AN ENHANCED EVOLUTIONARY ALGORITHM FOR REQUESTED COVERAGE IN WIRELESS SENSOR NETWORKS

KAMAL JADIDY AVAL

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Computer Science)

Faculty of Computing
Universiti Teknologi Malaysia

JUNE 2016

To my beloved family

ACKNOWLEDGEMENT

In the name of ALLAH, the most Merciful, the most Beneficent

All praise and thanks are due to ALLAH for support and guidance.

I would like to express my heartfelt gratitude to my wife, and my parents for their unlimited patience, support, and encouragement through the time of doing research.

I would like to thank my supervisors Dr. Shukor Abd Razak and Professor Abul Samad Bin Ismail, for all their guidance, advice, and patience. It was impossible to come all over the way up to now without their support.

Thanks to Dr. Hassan Chizari for his advice and comment which improved this study. I do appreciate all of the tips from colleagues and friends in UTM.

I would also like to thank the developers of the utmthesis LaTeX project for making the thesis writing process a lot easier for me.

Kamal Jadidy Aval, UTM

ABSTRACT

Wireless sensor nodes with specific and new sensing capabilities and application requirements have affected the behaviour of wireless sensor networks and created problems. Placement of the nodes in an application area is a well-known problem in the field. In addition, high per-node cost as well as need to produce a requested coverage and guaranteed connectivity features is a must in some applications. Conventional deployments and methods of modelling the behaviour of coverage and connectivity cannot satisfy the application needs and increase the network lifetime. Thus, the research designed and developed an effective node deployment evaluation parameter, produced a more efficient node deployment algorithm to reduce cost, and proposed an evolutionary algorithm to increase network lifetime while optimising deployment cost in relation to the requested coverage scheme. This research presents Accumulative Path Reception Rate (APRR) as a new method to evaluate node connectivity in a network. APRR, a node deployment evaluation parameter was used as the quality of routing path from a sensing node to sink node to evaluate the quality of a network deployment strategy. Simulation results showed that the behaviour of the network is close to the prediction of the APRR. Besides that, a discrete imperialist competitive algorithm, an extension of the Imperialist Competitive Algorithm (ICA) evolutionary algorithm was used to produce a network deployment plan according to the requested event detection probability with a more efficient APRR. It was used to reduce deployment cost in comparison to the use of Multi-Objective Evolutionary Algorithm (MOEA) and Multi-Objective Deployment Algorithm (MODA) algorithms. Finally, a Repulsion Force and Bottleneck Handling (RFBH) evolutionary-based algorithm was proposed to prepare a higher APRR and increase network lifetime as well as reduce deployment cost. Experimental results from simulations showed that the lifetime and communication quality of the output network strategies have proven the accuracy of the RFBH algorithm performance.

ABSTRAK

Nod sensor tanpa wayar dengan keupayaan penderiaan tertentu dan baru dan keperluan aplikasi telah memberi kesan kepada tingkah laku rangkaian sensor tanpa wayar dan ini mewujudkan masalah. Penempatan nod di sesuatu kawasan aplikasi adalah satu masalah yang terkenal di bidang ini. Di samping itu, kos setiap nod yang tinggi serta keperluan untuk menghasilkan liputan yang diminta dan ciri-ciri sambungan terjamin adalah satu kemestian dalam sesetengah aplikasi. Pergerakan konvensional dan kaedah pemodelan perilaku liputan dan sambungan tidak dapat memenuhi keperluan aplikasi dan meningkatkan jangka hayat rangkaian. Oleh itu, kajian ini mereka bentuk dan membangunkan satu parameter penilaian pergerakan nod berkesan, menghasilkan algoritma pergerakan nod yang lebih efisien untuk mengurangkan kos, dan mencadangkan satu algoritma evolusi untuk meningkatkan jangka hayat rangkaian semasa bagi mengoptimumkan kos pergerakan berhubung dengan skema liputan yang diminta. Kajian ini membentangkan Kadar Penerimaan Laluan Terkumpul (APRR) sebagai kaedah baru untuk menilai sambungan nod dalam rangkaian. APRR, suatu parameter penilaian pengaturan nod telah digunakan sebagai kualiti capaian laluan dari nod penderiaan kepada nod terbenam untuk menilai kualiti strategi penggunaan rangkaian. Keputusan simulasi menunjukkan bahawa perilaku rangkaian adalah hampir dengan ramalan APRR. Selain itu, algoritma kompetitif imperialis diskret, lanjutan daripada algoritma evolusi Algoritma Kompetitif Imperialis (ICA) telah diguna untuk menghasilkan pelan pergerakan rangkaian mengikut kebarangkalian pengesanan peristiwa yang diminta dengan APRR yang lebih cekap. Ia telah diguna untuk mengurangkan kos pergerakan berbanding dengan penggunaan Algoritma Evolusi Pelbagai Objektif (MOEA) dan Algoritma Pengaturan Pelbagai Objektif (MODA). Akhir sekali, satu algoritma berdasarkan evolusi Pengendalian Daya Tolakan dan Kesesakan (RFBH) dicadangkan untuk menyediakan APRR yang lebih tinggi dan meningkatkan jangka hayat rangkaian serta mengurangkan kos pengaturan. Keputusan eksperimen daripada simulasi menunjukkan bahawa strategi rangkaian output dan kualiti komunikasi dan jangka hayat telah membuktikan ketepatan prestasi algoritma RFBH.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

3G	–	Third Generations
4G	–	Fourth Generations
AMPS	–	Advanced Mobile Phone Service
APRR	–	Accumulated Path Reliability Rate
CCS	–	Connected Coverage node Set
CILAC	–	Circle Intersection Local Area Coverage
DICA	–	Discrete Imperialist Competitive Algorithm
DoS	–	Denial of Service
DPC	–	Direct neighbour Perimeter Covered
EA	–	Evolutionary Algorithm
GA	–	Genetic Algorithm
HiPerLAN	–	High Performance Radio LAN
HiSQAN	–	High Speed Wireless Access Network
IBEA	–	Indicator-Based Evolutionary Algorithm
ICA	–	Imperialist Competitive Algorithm
IPv6	–	Internet Protocol version 6
ISM	–	Industrial, Scientific, and Medical
LAN	–	Local Area Network
LEACH	–	Low-Energy Adaptive Clustering Hierarchy
MAC	–	Medium Access Control
MANET	–	Mobile Ad hoc NETwork
MEMS	–	MicroElectroMechanical Systems
MCSC	–	Minimum Connected-Sensor Cover
MODA	–	Multi-Objective Deployment Algorithm
MOEA	–	MultiObjective Evolutionary Algorithm
MPC	–	Multi-hop-neighbour Perimeter Covered
NP	–	Non-deterministic Polynomial-time
NSGA	–	Non-dominated Sorting in Genetic Algorithm

