UNIVERSITI PUTRA MALAYSIA

SCHEDULED ACTIVITY ENERGY-AWARE DISTRIBUTED CLUSTER-BASED ROUTING ALGORITHM FOR WIRELESS SENSOR NETWORKS WITH NON-UNIFORM NODE DISTRIBUTION

NOOSHIN NOKHANJI

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By

NOOSHIN NOKHANJI

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NOOSHIN NOKHANJI

September 2014

Chair: Zurina Mohd Hanapi, PhD

Faculty: Computer Science and Information Technology

The main and definitive target of routing protocols in Wireless Sensor Networks (WSN) is passing data from the sensor nodes to the sink in most energy efficient manner besides considering the accuracy of data. Among different categories of routing protocols based on the network architecture, cluster-based (hierarchical) routing protocols are more energy efficient and increase the scalability as well as lifetime of the network. The non-uniform node deployment makes the energy consumption of the nodes more imbalanced. It makes the cluster-based routing protocols less efficient. Energy Aware Distributed Clustering (EADC) is one of the cluster-based routing protocol proposed for networks with non-uniform node distribution, which can effectively balance the energy consumption among the nodes. However, since the density of nodes varies in each region due to the non-uniform node deployment, in the dense area the sensed and transmitted data are extremely co-related and redundant. Therefore, the sensor nodes consume more inessential energy. Nevertheless, this unnecessary energy consumption is not considered in the EADC. Therefore, in this study, a new algorithm called Scheduled-Activity Energy Aware Distributed Clustering (SA-EADC) is proposed. SA-EADC adds another phase as "sensor redundancy check and activation" to EADC. It identifies the redundant sensor nodes, whose sensing coverage area are also covered completely by their direct neighbors and turns off them. In order to schedule the activity of these sensor nodes and to avoid creation of coverage holes, a distributed self-inactivation approach is proposed, in which the redundant sensor nodes work alternatively based on their residual energy. The proposed algorithm maintains the original sensing coverage, and guarantees sensing reliability. The results shows that SA-EADC algorithm can effectively identify the redundant nodes and schedule them to activate alternatively in

a way that it reduces the overall system energy consumption and extends the network lifetime without degradation in coverage and sensing reliability of the network.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

AKTIVITI BERJADUAL TENAGA SEDAR ALGORITMA PENGHALAAN BERASASKAN KELOMPOK TERAGIH UNTUK RANGKAIAN SENSOR WAYARLES DENGAN PENGAGIHAN NOD TIDAK SERAGAM

Oleh

NOOSHIN NOKHANJI

September 2014

Pengerusi: Zurina Mohd Hanapi, PhD

Fakulti: Sains Komputer dan Teknologi Maklumat

Sasaran utama dan muktamad protokol penghalaan dalam rangkaian sensor wayarles (WSN) adalah menghantar data daripada nod sensor kepada lubuk data dengan tenaga yang cekap di samping memastikan ketepatan data. Diantara kategori protokol penghalaan yang berdasarkan seni bina rangkaian, protokol penghalaan berasaskan kelompok (hierarki) mempunyai tenaga yang efisen dan berkebolehan meningkatkan boleh skala dan juga hayat rangkaian. Namun, pelaksanaan nod tidak seragam menyebabkan penggunaan tenaga nod yang tidak seimbang. Ia menjadikan protokol penghalaan berasaskan kelompok menjadi kurang cekap. Kelompok Tenaga Sedar Teragih (EADC) adalah salah satu protokol penghalaan berasaskan kelompok yang dicadangkan untuk sesebuah rangkaian dengan pengagihan nod yang tidak seragam, yang berkesan dalam mengimbangi penggunaan tenaga antara nod dengan lebih berkesan. Walau bagaimanapun, disebabkan ketumpatan nod adalah berbeza bagi setiap kawasan kerana penggunaan nod yang tidak seragam, di kawasan yang padat, pengesanan dan penghantaran data mempunyai hubung kait yang rapat dan bertindan. Oleh itu, nod sensor menggunakan banyak tenaga yang tidak perlu. Namun, penggunaan tenaga yang tidak perlu ini tidak diambilkira dalam EADC. Oleh itu, dalam kajian ini, algoritma baru yang dipanggil Aktiviti Berjadual Tenaga Sedar Kelompok Teragih (SA-EADC) telah dicadangkan. SA-EADC menambah fasa lain iaitu "sensor pemeriksaan lebihan dan pengaktifan" untuk EADC. Ia mengenal pasti nod sensor yang bertindan, dimana penderiaan kawasan liputan juga dideria sepenuhnya oleh jiran-jiran secara terus dan dimatikan mereka. Untuk menjadualkan aktiviti nod sensor ini dan mengelakkan pembentukan lubang liputan, pendekatan pengaktifan secara bersendirian yang teragih adalah dicadangkan, di mana nod sensor yang bertindan bekerja secara alternatif berasaskan tenaga sisa mereka. Algoritma yang dicadangkan ini mengekalkan liputan penderiaan asal dan menjamin

