operating system installed PC platform.

Conclusion & Future Work

- Coverage and connectivity are important metrics to characterize quality of sensor networks
- A Genetic Algorithm and a fitness function is proposed in this paper
- This algorithm preserves node connectivity and k-coverage property for hotspot area
- Study continues to find minimum number of sensors for connected k-coverage problem
- Simulation tool development continues and we plan to test algorithm in major simulation environments (TOSSIM).

References

- A. Bharathidasan and V.A.S. Ponduru, Sensor networks: An overview. Online. Available: http://wwwcsif.cs.ucdavis.edu bharathi/sensor/survey.pdf
- H. Sengoku, I. Yoshihara, A Fast TSP Solver Using GA on Java, In Proc. of the 3rd Int. Symp. on Artificial Life and Robotics (AROB-III), 1998, pp. 283–288.
- C. Huang, and Y. Tseng, The coverage problem in a wireless sensor network, In Procs. of the 2nd ACM international Conference on Wireless Sensor Networks and Applications (WSNA '03), 2003, pp.115–121.
- X. Wang, G. Xing, Y. Zhang, C. Lu, R. Pless, and C. Gill, Integrated coverage and connectivity configuration in wireless sensor networks, In Proc. of the 1st international Conference

References

- S. Megerian, F. Koushanfar, M. Potkonjak, M.B. Srivastava, Worst and best-case coverage in sensor networks, Transactions on Mobile Computing , vol.4, no.1, Jan.-Feb. 2005, pp.84-92
- F.P. Quintao, F.G. Nakamura, G.R. Mateus, Evolutionary algorithm for the dynamic coverage problem applied to wireless sensor networks design, Evolutionary Computation, 2005, vol.2, pp.1589-1596
- J. Zhao, Y. Wen, R. Shang and G. Wang, Optimizing Sensor Node Distribution with Genetic Algorithm in Wireless Sensor Network, Advances in Neural Networks (ISNN'04), 2004, LNCS vol. 3174, pp.242-247
- M. Hefeeda and M. Bagheri, Efficient k-Coverage Algorithms for Wireless Sensor Networks, Technical Report TR 2006-22, Simon Fraser University School of Computing Science, 2006

References

- Z. Zhou, S. Das, H. Gupta, Connected K-coverage problem in sensor networks, Proc. of 13th International Conference on Computer Communications and Networks, 2004. ICCCN 2004), 11-13 Oct. 2004, pp. 373-378
- S. Gao, C.T. Vu, and Y .Li, Sensor Scheduling for k-Coverage in Wireless Sensor Networks, 2nd International Conference on Mobile Ad-hoc and Sensor Networks (MSN 2006), Hong Kong, China, December 13-15, 2006.
- S. Habib, M Safar, Sensitivity Study of Sensors' Coverage within Wireless Sensor Networks, Proc. of 16th International Conference on Computer Communications and Networks (ICCCN 2007), 13-16 Aug. 2007, pp.876-881
- H. Karl, A Willig, Protocols and Architectures for Wireless Sensor Networks, John Wiley & Sons 2005