OGDC	–	Optimal Geographical Density Control
PSO	–	Particle Swarm Optimisation
PER	–	Packet Error Rate
PRR	–	Packet Reception Rate
PSTN	–	Public Switched Telecommunications Network
QoM	–	Quality of Monitoring
QoS	–	Quality of Service
RD	–	Routing Degree
RF	–	Radio Frequency
RFBH	–	Repulsion Force and Bottleneck Handling
RSS	–	Received Signal Strength
RTT	–	Round Trip Time
SINR	–	Signal-to-Interference-Plus-Noise Ratio
SNR	–	Signal-to-Noise Ratio
TL	–	Tabu List
TOA	–	Time Of Arrival
TS	–	Tabu Search
UW-ASN	–	Under Water Acoustic Sensor Network
VLSI	–	Very Large Scale Integration
WiFi	–	Wireless Fidelity
WLAN	–	Wireless Local Area Network
WMN	–	Wireless Mesh Network
WSN	–	Wireless Sensor Network

LIST OF SYMBOLS

λ	–	Wavelength
α	–	Cost of a Country (ICA)
p	–	Power of the Country (ICA)
EC	–	Empire Cost (ICA)
EP	–	Empire Power (ICA)
R_c	–	Communication Range
R_s	–	Sensing Range
d	–	The distance of the sensed point from node
f	–	The packet size in bytes
σ	–	Shadowing Variance

CHAPTER 1

INTRODUCTION

1.1 Overview

Whenever a large number of tiny devices that have limited resources such as processing power, storage, battery power, communication range and communication bandwidth named as sensors come together to form a network, a wireless sensor network (WSN) is created. Various environmental phenomena can be sensed by these sensors which can process the data in the network and communicate to other nodes of the network including both sensors and sink (data gathering) nodes using their wireless communication capabilities. This communication is usually done using multihop communications. Potentially, a WSN can be deployed over a wide area covering many kilometres with edge nodes that are many kilometres distant from each other. Because of limitations in sensor nodes energy resources and the need for a great amount of energy to transmit data over long hops, multihopping is used in almost all WSN applications to increase the network lifetime. In addition, using multihopping gives the network the opportunity to reduce radio interference and extend the overall network bandwidth (Akkaya and Younis, 2005). Many applications dealing with surveillance, monitoring, and control can be handled using WSNs.

To date, most WSN-related research dealt with 2D settings, where sensors are deployed on a terrain. However, there are some applications where 2D modelling does not result in an efficient manner. Forests with trees of different heights, underwater environments, or buildings with multiple floors are some examples of environments that require the design and modelling of WSN applications to be in the 3D space. Some typical applications of underwater sensor networks include offshore exploration, assisted navigation, disaster prevention, pollution monitoring, and oceanographic data collection. Different strategies for deploying a network are presented for 2D and 3D communication architectures in underwater sensor networks. In such networks, the sensors are anchored to the floor of the ocean for 2D design and are floating at the oceans different depths to cover the whole 3D space. A 3D design is required for both routing the data efficiently in terms of energy consumption and covering for telepresence applications.

The present study investigates the coverage and connectivity issues WSNs where sensor nodes are deployed in a field such that every location is covered by at least one sensor. Because of limitations in the sensors battery power and the difficulty of recharging or replacing batteries in the operational environment, in some cases high density of sensor nodes is a must to have a long network lifetime. Due to the low battery power issues, the existence of faulty sensors should also be taken into account. As the aim of a WSN is to sense features of an area and send the sensed data to the sink node for processing, coverage has no meaning where the data cannot be transferred to the sink node due to the lack of communication route between the source sensor node and the sink node. In other words, it should be guaranteed that the sensed data will reach the sink node which is referred to as network connectivity.

Whenever both coverage and connectivity are maintained at the same time, the WSN functionality can be ensured. If failures in some sensor nodes occur in the network and the network still remains functionally connected, the WSN is said to be fault tolerant. Maintaining multiple routes in a WSN for every two nodes or at least the sensor nodes and the sink nodes is the prerequisite of such a network. Once the whole network is disconnected and two or more network components are formed, all sensor nodes of a network component should be connected to the sink nodes of the same component. This research proposes mechanisms to overcome the existing coverage and connectivity issues in WSNs by presenting both theoretical and simulation results.

1.2 Problem Background

Due to rapid evolution in recent years, WSNs are widely considered to be one of the most important technologies for the twenty-first century (Peter Coy, 1999). Developments in micro-electronic mechanical systems and wireless communication technologies have provided the opportunity to innovate a variety of civilian and military applications. Industry process control, battle field surveillance, and environmental monitoring are some examples of such applications (Chong and Kumar, 2003). Unique characteristics of WSNs such as higher density, unreliability of deployed nodes, and limited energy, storage, and computation resources have distinguished them from other wireless networks such as mobile ad hoc networks (MANETs) and cellular systems (Akyildiz *et al.*, 2002b). Nowadays, many military and civilian applications benefit from WSNs and basic changes have occurred in the way people live, work and interact with physical world just as predicted by Estrin *et al.* (2002).

Various physical parameters or conditions can be detected or monitored by sensors including sound, light, temperature, humidity, pressure, and air or water quality (Akyildiz *et al.*, 2002a). The development of WSNs was originally motivated by military applications including both large-scale applications such as acoustic surveillance systems for ocean surveillance and small-scale networks using unattended ground sensors to detect ground targets. Nowadays, the development of low-cost sensors and wireless communication devices has led to the development of various applications in both civilian and military fields (Zheng and Jamalipour, 2009).

WSN characteristics and their different applications have a significant effect on the network design objectives in terms of network performance and network capabilities. Small node size, low power consumption, low node cost, self-configurability, adaptability, scalability, security, reliability, and quality of service (QoS) support are the main design objectives for WSNs. The different requirements of various applications force the designers to only consider some parts of these objectives. The challenges in the design of WSNs are mainly classified into issues related to medium access control, time synchronization, node localization, routing and data dissemination, node clustering, broadcasting, multicasting, geocasting, query processing and data aggregation, transport protocols, QoS, power control and energy efficiency, and network security and attack defense (Zheng and Jamalipour, 2009). The lack of an algorithm to consider more than two main design objective is significant.

While there is no infrastructure in WSNs, connectivity is an important issue in order to ensure the successful transfer of sensed data. On the other hand, the nature of the sensor network gives rise to the coverage problem. Among the main challenges in WSN design, connectivity and coverage are included in the challenges related to routing, clustering, power control, energy efficiency, and node localization. There are various issues in the connectivity and coverage for WSNs. Among those many issues, some of the common problems are network coverage and connectivity, power management, and network deployment. Once an algorithm is capable of decreasing energy consumption along with optimization of the other design objectives the algorithm would lead to longer network lifetime with longer surveillance time.

A number of solutions have been proposed to solve these problems. Algorithms and protocols have been designed to provide a specific degree of connectivity and coverage between the sensor nodes and over the implementation area; these algorithms and protocols are classified into the network coverage and connectivity categories. On the other hand, power management issues deal with the protocols and algorithms which can be applied to WSNs in order to achieve less energy consumption and a longer network lifetime. The solutions dealing with network deployment include methods employing network characteristics such as the terrain, sensor coverage range, and sensor radio transmission range that can be used in the construction phase of WSNs in order to reach a predetermined connectivity and coverage degree.

