NODE PLACEMENT OPTIMIZATION USING EXTENDED VIRTUAL FORCE AND CUCKOO SEARCH ALGORITHM IN WIRELESS SENSOR NETWORK

PUTERI AZWA BT AHMAD

MASTER SCIENCE (INFORMATION TECHNOLOGY)
UNIVERSITI UTARA MALAYSIA
2014

Permission to Use

In presenting this thesis in fulfilment of the requirements for a postgraduate degree from Universiti Utara Malaysia, I agree that the Universiti Library may make it freely available for inspection. I further agree that permission for the copying of this thesis in any manner, in whole or in part, for scholarly purpose may be granted by my supervisor(s) or, in their absence, by the Dean of Awang Had Salleh Graduate School of Arts and Sciences. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to Universiti Utara Malaysia for any scholarly use which may be made of any material from my thesis.

Requests for permission to copy or to make other use of materials in this thesis, in whole or in part, should be addressed to:

Dean of Awang Had Salleh Graduate School of Arts and Sciences

UUM College of Arts and Sciences

Universiti Utara Malaysia

06010 UUM Sintok

Abstrak

Penempatan nod adalah salah satu daripada isu asas yang mempengaruhi prestasi kawasan liputan dan sambungan penderia tanpa wayar (WSN). Dalam WSN berskala besar, nod penderia disebarkan secara rawak di mana beberapa nod penderia adalah berselerakan terlalu rapat dan jauh dari satu sama lain. Penempatan rawak ini menyebabkan beberapa isu seperti lubang liputan, pertindihan dan kegagalan sambungan di mana ia yang menyumbang kepada prestasi kawasan liputan dan sambungan WSN. Model penempatan nod dibina untuk mencari penempatan nod yang optimum dan mengekalkan kawasan liputan serta menjamin penyambungan di dalam penempatan rawak. Prestasi Algoritma Perlanjutan Tolakan Maya (EVFA) dan algoritma Carian Cuckoo (CS) dinilai dari segi liputan dan sambungan. EVFA menunjukkan peningkatan kawasan liputan dan sambungan adalah terjamin berbanding dengan algoritma CS. Kedua-dua algoritma ini mempunyai kelebihan tersendiri dalam meningkatkan prestasi liputan selepas pelancaran rawak awal. Pendekatan EVFA boleh menyusun semula nod penderia menggunakan daya tolakan dan tarikan selepas pelancaran rawak awal dan algoritma CS adalah lebih cekap dalam meneroka carian kawasan liputan maksimum dalam penempatan rawak. Kajian ini mencadangkan algoritma Perlanjutan Tolakan Maya dan Carian Cuckoo (EVFCS) hasil gabungan antara algoritma EVFA dan CS untuk teknik penempatan nod dalam pencarian penempatan nod yang optimum. Ia bertujuan untuk meningkatkan liputan rangkaian dan hubungan dengan minimumkan lubang liputan dan kawasan bertindih. Satu siri kajian eksperimen kepada penilaian algoritma telah dijalankan dalam persekitaran simulasi. Dalam EVFCS, algoritma ini digunakan untuk mencari nilai jarak ambangan yang terbaik dan menggunakan nilai tersebut untuk menyusun semula kedudukan terbaru nod. Hasil kajian menunjukkan bahawa 18.212m adalah nilai jarak ambang terbaik yang mampu memaksimumkan kawasan liputan. Ia juga dapat mengurangkan masalah lubang liputan dan pertindihan serta menjamin kualiti sambungan. Ini membuktikan bahawa EVFCS mengatasi pendekatan EVFA dan mencapai peningkatan yang signifikan dalam kawasan liputan dan menjamin penyambungan. Perlaksanaan algoritma EVFCS dapat memperbaiki masalah yang dihadapi selepas penempatan rawak awal.