kebolehpercayaan penderiaan. Keputusan dalam penyelidikan ini menunjukkan bahawa algoritma SA-EADC berkesan dan boleh mengenal pasti nod bertindan dan menjadualkan pengaktifan alternatif dengan mengurangkan penggunaan keseluruhan sistem tenaga dan mampu memanjangkan jangka hayat rangkaian tanpa mengurangkan liputan dan kebolehpercayaan penderiaan rangkaian.

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Zurina Mohd Hanapi, PhD
Senior Lecturer
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Chairman)

Shamala Subramaniam, PhD
Associate Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Member)

Mohamad Afendee Mohamed, PhD
Senior Lecturer
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____
Name of
Chairman of
Supervisory
Committee:
Zurina Mohd. Hanapi, PhD

Signature: _____
Name of
Member of
Supervisory
Committee:
Mohamad Afendee Mohammed, PhD

Signature: _____
Name of
Member of
Supervisory
Committee: Shamala Subramaniam, PhD

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LIST OF ABBREVIATIONS

ACE	Algorithm for Cluster Establishment
ACT	Arranging Cluster Size and Transmission ranges
ADC	Analog-to-Digital Convertor
AMRP	Average Minimum Reachability Power
BCDCP	Base station Controlled Dynamic Clustering Protocol
BS	Base Station
CBC	Centralized Balanced Clustering Routing Protocol
CCM	Chain Cluster-based Mixed
CDMA	Code Division Multiple Access
CH	Cluster Head
CM	Cluster Member
DD	Directed Diffusion
DES	Discrete Event Simulation
DIST-TH	Distance Threshold
EADC	Energy-Aware Distributed Clustering
EADUC	Energy Aware Distributed Unequal Clustering
EAR	Energy Aware Routing
EECS	Energy Efficient Clustering Scheme
EEHC	Energy Efficient Heterogeneous Clustered
EEUC	Energy Efficient Unequal Clustering
FS	Free Space
FZ-LEACH	Far Zone- Low Energy Adaptive Clustering Hierarchy
GAF	Geographic Adaptive Fidelity
GEAR	Geographic and Energy Aware Routing
GOAFR	Greedy Other Adaptive Face Routing

GPS	Global Positioning System
HEED	Hybrid Energy-Efficient Distributed Clustering
ID	Identity
LEACH	Low Energy Adaptive Clustering Hierarchy
LEACH-C	Low Energy Adaptive Clustering Hierarchy Centralized
MAC	Medium Access Control
MEMS	Micro-Electro-Mechanical Systems
MECN	Minimum Energy Communication Network
MP	Multipath
MR-LEACH	Multi hop Routing with LEACH
MRP	Minimum Reachability Power
MSE	Mobile Sink-Based Improved Algorithm for Stable Election
MST	Minimum Spanning Tree
PEGASIS	Power-efficient Gathering in Sensor Information Systems
QoS	Quality of Service
RF	Radio Frequency
SA-EADC	Scheduled-Activity Energy-Aware Distributed Clustering
SAR	Sequential Assignment Routing
SMECN	Small Minimum-Energy Communication Network
SPIN	Sensor Protocols for Information via Negotiation
TDMA	Time Division Multiple Access
UCS	Unequal Clustering Size
WSN	Wireless Sensor Networks
ZH	Zone Head

CHAPTER 1

INTRODUCTION

1.1 Background

The combination of innovations in Micro-Electro-Mechanical Systems (MEMS) and the development of low power radio technologies, in addition to the advances in low-power embedded micro-controllers, result in appearing a special type of ad-hoc networks called Wireless Sensor Networks (WSN) (Younis & Fahmy, 2004; Lindsey, Raghavendra, & Sivalingam, 2002; Heinzelman, Chandrakasan, & Balakrishnan, 2000). WSNs have achieved a significant amount of attention in recent years, because of their benefits in sensing and gathering different kinds of data from various environments. WSNs consist of hundred to thousand sensor nodes, which measure a property from the environment as well as processing and transmitting the collected data to the Base Station (BS) (Yick, Mukherjee, & Ghosal, 2008).