Many studies have been conducted on the connectivity and coverage of two-dimensional WSNs including two significant studies by Ammari and Das (2008) and Xin *et al.* (2009b). Ammari and Das (2008) used the correlated disc model that includes two discs for each sensor with the radii of r for sensing and R for connectivity. Xin *et al.* (2009b) used a circle intersection algorithm named CILAC for nodes with radio radius greater than or equal to 3 times the sensing radius. When the radio radius is less than 3 times the sensing radius, an improved algorithm named CCS-CILAC is used to ensure that the active nodes of the network are already maintaining both connectivity and coverage. The method is based on loose connectivity critical conditions and uses a circle intersection localised coverage algorithm. A study conducted by Xin *et al.* (2009a) was concerned with the overall network connectivity instead of the single node connectivity. The results showed that the connectivity was related to both the number of nodes and the ratio between the sensing radius and the radio radius.

Aitsaadi *et al.* (2008) assumed the probabilistic event detection, geographical irregularity of a sensed event, and fixed communication ray. They used a pseudo-random method based on the tabu search algorithm to guarantee network connectivity and minimise the number of needed sensors. The work is actually a deployment method that uses a heuristic method to deploy sensors in the network. Akkaya and Janapala (2008) worked on wireless sensor and actor networks in which the actors are mobile and able to move around the surveillance environment. The aim of their work was to achieve maximal actor coverage considering network connectivity. In that study, the actors and sensors knew their locations. LP-RCC and ST-RCC theories were evaluated analytically and through simulation. The algorithms also worked on reducing the total distance travelled by the actors. The parameters of the experiments were: actor coverage, total distance travelled, total number of messages, and number of iterations.

The increased number of WSN applications has led researchers to focus on the realistic characteristics of WSNs and the issues related to those characteristics. Network coverage and connectivity issues are mostly affected by migration from the conventional binary disc model to the probabilistic models. A few studies have been conducted on coverage and connectivity using probabilistic models. Woehrle *et al.* (2010) focused on solving the problem of the number of deployed sensor nodes and their places in constructing an efficient WSN. They pointed out that the conflicting objectives of wireless transmission reliability and deployment costs make it difficult for decision-maker to find the right balance. They used an EA to address this problem. Aitsaadi *et al.* (2011) has tried to reduce the deployment cost along with ensuring the requested coverage while guaranteeing network connectivity and lifetime. The aim of their research was to propose a deployment algorithm using multiobjective optimisation methods based on evolutionary and neighbourhood search algorithms. There is still need for a mechanism to qualify the connectivity of a WSN for the whole terrain.

Various specifications for different applications of the new born sensor nodes has opened novel research area on WSNs. On the other hand most of these sensor nodes are equipped with costly sensors from GPS to laser detectors. The high cost of the nodes needs to do more calculations on finding more precise location for sensor nodes to provide full coverage. Unlike the traditional applications of the WSNs, these novel applications can define the level of the coverage for each point of the sensing field. These changes to the world of WSNs has led to the birth of need for coverage measurement mechanisms that better represent the real behabviour of them. Once such mechanism is defined, the algorithms for finding the optimum location of the sensor nodes should be revised too for solving the problem of finding the optimum network configuration.

1.3 Problem Statement

Most of the previous research works on WSNs, especially on routing and data dissemination, have considered the settings of the binary disc model for both detection and communication in which the sensor nodes detection capabilities are considered to be ”1” for any point inside the sensing circle and 0 for others. It is also assumed that if two nodes are in the communication range of each other, their connection is guaranteed. Nowadays, with the rising number of sensor network applications, there are some fields in which the so-called assumptions are not reasonable and assuming realistic models is inevitable. According to the experiments done by Sohrabi *et al.* (1999), using probabilistic models results in a more accurate network design and is more realistic.

Due to the need to transfer sensed data to the sink node or among the sensor nodes to make a decision and perhaps to do a reaction, the quality of communication among nodes in WSNs has become important. This gives rise to the following question: *How to assess the communication quality of a deployment in order to compare two possible deployments for an application?* More importantly, such qualification mechanism must be applicable in deployment algorithms to provide a network topology with higher quality. This prerequisite leads to the next question, namely: *How can an evolutionary deployment strategy consider* *communication quality in its evolving iterations to provide a network topology with higher communication quality?* At the same time, because of the nodes cost, deployment cost per node, and in some cases the maintenance fees per node, minimising the number of deployed nodes becomes significant. This issue gives rise to the following question: *How to reduce the deployment cost by minimising the number of deployed nodes?* Lastly, the real-time nature of some applications such as fire-fighting and nuclear plant monitoring requires a longer lifetime and more reliable delivery of data from the sensing node to the decision-making centre; this gives rise to the following question: *How to reduce the deployment cost along with increasing the network lifetime while improving the communication quality through the hops from a sensor to the sink in a multi-hop delivery network?*

1.4 Research Aim and Objectives

The aim of this research is to propose a mechanism that could improve the communication quality, extend the network lifetime and reduce the network deployment cost for WSN applications with a predefined requested event detection probability scheme and manual node placement.

The following objectives are set for this study:

i To develop a new mechanism for WSN communication quality evaluation that could complement the existing local communication quality measurements.

ii To design and develop an efficient node deployment location method for differentiated coverage requirements.

iii To propose an efficient node redundancy method to increase the network lifetime and at the same time decrease the total network deployment cost while providing WSN communication quality in the presence of differentiated event detection probability requirements.

1.5 Research Scope

The scope of this research is defined by the following parameters:

i The research is focused on WSNs that require differentiated event detection probability and manual deployment.

ii The results are analysed and evaluated using simulations and comparisons of the obtained results with the existing solutions for WSN deployment.

iii The sensor nodes are assumed to be equipped with common standard sensing and communication devices.

iv There must be a sink node in the WSN for data collection and analysis.

1.6 Significance of the Study

This research addresses the efficient deployment of nodes for providing the requested coverage in environments using WSNs. The significant output of this research is to propose an alternative mechanism to achieve the desired coverage and connectivity. To make the results more close to the real environment, a more realistic mechanism to evaluate the communication quality is proposed. In addition, the existing problems in the area of coverage and connectivity are reviewed and classified and an evaluation method is presented in order to compare the solutions for these problems.

1.7 Thesis Organization

The remainder of this thesis is organised as follows: Chapter 2 presents an introduction to WSNs and their evolutionary history. The common problems related to these networks are then addressed. The connectivity and coverage problem is discussed and an overview of the state-of-the-art research on WSN deployment algorithms, coverage and connectivity issues, and limitations is presented.

Chapter 3 presents the methodology of the research as well as the procedure and research framework. A flowchart is provided to illustrate the procedures that lead to the fulfilment of the research objectives. The simulation approaches are described and the schedule of the research is presented.