Kata kunci : Rangkaian penderia tanpa wayar, Lubang liputan, Pertindihan kawasan, Algoritma Perlanjutan Tolakan Maya dan Carian Cuckoo (EVFCS)

Abstract

Node placement is one of the fundamental issues that affects the performance of coverage and connectivity in Wireless Sensor Network (WSN). In a large scale WSN, sensor nodes are deployed randomly where they are scattered too close or far apart from each other. This random deployment causes issues such as coverage hole, overlapping and connectivity failure that contributes to the performance of coverage and connectivity of WSN. Therefore, node placement model is develop to find the optimal node placement in order to maintain the coverage and guaranteed the connectivity in random deployment. The performance of Extended Virtual Force-Based Algorithm (EVFA) and Cuckoo Search (CS) algorithm are evaluated and EVFA shows the improvement of coverage area and exhibits a guaranteed connectivity compared to CS algorithm. Both algorithms have their own strength in improving the coverage performance. The EVFA approach can relocate the sensor nodes using a repulsive and attractive force after initial deployment and CS algorithm is more efficient in exploring the search of maximum coverage area in random deployment. This study proposed Extended Virtual Force and Cuckoo Search (EVFCS) algorithm with a combination of EVFA and CS algorithm to find an optimal node placement. A series of experimental studies on evaluation of proposed algorithm were conducted within simulated environment. In EVFCS, the algorithm searches the best value of threshold distance and relocated the new position of sensor nodes. The result suggested 18.212m is the best threshold distance that maximizes the coverage area. It also minimizes the problems of coverage hole and overlapping while guaranteeing a reasonable connectivity quality. It proved that the proposed EVFCS outperforms the EVFA approach and achieved a significant improvement in coverage area and guaranteed connectivity. The implementation of the EVFCS improved the problems of initial random deployment.

Keywords: Wireless sensor network, Node placement, Coverage hole, Overlapping area Extended Virtual Force and Cuckoo Search (EVFCS) algorithm

Acknowledgement

In the name of Allah, the Most Gracious and the Most Merciful.

I would like to extend my thanks and gratitude to:

Allah the Almighty for giving me excellent health and mind for doing this research;

The Politeknik Tuanku Syed Sirajuddin (PTSS) and Ministry of Education (MOE) for the study leave and their financial support;

UUM College of Arts and Sciences and the School of Computing for the facilities and resources provided;

Both my supervisors, Dr Massudi bin Mahmuddin and Dr Mohd Hasbullah bin Omar for their help, guidance and support during the course of my research study;

My beloved husband, Shanizan Herman Mohd Radzi for his love, patience and never ending support; my kids, Tun Muhammad Luqman Aizad, Tun Nur Ainin Sofiya and Tun Muhammad Danial Mirza; both my parents, parents-in-law and siblings for being there;

My colleagues in InterNetWorks Research Group, for their kindness, support and series of discussions we had;

And last but not least, all individuals involved in the establishment of this research.

Table of Contents

List of Tables

List of Figures

List of Abbreviation

ABC	Artificial Bee Colony
ACO	Ant Colony Optimization
CCP	Coverage Connectivity Protocol
CS	Cuckoo Search
EVFA	Extended Virtual Force-Based Algorithm
EVFCS	Extended Virtual Force and Cuckoo Search
FSA	Fish Swarm Algorithm
GA	Genetic Algorithm
GP	Genetic Programming
IPO	Individual Particle Optimization
PSO	Particle Swarm Optimization
QoS	Quality of Service
ROI	Region Of Interest
VFA	Virtual Force Algorithm
VFDEA	Virtual Force Based Deployment-Enhanced Algorithm
VFIPO	Virtual Force algorithm and Individual Particle Optimization
WSN	Wireless Sensor Network