There are many factors, which influence the design of a sensor network, such as fault tolerance, scalability, resources constraints, power consumption, transmission media, and security. In many applications, battery replacement or node redeployment is impossible. Therefore, the network strongly depends on the battery lifetime of sensor nodes. The malfunction of nodes may cause significant topology changes, rerouting of packets and network reorganization (Akyildiz, Su, Sankarasubramaniam, & Cayirci, 2002). Thus, energy efficiency is a very critical issue, which notably affects the network lifetime. Hence, the main concern in designing protocols is how to minimize the energy consumption and maximize the network lifetime (Gu, Yu, Yu, Wang, & Lv, 2014).

The problem of energy consumption can be discussed in two aspects; developing energy efficient communication protocols and identifying wasteful and unnecessary activities in the network and pacifying their impact (Dargie & Poellabauer, 2010). Routing protocols has a key role in WSNs, since it is the most energy-conserving factor. They are responsible for discovering and maintaining energy efficient route in the network, in order to make communication reliable and efficient (Roseline & Sumath, 2011; Al-Karaki & Kamal, 2004).

Node deployment is one of the challenging factors in design of routing protocols. It has influence on energy consumption, coverage, lifetime, throughput of network. Node deployment can be manual, randomized, uniform, or non-uniform (Al-Karaki & Kamal, 2004). It has been proved by many researchers that among different categories of protocols based on the network architecture, cluster-based (hierarchical) routing protocols are more energy efficient than non-cluster based routing protocols, since they increase the scalability and lifetime of the network (Liu, 2012; Naeimi, Ghafghazi, Chow, & Ishii, 2012; Yu, Qi, & Wang, 2011; Heinzelman et al., 2000). However, non-uniform node deployment makes the cluster-based routing protocols less efficient, since the energy consumption of the nodes are more imbalanced.

The main motivation of this research work is to design a cluster- based routing algorithm for the network with non-uniform node distribution in order to extend the lifetime and decrease the energy consumption.

1.2 Problem Statement

In the network with a non-uniform node deployment, the mechanisms used to balance the energy consumption and extend the network lifetime are not always effective. The non-uniform node deployment makes the energy consumption of the nodes more imbalanced (Yu, Qi, Wang, & Gu, 2012). It makes the cluster-based routing protocols less efficient (Yu et al., 2012; Shin, Moh, & Chung, 2011). Yu et al. (2012) proposed a cluster-based routing protocol for the network with non-uniform node distribution, which includes EADC, and a cluster-based routing algorithm. This routing protocol significantly balances the energy consumption among the nodes and prolongs the network lifetime.

However, as the density of the sensor nodes varies in each region due to the non-uniform node distribution, in the dense area the sensed and transmitted data are extremely correlated and redundant. Thus, the sensor nodes consume more inessential energy for sensing and transmitting redundant data. Nevertheless, this unnecessary energy consumption is not considered in EADC, which decreases the network lifetime.

1.3 Research Objective

The aim of this research work is to propose a scheduled activity energy-aware distributed clustering algorithm, which identifies the redundant sensor nodes, and schedules their activity alternatively in order to reduce the energy consumption and increase the lifetime of the network with non-uniform node distribution.

1.4 Research Scope

This research work focuses on the EADC routing protocol, since it balances the energy consumption among the nodes in the network with non-uniform node distribution and increases the network lifetime significantly. Furthermore, it is a distributed routing protocol, which takes the advantage of heterogeneous nodes in terms of energy. Therefore, the choice of the EADC protocol is considered as a good platform to fulfil the objectives. This study focuses on the lifetime and energy consumption improvements of the network, since they are the main concern in the design of the protocols for WSN.

The study covers two main scenarios, in which the sensor nodes are distributed randomly (i.e. the location of the nodes is chosen randomly) and non-uniformly (i.e. the nodes are more grouped in certain parts of the network) in a square field, while the BS is located outside of the field. The location of the BS and the sensor nodes are fixed. The BS has sufficient energy resource and its location is known by each node. All the sensor nodes are heterogeneous in terms of energy and location unaware. They can use power control to vary the amount of transmit power. Additionally, they are

required to be time synchronized. The failure of the sensor nodes is due to the energy depletion.

1.5 Research Contribution

In this research work, an energy aware distributed clustering algorithm for the network with non-uniform node distribution was proposed in order to solve the existing problem of EADC. The proposed algorithm improves the performance of EADC algorithm in terms of energy consumption and lifetime. The contribution of this study can be defined in details as follows:

A Scheduled-Activity Energy-Aware Distributed Clustering (SA-EADC) was proposed in order to solve the problem of inessential energy consumption of the network due to the redundancy of the nodes. SA-EADC exploits the redundant nodes and turns them off for the current round. The redundant nodes are scheduled based on their residual energy to work alternately. The proposed algorithm preserves the original sensing coverage, and guarantees a certain redundancy. Consequently, SA-EADC avoids unnecessary redundant sensing and transmission of data, which results in reducing the overall energy consumption of the system and extending the network lifetime.