Chapter 4 discusses the first contribution of this research which is the design and analysis of the accumulative path reliability rate (APRR) and its mathematical model. The algorithms for calculating the APRR for running networks and prior to deployment are presented. In addition, sample WSN topologies are illustrated for a better understanding. The results of simulation runs for the output of existing node location identification algorithms and methods are also presented.

Chapter 5 discusses the second contribution of this research which is the design and implementation of the discrete imperialist competitive algorithm (DICA). The flowchart of the DICA and its results are presented in this chapter. The detailed algorithm of the repulsion force is presented and the underlying mathematical and physical bases are discussed. The chapter also presents the illustrative results of the DICA while analysing the results of the DICA and discussing its comparison with other existing solutions for the same problem.

Chapter 6 details the third contribution of the research which is the repulsion force and bottleneck handling (RFBH) algorithm based on the tabu search meta-heuristic. The details of the bottleneck handling algorithm and the calculations related to the identification and treatment of bottleneck nodes in the network are explained. The flowchart and results of the RFBH algorithm are presented. In addition, the results of running the RFBH algorithm are discussed and the simulation results are analysed.

Chapter 7 concludes the thesis and explains the details of the achievements in this research work. A mapping of the achievements by reference to the objectives is presented. The limitations of the proposed solutions are presented in order to provide prospective researchers with perspectives on the existing work and promising directions for future research in the same problem area.

REFERENCES

Ahlswede, R., Cai, N., Li, S.-Y. R. and Yeung, R. W. (2000). Network information flow. *IEEE Transactions on Information Theory*. 46(4), 1204–1216.

Aitsaadi, N., Achir, N., Boussetta, K. and Pujolle, G. (2008). Heuristic Deployment to achieve both Differentiated Detection and Connectivity in WSN. In *Vehicular Technology Conference, 2008. VTC Spring 2008. IEEE.* IEEE, 123–127.

Aitsaadi, N., Achir, N., Boussetta, K. and Pujolle, G. (2010). Multi-objective WSN deployment: quality of monitoring, connectivity and lifetime. In *2010 IEEE International Conference on Communications (ICC).* IEEE, 1–6.

Aitsaadi, N., Achir, N., Boussetta, K. and Pujolle, G. (2011). Artificial potential field approach in WSN deployment: Cost, QoM, connectivity, and lifetime constraints. *Computer Networks.* 55(1), 84–105.

Akkaya, K. and Janapala, S. (2008). Maximizing connected coverage via controlled actor relocation in wireless sensor and actor networks. *Computer Networks.* 52(14), 2779–2796.

Akkaya, K. and Younis, M. (2005). A survey on routing protocols for wireless sensor networks. *Ad hoc Networks.* 3(3), 325–349.

Akyildiz, I. F., Su, W., Sankarasubramaniam, Y. and Cayirci, E. (2002a). A survey on sensor networks. *Communications Magazine, IEEE.* 40(8), 102–114.

Akyildiz, I. F., Su, W., Sankarasubramaniam, Y. and Cayirci, E. (2002b). Wireless sensor networks: a survey. *Computer Networks.* 38(4), 393–422.

Akyildiz, I. F. and Vuran, M. C. (2010). *Wireless Sensor Networks.* vol. 4. John Wiley & Sons.

Alam, S. N. and Haas, Z. J. (2015). Coverage and connectivity in three-dimensional networks with random node deployment. *Ad Hoc Networks.* 34, 157 – 169. ISSN 1570-8705.

Ammari, H. M. and Das, S. K. (2006). An energy-efficient data dissemination protocol for wireless sensor networks. In *Fourth Annual IEEE International Conference on Pervasive Computing and Communications Workshops,* 2006. IEEE, 5–pp.

Ammari, H. M. and Das, S. K. (2008). Integrated coverage and connectivity in wireless sensor networks: A two-dimensional percolation problem. *IEEE Transactions on Computers.* 57(10), 1423–1434.

Ammari, H. M. and Das, S. K. (2010). Forwarding via checkpoints: Geographic routing on always-on sensors. *Journal of Parallel and Distributed Computing.* 70(7), 719–731.

Ammari, H. M. and Das, S. K. (2011). Scheduling protocols for homogeneous and heterogeneous k-covered wireless sensor networks. *Pervasive and Mobile Computing.* 7(1), 79–97.

Anoh, K. O., Noras, J. M., Abd-Alhameed, R. A., Jones, S. M. and Voudouris, K. N. (2014). A new approach for designing orthogonal wavelets for multicarrier applications. *AEU-International Journal of Electronics and Communications.* 68(7), 616–622.

Atashpaz-Gargari, E. and Lucas, C. (2007). Imperialist competitive algorithm: an algorithm for optimization inspired by imperialistic competition. In *IEEE Congress on Evolutionary Computation, 2007. IEEE,* 4661–4667.

Aurenhammer, F. (1991). Voronoi diagramsa survey of a fundamental geometric data structure. *ACM Computing Surveys (CSUR).* 23(3), 345–405.

Aval, K. J., Razak, S. A. and Ismail, A. S. (2013). Analysing wireless sensor network deployment performance using connectivity. *Science Asia.* 39, 80–84.

Bai, X., Kumar, S., Xuan, D., Yun, Z. and Lai, T. H. (2006). Deploying wireless sensors to achieve both coverage and connectivity. In *Proceedings of the 7th ACM International Symposium on Mobile Ad hoc Networking and Computing. ACM*, 131–142.

Bohge, M. and Trappe, W. (2003). An authentication framework for hierarchical ad hoc sensor networks. In *Proceedings of the 2nd ACM Workshop on Wireless Security. ACM*, 79–87.

Braginsky, D. and Estrin, D. (2002). Rumor routing algorthim for sensor networks. In *Proceedings of the 1st ACM International Workshop on Wireless Sensor Networks and Applications. ACM*, 22–31.

Buczak, A. and Jamalabad, V. (1998). Self-organization of a heterogeneous sensor network by genetic algorithms. *Intelligent Engineering Systems Through Artificial Neural Networks*. 8, 259–264.

Capkun, S. and Hubaux, J.-P. (2005). Secure positioning of wireless devices with application to sensor networks. In *INFOCOM 2005. 24th Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings IEEE, vol. 3. IEEE*, 1917–1928.

Cardei, M. and Wu, J. (2004). *Coverage problems in wireless ad hoc sensor networks.*

Chizari, H., Hosseini, M., Poston, T., Razak, S. A. and Abdullah, A. H. (2011). Delaunay triangulation as a new coverage measurement method in wireless sensor network. *Sensors.* 11(3), 3163–3176.

Chizari, H., Razak, S. A., Bahar, A. and Abdullah, A. H. (2010). Deployment density estimation for -covering problem in wireless sensor network. In *2010 International Symposium in Information Technology (ITSim), vol. 2. IEEE*, 592–596.

Chong, C.-Y. and Kumar, S. P. (2003). Sensor networks: evolution, opportunities, and challenges. *Proceedings of the IEEE*. 91(8), 1247–1256.