CHAPTER ONE
INTRODUCTION

1.1 Background

In recent years, Wireless Sensor Networks (WSNs) have become one of the most promising technologies in sensing application environment. The WSNs provide flexibility in sensor nodes deployment and maintenance. Furthermore, it has the ability to be deployed in highly dynamic environments hence enable the sensor networks to be potentially used in a wide range of civilian and military applications [1], including security surveillance, environmental monitoring, habitat monitoring, hazard and disaster monitoring, health field applications, under-water communication [2], home applications such as smart environments and smart agriculture system [3-5]. The basic goals of a WSN generally depend on the application and have many functions which include determining the value of parameters at given location, to detect and monitor the occurrence of events and tracking an object. A wireless sensor network consists of distributed autonomous sensor nodes to cooperatively sense and monitor a physical or environmental condition, such as temperature, sound, vibration, pressure, motion or pollutants. In an environmental network [6], sensor nodes can be used to measure the temperature under atmospheric pressure, the amount of sunlight and humidity. The sensor nodes are also used to detect a vehicle movement, estimating the speed and direction of the vehicle. In a military sensor network, sensor nodes are used for battle surveillance [1] to track the enemies as they move through the geographic area covered by the network.

The contents of the thesis is for internal user only

REFERENCES

[1] Q. Wang and I. Balasingham, "Wireless Sensor Networks - An Introduction," in *Wireless Sensor Networks: Application - Centric Design*, Y. K. Tan, Ed., ed: InTech, 2010.

[2] M. Yadav and Y. Mulge, "Review on coverage and connectivity in underwater wireless sensor networks," *International Journal of Computer Science & Engineering Technology (IJCSET)*, vol. 4, pp. 596-599, 2013.

[3] W. Dargie and C. Poellabauer, *Fundamenal of wireless sensor network : theory and practice*. Singapore: John Wiley & Sons Ltd, 2010.

[4] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless sensor networks: a survey," *Computer Networks*, vol. 38, pp. 393–422, 2002.

[5] C. Chee-Yee and S. P. Kumar, "Sensor networks: evolution, opportunities, and challenges," *Proceedings of the IEEE*, vol. 91, pp. 1247-1256, 2003.

[6] R. Mittal and M. P. S. Bhatia, "Wireless sensor networks for monitoring the environmental activities," in *IEEE International Conference on Computational Intelligence and Computing Research (ICCIC)*, 2010, pp. 1-5.

[7] W. N. W. Muhamad, N. H. Rodzi, N. Mat Isa, and N. Ab Wahab, "Efficient network coverage for wireless sensor networks," in *TENCON 2010 - 2010 IEEE Region 10 Conference*, 2010, pp. 240-244.

[8] G. Fan and S. Jin, "Coverage problem in wireless sensor network: a survey," *Journal of Networks,* vol. 5, pp. 1033-1040, 2010.

[9] R. Mulligan and H. M. Ammari, "Coverage in wireless sensor networks: a survey," *Network Protocols and Algorithms,* vol. 2, pp. 27-53, 2010.

[10] S. Zhang, J. Pu, X. Zeng, Y. Liu, and Z. Xiong, "Issue and solution on coverage and performance for wireless sensor networks," *AINTEC'08,* 2008.

[11] R. Trivedi and V. P. Singh, "Coverage and Connectivity Issue in Wireless Sensor Networks," *Indonesian Journal of Electrical Engineering and Informatics (IJEEI),* vol. 1, pp. 49-52, 2013.

[12] P. Sahu and S. R.Gupta, "Deployment techniques in wireless sensor networks," *International Journal of Soft Computing and Engineering (IJSCE),* vol. 2, pp. 525-526, 2012.

[13] S. Mini and S. K. Udgata, "Coverage and deployment algorithms in wireless sensor networks," *IJCCT,* vol. 2, pp. 50-56, 2011.

[14] S. Niranchana and E. Dinesh, "Optimized tracking and detection of target nodes in wireless sensor networks," in *2013 International Conference on Information Communication and Embedded Systems (ICICES)*, 2013, pp. 695-700.

[15] T. Mácha and V. N. Peter Stančík, "Connectivity in a wireless sensor network," *IJCSNS International Journal of Computer Science and Network Security,* vol. 2, pp. 382-387, 2008.

[16] D. Tian and N. D. Georganas, "Connectivity maintenance and coverage preservation in wireless sensor networks," *Ad Hoc Networks* vol. 3, pp. 744–761, 2005.

[17] S.Mini, S. K. Udgata, and S. L. Sabat, "M-connected coverage problem in wireless sensor metworks," *ISRN Sensor Networks,* vol. 2012, pp. 1-9, 2012.

[18] J. J. Winston and B. Paramasivan, "A survey on connectivity maintenance and preserving coverage for wireless sensor networks," *International Journal of Research and Reviews in Wireless Sensor Networks (IJRRWSN),* vol. 1, pp. 11-18, 2011.

[19] W. Jun and Z. Jihua, "Sensor node optimal placement algorithm based on coverage rates," in *International Conference on Computer Science and Service System (CSSS)*, 2011, pp. 2547-2550.

[20] M. Younis and K. Akkaya, "Strategies and techniques for node placement in wireless sensor networks: A survey," *Ad Hoc Networks,* vol. 6, pp. 621–655, 2008.

[21] M. Ishizuka and M. Aida, "Performance study of node placement in sensor networks," in *24th International Conference on Distributed Computing Systems Workshops*, 2004.

[22] R. Soua, L. Saidane, and P. Minet, "Sensors deployment enhancement by a mobile robot in wireless sensor networks," in *Ninth International Conference on Networks (ICN),* 2010, pp. 121-126.

[23] S. Abdel-Mageid and R. A. Ramadan, "Efficient deployment algorithms for mobile sensor networks," in *International Conference on Autonomous and Intelligent Systems (AIS),* 2010, pp. 1-6.

[24] X. Wang, G. Xing, Y. Zhang, C. Lu, R. Pless, and C. Gill, "Integrated coverage and connectivity configuration in wireless sensor networks," in *1st International Conference on Embedded Networked Sensor System*, 2003, pp. 28-39.

[25] M. Hasannejad, M. Mehrani, J. Shanbehzadeh, A. Sarrafzadeh, and E. Bidokh, "A new method in coverage for wireless sensor networks," in *2010 Sixth Advanced International Conference on Telecommunications (AICT)*, 2010, pp. 434-438.

[26] A. Ghosh and S. K.Das, "Coverage and connectivity issues in wireless sensor networks," in *Mobile, Wireless, and Sensor Networks: Technology, Applications, and Future Directions*, R. Shorey*, et al.*, Eds., ed: John Wiley & Sons, Inc., 2006.

[27] K. Kar and S. Banerjee, "Node placement for connected coverage in sensor networks," in *Workshop on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks*, Sophia Antipolis, France, 2003.

[28] M. A. Guvensan and A. G. Yavuz, "On coverage issues in directional sensor networks: A survey," *Ad Hoc Networks*, vol. 9, pp. 1238–1255, 2011.

[29] L. Yuling, Z. Yan, and Z. Yanjuan, "The research of coverage problems in wireless sensor network," in *International Conference on Wireless Networks and Information Systems*, 2009, pp. 31-34.

[30] N. A. A. Aziz, K. A. Aziz, and W. Z. W. Ismail, "Coverage strategies for wireless sensor networks," *World Academy of Science, Engineering and Technology*, vol. 50, 2009.

[31] W. Z. Wan Ismail and S. A. Manaf, "Study on coverage in wireless sensor network using grid based strategy and particle swarm optimization," in *IEEE Asia Pacific Conference on Circuits and Systems (APCCAS)*, 2010, pp. 1175-1178.

[32] Y. Zou and K. Chakrabarty, "Sensor deployment and target localization based on virtual forces," presented at the Twenty-Second Annual Joint Conference of the IEEE Computer and Communication, 2003.