Chu, M., Haussecker, H. and Zhao, F. (2002). Scalable information-driven sensor querying and routing for ad hoc heterogeneous sensor networks. *International Journal of High Performance Computing Applications*. 16(3), 293–313.

Crossbow-Technology (2011). Moog. Retrievable at http://www.xbow.com.

Dargie, W. W. and Poellabauer, C. (2010). *Fundamentals of wireless sensor networks: theory and practice.* John Wiley & Sons.

Deb, K., Pratap, A., Agarwal, S. and Meyarivan, T. (2002). A fast and elitist multiobjective genetic algorithm: NSGA-II. *IEEE Transactions on Evolutionary Computation.* 6(2), 182–197.

Dhawan, S. (2007). Analogy of promising wireless technologies on different frequencies: Bluetooth, wifi, and wimax. In *The 2nd International Conference on Wireless Broadband and Ultra Wideband Communications, 2007. AusWireless 2007. IEEE*, 14–14.

Dow, C.-R., Lin, P.-J., Chen, S.-C., Lin, J.-H. and Hwang, S.-F. (2005). A study of recent research trends and experimental guidelines in mobile ad-hoc network. In 19th International Conference on Advanced Information Networking and Applications, 2005. AINA 2005., vol. 1. IEEE, 72–77.

Du, K.-L. and Swamy, M. N. (2010). *Wireless communication systems: from RF subsystems to 4G enabling technologies*. Cambridge University Press.

Dulman, S., Nieberg, T., Wu, J. and Havinga, P. (2003). Trade-off between traffic overhead and reliability in multipath routing for wireless sensor networks. In *Wireless Communications and Networking, 2003. WCNC 2003. 2003 IEEE*, vol. 3, 1918-1922.

Estrin, D., Culler, D., Pister, K. and Sukhatme, G. (2002). Connecting the physical world with pervasive networks. *IEEE Pervasive Computing*. 1(1), 59–69. ISSN 1536-1268.

Fonseca, C. M. and Fleming, P. J. (1995). An overview of evolutionary algorithms in multiobjective optimization. *Evolutionary Computation*. 3(1), 1–16.

Gage, D. W. (1992). Command control for many-robot systems. Technical report. DTIC Document.

Ganesan, D., Govindan, R., Shenker, S. and Estrin, D. (2001). Highly-resilient, energy-efficient multipath routing in wireless sensor networks. *ACM SIGMOBILE Mobile Computing and Communications Review*. 5(4), 11–25.

Gavrilovska, L., Krco, S., Milutinovic, V., Stojmenovic, I. and Trobec, R. (2010). Application and multidisciplinary aspects of wireless sensor networks: concepts, integration, and case studies. *Springer Science & Business Media*.

Ghosh, A. and Das, S. K. (2008). Coverage and connectivity issues in wireless sensor networks: A survey. *Pervasive and Mobile Computing*. 4(3), 303–334.

Goldsmith, A. J. and Wicker, S. B. (2002). Design challenges for energy-constrained ad hoc wireless networks. *Wireless Communications, IEEE*. 9(4), 8–27.

Haykin, S. and Liu, K. R. (2010). *Handbook on array processing and sensor networks*. vol. 63. John Wiley & Sons.

Heinzelman, W. R., Kulik, J. and Balakrishnan, H. (1999). Adaptive protocols for information dissemination in wireless sensor networks. In *Proceedings of the 5th Annual ACM/IEEE International Conference on Mobile Computing and Networking. ACM*, 174–185.

Hoblos, G., Staroswiecki, M. et al. (2000). Optimal design of fault tolerant sensor networks. *In Proceedings of the 2000 IEEE International Conference on Control Applications. IEEE*, 467–472.

Howard, A. and Mataric, M. J. (2002). Cover me! a self-deployment algorithm for mobile sensor networks. In *International Conference on Robotics and Automation.* 1-8.

Howard, A., Mataric,´ M. J. and Sukhatme, G. S. (2002a). An incremental self-deployment algorithm for mobile sensor networks. *Autonomous Robots*. 13(2), 113– 126.

Howard, A., Mataric,´ M. J. and Sukhatme, G. S. (2002b). Mobile sensor network deployment using potential fields: A distributed, scalable solution to the area coverage problem. In *Distributed Autonomous Robotic Systems* 5. (pp. 299–308). Springer.

Huang, C.-F. and Tseng, Y.-C. (2005). The coverage problem in a wireless sensor network. *Mobile Networks and Applications*. 10(4), 519–528.

Intanagonwiwat, C., Govindan, R. and Estrin, D. (2000). Directed diffusion: a scalable and robust communication paradigm for sensor networks. In *Proceedings of the 6th Annual International Conference on Mobile Computing and Networking. ACM*, 56– 67.

Ismail, Z., Hassan, R., Patel, A. and Razali, R. (2009). A study of routing protocol for topology configuration management in mobile ad hoc network. In *International Conference on Electrical Engineering and Informatics, 2009. ICEEI'09.*, vol. 2. IEEE, 412–417.

Iyengar, R., Kar, K. and Banerjee, S. (2005). Low-coordination topologies for redundancy in sensor networks. In *Proceedings of the 6th ACM International Symposium on Mobile Ad hoc Networking and Computing. ACM*, 332–342.

Jafari, R., Encarnacao, A., Zahoory, A., Dabiri, F., Noshadi, H. and Sarrafzadeh, M. (2005). Wireless sensor networks for health monitoring. In *The Second Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services, 2005. MobiQuitous 2005*. IEEE, 479–481.

Jian, Z. and Hai, Z. (2009). A link quality evaluation model in wireless sensor networks. In *Third International Conference on Sensor Technologies and Applications, 2009. SENSORCOMM'09*. IEEE, 1–5.

Jurdak, R. (2007). *Wireless ad hoc and sensor networks: a cross-layer design perspective.* Springer Science & Business Media.

Kahn, J. M., Katz, R. H. and Pister, K. S. (1999). Next century challenges: mobile networking for Smart Dust. In *Proceedings of the 5th Annual ACM/IEEE International Conference on Mobile Computing and Networking*. *ACM*, 271–278.

Kamat, M., Ismail, A. S. and Olariu, S. (2007). Modified hilbert space-filling curve for ellipsoidal coverage in wireless ad hoc sensor networks. In *IEEE International Conference on Signal Processing and Communications, 2007. ICSPC 2007. IEEE*, 1407–1410.

Karlof, C., Sastry, N. and Wagner, D. (2004). TinySec: a link layer security architecture for wireless sensor networks. In *Proceedings of the 2nd International Conference on Embedded Networked Sensor Systems. ACM*, 162–175.

Kelvin, W. T. B. and Weaire, D. L. (1996). The Kelvin problem: foam structures of minimal surface area. Taylor & Francis. Khatib, O. (1986). Real-time obstacle avoidance for manipulators and mobile robots. *The International Journal of Robotics Research*. 5(1), 90–98.