[33] Y. Zou and K. Chakrabarty, "Sensor deployment and target localization in distributed sensor networks," *ACM Transactions on Embedded Computing Systems*, vol. 3, pp. 61-91, 2004.

[34] J. Li, B. Zhang, L. Cui, and S. Chai, "An extended virtual force-based approach to distributed self-deployment in mobile sensor network," *International Journal of Distributed Sensor Networks,* vol. 2012, pp. 1-14, 2012.

[35] A. Dirafzoon, S. M. A. Salehizadeh, S. Emrani, and M. Menhaj, "Virtual force based individual particle optimization for coverage in wireless sensor networks," in *23rd Canadian Conference Electrical and Computer Engineering (CCECE)*, Calgary, AB, 2010, pp. 1-4.

[36] Y. Xiangyu, H. Weipeng, L. Junjian, and Q. Xin, "A novel virtual force approach for node deployment in wireless sensor network," in *IEEE 8th International Conference on Distributed Computing in Sensor Systems (DCOSS)*, 2012, pp. 359-363.

[37] Z. Bin, M. Jianlin, and L. Haiping, "A hybrid algorithm for sensing coverage problem in wireless sensor networks," in *IEEE International Conference on Cyber Technology in Automation, Control, and Intelligent Systems*, Kunming, China, 2011.

[38] T. Suzuki, K. Kawabata, Y. Hada, and Y. Tobe, "Deployment of wireless sensor network using mobile robots to construct an intelligent environment in a multi-robot sensor network," in *Advances in Service Robotics*, H. S. Ahn, Ed., ed: InTech, 2008.

[39] S. Meguerdichian, F. Koushanfar, M. Potkonjak, and M. B. Srivastava, "Coverage problems in wireless ad-hoc sensor networks," in *INFOCOM 2001*, 2001, pp. 1380-1387

[40] Z. Yi and K. Chakrabarty, "Uncertainty-aware sensor deployment algorithms for surveillance applications," in *IEEE Global Telecommunications Conference*, 2003, pp. 2972-2976

[41] J. Chen, E. Shen, and Y. Sun, "The deployment algorithm in wireless sensor network : a survey," *Information Technology Journal,* vol. 8, pp. 293-301, 2009.

[42] W. Xueqing and Z. Shuqin, "Research on efficient coverage problem of node in wireless sensor networks," in *Second International Symposium on Electronic Commerce and Security*, 2009, pp. 532-536.

[43] P. Song, J. Li, K. Li, and L. Sui, "Researching on optimal distribution of mobile nodes in wireless sensor networks being deployed randomly," in

International Conference on Computer Science and Information Technology 2008, pp. 322 - 326

[44] A. Filippou, D. A. Karras, and R. C. Papademetriou, "Coverage problem for sensor networks: an overview of solution strategies," presented at the 17th Telecommunications Forum TELFOR 2009, Serbia, Belgrade, 2009.

[45] G. Fan, R. Wang, H. Huang, L. Sun, and C. Sha, "Coverage-guaranteed sensor node deployment strategies for wireless sensor networks," *Sensors,* vol. 10, pp. 2064-2087, 2010.

[46] R. Ranjan and S. Kar, "A novel approach for finding optimal number of cluster head in wireless sensor network," presented at the Communications (NCC), 2011 National Conference, 2011.

[47] C.-F. Huang and Y.-C. Tseng, "The coverage problem in a wireless sensor network," presented at the WSNA'03, San Diego, California, USA, 2003.

[48] H. Zhang and J. C. Hou, "Maintaining sensing coverage and connectivity in large sensor networks," *Ad Hoc & Sensor Wireless Networks,* vol. 1, pp. 89-124, 2005.

[49] S.Indu, A. Bhattacharyya, V. Kesham, and S. Chaudhury, "Sensor network for optimal coverage " *International Journal of Engineering Science and Technology,* vol. 2, pp. 2968-2975, 2010.

[50] A. Mateska and L. Gavrilovska, "WSN coverage and connectivity improvement utilizing sensors mobility," presented at the European Wireless 2011, Vienna, Austria, 2011.

[51] B. Liu, P. Brass, O. Dousse, P. Nain, and D. Towsley, "Mobility improves coverage of sensor networks," presented at the MobiHoc'05, USA, 2005.

[52] G. Fletcher, L. Xu, A. Nayak, and I. Stojmenovic, "Randomized robot-assisted relocation of sensors for coverage repair in wireless sensor networks," in *IEEE 72nd Vehicular Technology Conference Fall (VTC 2010-Fall),* 2010, pp. 1-5.

[53] Z. Ming, D. Xiaojiang, and K. Nygard, "Improving coverage performance in sensor networks by using mobile sensors," in *IEEE Military Communications Conference,* 2005, pp. 3335-3341

[54] M. Asim, H. Mokhtar, M. Z. Khan, and M. Merabti, "A sensor relocation scheme for wireless sensor networks," presented at the 2011 Workshops of

International Conference on Advanced Information Networking and Applications, 2011.

[55] G. Wang, G. Cao, and T. L. Porta, "Movement-assisted sensor deployment," presented at the INFOCOM 2004, 2004.

[56] N. Ahmed, S. S. Kanhere, and S. Jha, "The holes problem in wireless sensor networks: a survey," *Mobile Computing and Communications Review*, vol. 9, pp. 4-18, 2005.

[57] M. Senouci, M. Abdelhamid, and K. Assnoune, "Localized movement-assisted sensor deployment algorithm for hole detection and healing," *IEEE Transactions on Parallel and Distributed Systems*, vol. PP, pp. 1-11, 2013.

[58] N. A. A. Aziz, A. W. Mohemmed, and M. Y. Alias, "A wireless sensor network coverage optimization algorithm based on particle swarm optimization and voronoi diagram," in *2009 IEEE International Conference on Networking, Sensing and Control*, Okayama, Japan, 2009, pp. 602 - 607.

[59] Y.-C. Wang and Y.-C. Tseng, "Distributed deployment schemes for mobile wireless sensor networks to ensure multilevel coverage," *IEEE Transactions Parallel and Distributed Systems* vol. 19, pp. 1280-1294, 2008.

[60] J. Li, L. L. H. Andrew, C. H. Foh, M. Zukerman, and H.-H. Chen, "Connectivity, coverage and placement in wireless sensor networks," *Sensors*, vol. 9, pp. 7664-7693, 2009.

[61] X. Qi, L. Liu, and S. Liu, "Experimental study on connectivity for wireless sensor networks," presented at the International Conference on Communication Software and Networks, 2009.

[62] X. Kenan, W. Quanhong, H. Hassanein, and G. Takahara, "Optimal wireless sensor networks (WSNs) deployment: minimum cost with lifetime constraint," in *IEEE International Conference on Wireless And Mobile Computing, Networking And Communications, 2005. (WiMob'2005)*, 2005, pp. 454-461.

[63] B. Khelifa, H. Haffaf, M. Madjid, and D. Llewellyn-Jones, "Monitoring connectivity in wireless sensor networks," *International Journal of Future Generation Communication and Networking*, vol. 2, pp. 1-10, 2009.

[64] M. Marks, "A survey of multi-objective deployment in wireless sensor networks," *Journal of Telecommunications and Information Technology*, vol. 3, pp. 36-41, 2010.

[65] B. Wang, "Coverage problems in sensor networks: a survey," *ACM Computing Surveys,* vol. 43, pp. 1-53, 2011.

[66] N. Tezcan and W. Wang, "Effective coverage and connectivity preserving in wireless sensor networks," in *IEEE Wireless Communications and Networking Conference,* 2007, pp. 3388-3393.

[67] N. Kukunuru, B. R. Thella, and R. L. Cavuluri, "Sensor deployment using particle swarm optimization " *International Journal of Engineering Science and Technology,* vol. 2, pp. 5395-5401, 2010.