Kolar, V., Razak, S., Mah¨onen,¨ P. and Abu-Ghazaleh, N. B. (2011). Link quality analysis and measurement in wireless mesh networks. *Ad Hoc Networks*. 9(8), 1430–1447.

Konstantinidis, A. and Yang, K. (2011a). Multi-objective energy-efficient dense deployment in Wireless Sensor Networks using a hybrid problem-specific MOEA/D. *Applied Soft Computing*. 11(6), 4117–4134.

Konstantinidis, A. and Yang, K. (2011b). Multi-objective k-connected deployment and power assignment in wsns using a problem-specific constrained evolutionary algorithm based on decomposition. *Computer Communications*. 34(1), 83–98.

Krishnamachari, B., Mourtada, Y. and Wicker, S. (2003). The energy-robustness tradeoff for routing in wireless sensor networks. In *IEEE International Conference on Communications, 2003. ICC'03*., vol. 3. IEEE, 1833–1837.

Kulkarni, R. V. and Venayagamoorthy, G. K. (2011). Particle swarm optimization in wireless-sensor networks: A brief survey. *IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews*. 41(2), 262–267.

Langendoen, K. and Reijers, N. (2003). Distributed localization in wireless sensor networks: a quantitative comparison. *Computer Networks*. 43(4), 499–518.

Lasassmeh, S. M. and Conrad, J. M. (2010). Time synchronization in wireless sensor networks: A survey. In *Proceedings of the IEEE SoutheastCon 2010 (SoutheastCon). IEEE*, 242–245.

Lehr, W. and McKnight, L. W. (2003). Wireless internet access: 3G vs. WiFi? *Telecommunications Policy*. 27(5), 351–370.

Lei, Z. and Jianhua, L. (2010). Distributed coverage of forest fire border based on WSN. In *The 2nd International Conference on Industrial and Information Systems (IIS), 2010*, vol. 1. IEEE, 341–344.

Li, L. and Halpern, J. Y. (2001). Minimum-energy mobile wireless networks revisited. In *IEEE International Conference on Communications, 2001*, vol. 1. IEEE, 278– 283.

Li, X.-Y., Wan, P.-J. and Frieder, O. (2003). Coverage in wireless ad hoc sensor networks. *IEEE Transactions on Computers*. 52(6), 753–763.

Li, Y., Song, Y.-Q., Zhu, Y.-h. and Schott, R. (2010). Deploying wireless sensors for differentiated coverage and probabilistic connectivity. In *Wireless Communications and Networking Conference (WCNC), 2010 IEEE*. IEEE, 1–6.

Li, Z., Trappe, W., Zhang, Y. and Nath, B. (2005). Robust statistical methods for securing wireless localization in sensor networks. In *IPSN 2005. Fourth International Symposium on Information Processing in Sensor Networks, 2005. April*. 91–98.

Lin, C. R. and Gerla, M. (1997). Adaptive clustering for mobile wireless networks. *IEEE Journal on Selected Areas in Communications*. 15(7), 1265–1275.

Lindsey, S., Raghavendra, C. and Sivalingam, K. (2001). Data gathering in sensor networks using the energy*delay metric. In *Proceedings 15th International Parallel and Distributed Processing Symposium. April*. ISSN 1530-2075, 2001–2008.

Lindsey, S., Raghavendra, C. and Sivalingam, K. M. (2002). Data gathering algorithms in sensor networks using energy metrics. *IEEE Transactions on Parallel and Distributed Systems*. 13(9), 924–935.

Liu, D. and Ning, P. (2004). Multilevel TESLA: Broadcast authentication for distributed sensor networks. *ACM Transactions on Embedded Computing Systems (TECS)*. 3(4), 800–836.

Liu, L., Li, J., Wu, Z. and Shu, J. (2009a). Research on warning mechanism of link quality for Event-driven wireless sensor network. In *Second International Symposium on Electronic Commerce and Security, 2009. ISECS'09*., vol. 2. IEEE, 510–515.

Liu, T., Li, Z., Xia, X. and Luo, S. (2009b). Shadowing effects and edge effect on sensing coverage for wireless sensor networks. In *5th International Conference on Wireless Communications, Networking and Mobile Computing, 2009. WiCom'09*.IEEE, 1–4.

Mainwaring, A., Culler, D., Polastre, J., Szewczyk, R. and Anderson, J. (2002). Wireless sensor networks for habitat monitoring. In *Proceedings of the 1st ACM International Workshop on Wireless Sensor Networks and Applications*. ACM, 88– 97.

Makhecha, K. P. and Wandra, K. H. (2009). 4G Wireless Networks: Opportunities and Challenges. In *India Conference (INDICON), 2009 Annual IEEE*. IEEE, 1–4.

Manjeshwar, A. and Agrawal, D. P. (2001). TEEN: a routing protocol for enhanced efficiency in wireless sensor networks. In *Proceedings 15th International Parallel and Distributed Processing Symposium. April*. ISSN 1530-2075, 2009–2015.

Manjeshwar, A. and Agrawal, D. P. (2002). APTEEN: a hybrid protocol for efficient routing and comprehensive information retrieval in wireless. In *Proceedings International Parallel and Distributed Processing Symposium, IPDPS 2002. April*. 8, p. 0195b.

Mann, P. S. (2007). *Introductory statistics*. John Wiley & Sons.

Mao, G. (2009). *Localization Algorithms and Strategies for Wireless Sensor Networks: Monitoring and Surveillance Techniques for Target Tracking.* IGI *Global.*

Marks, M. (2010). A survey of multi-objective deployment in wireless sensor networks. *Journal of Telecommunications and Information Technology*, 36–41.

McLeod, B. (2013). *The effect of static electricity*. Retrievable at http://www.flickr.com/photos/benmcleod/4337226679/ sizes/l/in/gallery-physicsclassroom-72157624896741488/.

Megerian, S., Koushanfar, F., Qu, G., Veltri, G. and Potkonjak, M. (2002). Exposure in wireless sensor networks: theory and practical solutions. *Wireless Networks*. 8(5), 443–454.

Meier, A., Rein, T., Beutel, J. and Thiele, L. (2008). Coping with unreliable channels: Efficient link estimation for low-power wireless sensor networks. In *5th international Conference on Networked Sensing Systems, 2008. INSS 2008*. IEEE, 19–26.

MIT (2004). *The Cricket Indoor Location System*. Retrievable at http://nms. lcs.mit.edu/projects/cricket.

Moscibroda, T., Wattenhofer, R. and Zollinger, A. (2006). Topology control meets SINR: the scheduling complexity of arbitrary topologies. In *Proceedings of the 7th ACM International Symposium on Mobile Ad hoc Networking and Computing*. ACM, 310–321.

Newsome, J., Shi, E., Song, D. and Perrig, A. (2004). The sybil attack in sensor networks: analysis & defenses. In *Proceedings of the 3rd International Symposium on Information Processing in Sensor Networks.* ACM, 259–268.

Nguyen, D., Tran, T., Nguyen, T. and Bose, B. (2009). Wireless Broadcast Using Network Coding. vol. 58. Feb. ISSN 0018-9545, 914–925.