[68] Y. Kim, M. Yeo, D. Kim, and K. Chung, "A node deployment strategy considering environmental factors and the number of nodes in surveillance and reconnaissance sensor networks," *International Journal of Distributed Sensor Networks,* vol. 2012, pp. 1-11, 2012.

[69] N. Akshay, M. P. Kumar, B. Harish, and S. Dhanorkar, "An efficient approach for sensor deployments in wireless sensor network," in *International Conference on Emerging Trends in Robotics and Communication Technologies (INTERACT),* 2010, pp. 350-355.

[70] F. M. Al-Turjman, H. S. Hassanein, and M. A. Ibnkahla, "Connectivity optimization for wireless sensor networks applied to forest monitoring," in *IEEE International Conference on Communications, 2009.* , 2009, pp. 1-6.

[71] F. M. Al-Turjman, H. S. Hassanein, and M. A. Ibnkahla, "Connectivity optimization with realistic lifetime constraints for node placement in environmental monitoring," presented at the 2009 IEEE 34th Conference on Local Computer Networks, Zürich, Switzerland, 2009.

[72] D. Wang, J. Liu, and Q. Zhang, "On mobile sensor assisted field coverage," *ACM Transactions on Sensor Networks,* vol. 9, pp. 1-18, 2013.

[73] B. Wang, H. B. Lim, and D. Ma, "A survey of movement strategies for improving network coverage in wireless sensor networks," *Computer Communications,* vol. 32, pp. 1427–1436, 2009.

[74] J. Chen, S. Li, and Y. Sun, "Novel deployment schemes for mobile sensor networks," *Sensors,* vol. 7, pp. 2907-2919, 2007.

[75] F. Kribi, P. Minet, and A. Laouiti, "Redeploying mobile wireless sensor networks with virtual forces," presented at the Wireless Days, Paris, 2009.

[76] S. Ping, L. Jize, L. Kejie, and S. Li, "Researching on Optimal Distribution of Mobile Nodes in Wireless Sensor Networks being Deployed Randomly," in

Computer Science and Information Technology, 2008. ICCSIT '08. International Conference on, 2008, pp. 322-326.

[77] B. Liu and D. Towsley, "On the coverage and detectability of large-scale wireless sensor networks," in *Workshop on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks*, 2003.

[78] S. Megerian, F. Koushanfar, M. Potkonjak, and M. B. Srivastava, "Worst and best-case coverage in sensor networks," *IEEE Transactions on Mobile Computing*, vol. 4, pp. 84-92, 2005.

[79] C. Jun, Y. Jiang, K. Juan, and H. Jingsong, "Simulation of worst and best-case coverage for wireless sensor network," in *International Conference on Information Networking and Automation (ICINA)*, 2010, pp. 291-295.

[80] W. Chun-Hsien, L. Kuo-Chuan, and C. Yeh-Ching, "A Delaunay triangulation based method for wireless sensor network deployment," *12th International Conference on Parallel and Distributed Systems*, vol. 1, pp. 1-8, 2006.

[81] H. Chizari, M. Hosseini, T. Poston, S. A. Razak, and A. H. Abdullah, "Delaunay triangulation as a new coverage measurement method in wireless sensor network," *Sensors*, vol. 11, pp. 3163-3176, 2011.

[82] J. Chen, E. Shen, and Y. Sun, "The deployment algorithms in wireless sensor net works: a survey," *Information Technology Journal*, vol. 8, pp. 293-301, 2009.

[83] M. Garetto, M. Gribaudo, C.-F. Chiasserini, and E. Leonardi, "A distributed sensor relocation scheme for environmental control," *Mobile Adhoc and Sensor System*, pp. 1 - 10 2007.

[84] M. Yang, Y. Cao, L. Tan, and J. Yu, "A new self-deployment algorithm in hybrid sensor network," presented at the International Symposium on Intelligent Information Technology Application, 2008.