Oracle-Labs (2011). *SunSPOTs mote*. Retrievable at http://www. sunspotworld.com.

O'Rourke, D., Fedor, S., Brennan, C. and Collier, M. (2007). Reception region characterisation using a 2.4 GHz direct sequence spread spectrum radio. In *Proceedings of the 4th workshop on Embedded networked sensors.* ACM, 68–72.

O'rourke, J. (1987). *Art gallery theorems and algorithms.* vol. 57. Oxford University Press Oxford.

Pahlavan, K., Akguel, F. O., Heidari, M., Hatami, A., Elwell, J. M. and Tingley, R. D. (2006). Indoor geolocation in the absence of direct path. *Wireless Communications*, IEEE. 13(6), 50–58.

Pahlavan, K., Li, X. and Makel¨a,¨ J.-P. (2002). Indoor geolocation science and technology. *Communications Magazine*, IEEE. 40(2), 112–118.

Perrig, A., Canetti, R., Tygar, J. D. and Song, D. (2005). The TESLA broadcast authentication protocol. *RSA CryptoBytes*. 5.

Perrig, A., Szewczyk, R., Tygar, J. D., Wen, V. and Culler, D. E. (2002). SPINS: Security protocols for sensor networks. *Wireless Networks*. 8(5), 521–534.

Peter Coy, N. G. (1999). *21 ideas for the 21st century. Business Week*, 78– 167. Retrievable at http://www.businessweek.com/1999/99_35/ 2121_content.htm.

Poduri, S., Pattem, S., Krishnamachari, B. and Sukhatme, G. S. (2006). Sensor network configuration and the curse of dimensionality. *Proc. Third Workshop on Embedded Networked Sensors (EmNets 2006)*, Cambridge, MA, USA.

Poduri, S. and Sukhatme, G. S. (2004). Constrained coverage for mobile sensor networks. *IEEE International Conference on Robotics and Automation, 2004. Proceedings. ICRA'04*. 2004. 1, 165–171.

Pompili, D., Melodia, T. and Akyildiz, I. F. (2009). Three-dimensional and two-dimensional deployment analysis for underwater acoustic sensor networks. *Ad Hoc Networks.* 7(4), 778–790.

Przydatek, B., Song, D. and Perrig, A. (2003). SIA: Secure information aggregation in sensor networks. In *Proceedings of the 1st International Conference on Embedded Networked Sensor Systems.* ACM, 255–265.

Rabiner Heinzelman, W., Chandrakasan, A. and Balakrishnan, H. (2000). Energy-efficient communication protocol for wireless sensor networks. In *Proceedings of the 3rd Hawaii International Conference on System Sciences.* 1–10.

Raghavendra, C. S., Sivalingam, K. M. and Znati, T. (2006). *Wireless sensor networks. Springer.*

Rodoplu, V. and Meng, T. H. (1998). Minimum energy mobile wireless networks. In *IEEE International Conference on Communications, 1998. ICC 98. Conference Record*. 1998, vol. 3. IEEE, 1633–1639.

Sadagopan, N., Krishnamachari, B. and Helmy, A. (2003). The ACQUIRE mechanism for efficient querying in sensor networks. In *Proceedings of the First IEEE International Workshop on Sensor Network Protocols and Applications*, 2003. IEEE, 149–155.

Sankarasubramaniam, Y., McLaughlin, S. W. et al. (2003). Energy efficiency based packet size optimization in wireless sensor networks. In *Proceedings of the*

First IEEE International Workshop on Sensor Network Protocols and Applications, 2003. IEEE, 1–8.

Sarkar, N., Lol, W. G. et al. (2010). A study of manet routing protocols: Joint node density, packet length and mobility. In *IEEE Symposium on Computers and Communications (ISCC)*, 2010. IEEE, 515–520.

Schurgers, C. and Srivastava, M. B. (2001). Energy efficient routing in wireless sensor networks. In *Military Communications Conference*, 2001. MILCOM 2001. Communications for Network-Centric Operations: Creating the Information Force. IEEE, vol. 1. IEEE, 357–361.

Seshadri, A., Luk, M., Perrig, A., van Doorn, L. and Khosla, P. (2006). SCUBA: Secure code update by attestation in sensor networks. In *Proceedings of the 5th ACM workshop on Wireless security*. ACM, 85–94.

Seshadri, A., Luk, M., Shi, E., Perrig, A., van Doorn, L. and Khosla, P. (2005). Pioneer: verifying code integrity and enforcing untampered code execution on legacy systems. *ACM SIGOPS Operating Systems Review*. 39(5), 1–16.

Seshadri, A., Perrig, A., Van Doorn, L. and Khosla, P. (2004). Swatt: Software-based attestation for embedded devices. In *IEEE Symposium on Security and Privacy, 2004. Proceedings. 2004*. IEEE, 272–282.

Shah, R. C. and Rabaey, J. M. (2002). Energy aware routing for low energy ad hoc sensor networks. In *Wireless Communications and Networking Conference, 2002. WCNC2002*. 2002 IEEE, vol. 1. IEEE, 350–355.

Shen, C.-C., Srisathapornphat, C. and Jaikaeo, C. (2001). Sensor information networking architecture and applications. *Personal communications*, IEEE. 8(4), 52–59.

Shih, E., Cho, S.-H., Ickes, N., Min, R., Sinha, A., Wang, A. and Chandrakasan, A. (2001). Physical layer driven protocol and algorithm design for energy-efficient wireless sensor networks. In *Proceedings of the 7th Annual International Conference on Mobile Computing and Networking*. ACM, 272–287.

Sohrabi, K., Manriquez, B. and Pottie, G. J. (1999). Near ground wideband channel measurement in 800-1000 MHz. In *Vehicular Technology Conference*, 1999 IEEE 49th, vol. 1. IEEE, 571–574.

Srinivas, N. and Deb, K. (1994). Muiltiobjective optimization using nondominated sorting in genetic algorithms. Evolutionary computation. 2(3), 221–248.

Subramanian, L. and Katz, R. H. (2000). An architecture for building self-configurable systems. In *First Annual Workshop on Mobile and Ad Hoc Networking and Computing, 2000. MobiHOC*. 2000. IEEE, 63–73.

Tran-Quang, V. and Miyoshi, T. (2009). A novel gossip-based sensing coverage algorithm for dense wireless sensor networks. *Computer Networks*. 53(13), 2275– 2287.

Trossen, D. and Pavel, D. (2007). Sensor networks, wearable computing, and healthcare Applications. *Pervasive Computing*, IEEE. 6(2), 58–61.

Vasilescu, I., Kotay, K., Rus, D., Dunbabin, M. and Corke, P. (2005). Data collection, storage, and retrieval with an underwater sensor network. In *Proceedings of the 3rd International Conference on Embedded Networked Sensor Systems*. ACM, 154–165.

Veltri, G., Huang, Q., Qu, G. and Potkonjak, M. (2003). Minimal and maximal exposure path algorithms for wireless embedded sensor networks. In *Proceedings of the 1st International Conference on Embedded Networked Sensor Systems*. ACM, 40–50.

Wang, G., Cao, G. and La Porta, T. (2006a). Movement-assisted sensor deployment. *IEEE Transactions on Mobile Computing*. 5(6), 640–652.

Wang, G., Cao, G. and La Porta, T. (2006b). Movement-assisted sensor deployment. *IEEE Transactions on Mobile Computing*. 5(6), 640–652.

Wang, G., Cao, G. and LaPorta, T. (2003a). A bidding protocol for deploying mobile sensors. In *Proceedings of the 11th IEEE International Conference on Network Protocols, 2003.* IEEE, 315–324.

Wang, G., Guo, L., Duan, H., Liu, L. and Wang, H. (2012). Dynamic deployment of wireless sensor networks by biogeography based optimization algorithm. *Journal of Sensor and Actuator Networks*. 1(2), 86–96.

Wang, X., Wang, S. and Ma, J.-J. (2007). An improved co-evolutionary particle swarm optimization for wireless sensor networks with dynamic deployment. *Sensors*. 7(3), 354–370.

Wang, X., Xing, G., Zhang, Y., Lu, C., Pless, R. and Gill, C. (2003b). Integrated coverage and connectivity configuration in wireless sensor networks. In *Proceedings of the 1st International Conference on Embedded Networked Sensor Systems*. ACM, 28–39.

Woehrle, M., Brockhoff, D., Hohm, T. and Bleuler, S. (2010). Investigating coverage and connectivity trade-offs in wireless sensor networks: The benefits of MOEAs. In *Multiple Criteria Decision Making for Sustainable Energy and Transportation Systems*. (pp. 211–221). Springer.

Woo, A. and Culler, D. E. (2001). A transmission control scheme for media access in sensor networks. In *Proceedings of the 7th Annual International Conference on Mobile Computing and Networking*. ACM, 221–235.

Wu, J. and Yang, S. (2007). Polylogarithmic store-carry-forward routing using mobile nodes. In *IEEE International Conference on Mobile Adhoc and Sensor Systems, 2007. MASS 2007*. IEEE, 1–11.

Wu, Y., Chou, P., Kung, S.-Y. et al. (2005). Minimum-energy multicast in mobile ad hoc networks using network coding. *IEEE Transactions on Communications*. 53(11), 1906–1918.

Xiao, L., Greenstein, L., Mandayam, N. and Trappe, W. (2007). Fingerprints in the ether: Using the physical layer for wireless authentication. In *IEEE International Conference on Communications, 2007. ICC'07*. IEEE, 4646–4651.

Xin, H., Hua, Y., Xiaolin, G. and Wei, W. (2009a). The loose connectivity critical condition to ensure coverage and connectivity for WSN localized area coverage algorithm. In *IEEE International Workshop on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, 2009. IDAACS 2009.* IEEE, 688–693.

Xin, H., Ke, Y. and Xiaolin, G. (2009b). The area coverage algorithm to maintain connectivity for WSN. In *Ninth IEEE International Conference on Computer and Information Technology, 2009. CIT'09*., vol. 2. IEEE, 81–86.

Xing, G., Wang, X., Zhang, Y., Lu, C., Pless, R. and Gill, C. (2005). Integrated coverage and connectivity configuration for energy conservation in sensor networks. ACM Transactions on Sensor Networks (TOSN). 1(1), 36–72.

Xu, Y., Heidemann, J. and Estrin, D. (2001). Geography-informed energy conservation for ad hoc routing. In *Proceedings of the 7th Annual International Conference on Mobile Computing and Networking*. ACM, 70–84.

Yao, Y. and Gehrke, J. (2002). The cougar approach to in-network query processing in sensor networks. *ACM Sigmod Record*. 31(3), 9–18.

Younis, M., Youssef, M. and Arisha, K. (2002). Energy-aware routing in cluster-based sensor networks. In *Proceedings of the 10th IEEE International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunications Systems, 2002. MASCOTS 2002*. IEEE, 129–136.

Yu, Y., Govindan, R. and Estrin, D. (2001*). Geographical and energy aware routing: A recursive data dissemination protocol for wireless sensor networks.* Technical report. Technical report ucla/csd-tr-01-0023, UCLA Computer Science Department.

Zhang, C., Bai, X., Teng, J., Xuan, D. and Jia, W. (2010). Constructing low-connectivity and full-coverage three dimensional sensor networks. *IEEE Journal on Selected Areas in Communications*,. 28(7), 984–993.

Zhang, H. and Hou, J. C. (2005). Maintaining sensing coverage and connectivity in large sensor networks. *Ad Hoc & Sensor Wireless Networks*. 1(1-2), 89–124.

Zhang, H., Nixon, P. and Dobson, S. (2009). Partial coverage in homological sensor networks. In *IEEE International Conference on Wireless and Mobile Computing, Networking and Communications, 2009. WIMOB 2009*. IEEE, 42–47.

Zhang, J., Fan, P. and Ben Letaief, K. (2008). Network coding for efficient multicast routing in wireless ad-hoc networks. *IEEE Transactions on Communications*. 56(4), 598–607.

Zhang, Q., Wang, P., Reeves, D. S. and Ning, P. (2005). Defending against sybil attacks in sensor networks. In *25th IEEE International Conference on Distributed Computing Systems Workshops*, 2005. IEEE, 185–191.

Zhao, F. and Guibas, L. J. (2004). *Wireless sensor networks: an information processing approach.* Morgan Kaufmann.

Zheng, J. and Jamalipour, A. (2009). *Wireless sensor networks: a networking perspective*. John Wiley & Sons.

Zhu, S., Xu, S., Setia, S. and Jajodia, S. (2003). LHAP: a lightweight hop-by-hop authentication protocol for ad-hoc networks. In *23rd International Conference on Distributed Computing Systems Workshops, 2003. Proceedings*. IEEE, 749–755.

Zitzler, E. and Thiele, L. (1999). Multiobjective evolutionary algorithms: a comparative case study and the strength Pareto approach. IEEE transactions on evolutionary computation. 3(4), 257–271.

Zou, Y. and Chakrabarty, K. (2003). Sensor deployment and target localization based on virtual forces. In *INFOCOM 2003. Twenty-Second Annual Joint Conference of the IEEE Computer and Communications. IEEE Societies*, vol. 2. IEEE, 1293–1303.

Zou, Y. and Chakrabarty, K. (2004a). Sensor deployment and target localization in distributed sensor networks. *ACM Transactions on Embedded Computing Systems (TECS)*. 3(1), 61–91.

Zou, Y. and Chakrabarty, K. (2004b). Uncertainty-aware and coverage-oriented deployment for sensor networks. *Journal of Parallel and Distributed Computing*. 64(7), 788–798.

Zuniga, M. and Krishnamachari, B. (2004). Analyzing the transitional region in low power wireless links. In *First Annual IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks, 2004. IEEE SECON 2004*. IEEE, 517–526.