[85] M. Zou, Z. Ping, S. Zheng, X. Qin, and H. Tongzhi, "A novel energy efficient coverage control in WSN's based on ant colony optimization," presented at the 2010 International Symposium on Computer, Communication, Control and Automation, 2010.

[86] X.-S. Yang, *Nature inspired metaheuristic algorithm*. United Kingdom: Luniver Press, 2010.

[87] X.-S. Yang, "Review of metaheuristics and generalized evolutionary walk algorithm," *International Journal of Bio-Inspired Computation*, vol. 3, pp. 77- 84, 2011.

[88] X.-S. Yang. (2011, 12/2/2012). *Metaheuristic optimization*. Available: http://www.scholarpedia.org

[89] C. D. Souza, S. Mulkuthar, K. Salva, and S. Gandhe, "Implementation of particle swarm optimization based methodology for node placement in wireless sensor networks," presented at the Interntional Conference Workshop on Emerging Trendin Technology, India, 2011.

[90] R. V. Kulkarni and G. K. Venayagamoorthy, "Particle swarm optimization in wireless-sensor networks: a brief survey " *IEEE Systems, Man, and Cybernetics Society,* vol. 41, pp. 1-7, 2011.

[91] R. H. Jacobsen, Q. Zhang, and T. S. Toftegaard, "Bioinspired principles for large-scale networked sensor systems: an overview," *Sensors*, vol. 11, pp. 4137-4151, 2011.

[92] K. S. S. Rani and N. Devarajan, "Optimization model for sensor node deployment," *European Journal of Scientific Research*, vol. 70, pp. 491-498, 2012.

[93] A. P. Bhondekar, Renu Vig, M. L. Singla, C. Ghanshyam, and P. Kapur, "Genetic algorithm based node placement methodology for wireless sensor networks," in *International MultiConference of Engineers and Computer Scientists* Hong Kong, 2009.

[94] N. Rahmani, F. Nematy, A. M. Rahmani, and M. Hosseinzadeh, "Node placement for maximum coverage based on voronoi diagram using genetic algorithm in wireless sensor networks," *Australian Journal of Basic and Applied Sciences,* vol. 5, pp. 3221-3232, 2011.

[95] A. Tripathi, P. Gupta, A. Trivedi, and R. Kala, "Wireless sensor node placement using hybrid genetic programming and genetic algorithms," *International Journal of Intelligent Information Technologies,* vol. 7, pp. 63-83, 2011.

[96] G. De Marco, "MOGAMESH: A multi-objective algorithm for node placement in wireless mesh networks based on genetic algorithms," in *6th International Symposium on Wireless Communication Systems*, 2009, pp. 388-392.

[97] M. Dhivya, M. Sundarambal, and L. N. Anand, "Energy efficient computation of data fusion in wireless sensor networks using cuckoo based particle approach (CBPA)," *Int. J. Communications, Network and System Sciences, 2011*, vol. 4, pp. 249-255, 2011.

[98] X.-S. Yang and S. Deb, "Cuckoo search via levy flights," in *Proceedings of World Congress on Nature & Biologically Inspired Computing*, New Delhi, 2009, pp. 210- 214.

[99] X.-S. Yang and S. Deb, "Multiobjective cuckoo search for design optimization," *Computer and Operations Research*, pp. 1-9, 2011.

[100] P. Civicioglu and E. Besdok, "A conceptual comparison of the cuckoo-search, particle swarm optimization, differential evolution and artificial bee colony algorithms," *Artificial Intelligence Review*, pp. 1-32, 2013.

[101] R. Jain, *Art of Computer Systems Performance Analysis Techniques For Experimental Design*: Wiley Computer Publishing, John Wiley & Sons, Inc., 1991.

[102] E. Lamsal. (2012, 23.02.2012). *Comparing various network simulators and emulators*. Available: http://www.ekendraonline.com