1.6 Thesis Organization

The thesis includes five chapters. Chapter 1 presents a brief discussion on the background, problem statement, objectives, scopes, and findings of the research work.

Chapter 2 presents a literature study to review the main principles in WSN, energy efficiency issues, classifications of routing protocols in WSN, cluster-based routing protocols, deep analysis of prominent cluster-based routing protocols, and sensor activity scheduling.

Chapter 3 explains the general research methodology used to accomplish the objective. It presents the framework of the research work and explores each stage in details. It covers the aspects of design, algorithm implementation, simulation parameters, and performance metrics.

Chapter 4 presents the proposed clustering algorithm SA-EADC in detail. The design of SA-EADC is described thoroughly and its performance is evaluated based on the simulation analysis in this chapter.

Finally, this study is concluded and directions for future work are presented in chapter 5.

REFERENCES

Abbasi, A. A., & Younis, M. (2007). A survey on clustering algorithms for wireless sensor networks. *Computer Communications, 30*(14–15), 2826-2841.

Akyildiz, I. F., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). A survey on sensor networks. *IEEE Communications magazine, 40*(8), 102-114.

Akyildiz, I. F., & Vuran, M. C. (2010). *Wireless Sensor Networks*: Wiley.

Al-Karaki, J. N., & Kamal, A. E. (2004). Routing techniques in wireless sensor networks: a survey. *IEEE Wireless Communications, 11*(6), 6-28.

Amgoth, T., & Jana, P. K. (2014). Energy-aware routing algorithm for wireless sensor networks. *Computers & Electrical Engineering*.

Bajaber, F., & Awan, I. (2011). Adaptive decentralized re-clustering protocol for wireless sensor networks. *Journal of Computer and System Sciences, 77*(2), 282-292.

Boyinbode, O., Le, H., Mbogho, A., Takizawa, M., & Poliah, R. *A survey on clustering algorithms for wireless sensor networks.* Paper presented at the 13th International Conference on Network-Based Information Systems (NBiS), Gifu, Japan. September 2010.

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

Cardei, M., & Du, D.-Z. (2005). Improving wireless sensor network lifetime through power aware organization. *Wireless Networks, 11*(3), 333-340.

Chan, H., & Perrig, A. (2004). ACE: An emergent algorithm for highly uniform cluster formation. *Wireless Sensor Networks* (pp.154-171). Springer Berlin Heidelberg.

Chen, B., Jamieson, K., Balakrishnan, H., & Morris, R. (2002). Span: An energy-efficient coordination algorithm for topology maintenance in ad hoc wireless networks. *Wireless Networks, 8*(5), 481-494.

Chen, J. (2011). *Improvement of LEACH Routing Algorithm Based on Use of Balanced Energy in Wireless Sensor Networks.* Proceedings from *the 7th International Conference on Advanced Intelligent Computing*. Springer-Verlag.

Chen, J., Li, Z., & Kuo, Y.-H. (2013). A centralized balance clustering routing protocol for wireless sensor network. *Wireless Personal Communications, 72*(1), 623-634.

Chen, Y.-L., & Lin, J.-S. (2012). Energy efficiency analysis of a chain-based scheme via intra-grid for wireless sensor networks. *Computer Communications, 35*(4), 507-516.

Dargie, W., & Poellabauer, C. (2010). *Fundamentals of Wireless Sensor Networks: Theory and Practice*. John Wiley & Sons.

Farooq, M. O., Dogar, A. B., & Shah, G. A. (2010). *MR-LEACH: multi-hop routing with low energy adaptive clustering hierarchy.* Proceedings from *the Fourth International Conference on Sensor Technologies and Applications (SENSORCOMM)*. IEEE.

Fu, S., Ma, J., Li, H., & Wang, C. (2013). Energy-balanced separating algorithm for cluster-based data aggregation in wireless sensor networks. *International Journal of Distributed Sensor Networks, 2013,* 1-15.

Gu, X., Yu, J., Yu, D., Wang, G., & Lv, Y. (2014). ECDC: An energy and coverage-aware distributed clustering protocol for wireless sensor networks. *Computers & Electrical Engineering, 40*(2), 384-398.

Hanapi, Z. M. (2011). *Adaptive and Dynamic Implicity Secured Routing Protocol for Wireless Sensor Network.* Doctor of Philosophy, Universiti Kebangsaan Malaysia (UKM), Malaysia.

Haneef, M. S., & Zhongliang, D. (2012). Design challenges and comparative analysis of cluster based routing protocols used in wireless sensor networks for improving network life time. *Advances in Information Sciences and Service Sciences, 4*(1), 450-459.

Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000). *Energy-Efficient Communication Protocol forWireless Microsensor Networks.* Proceedings from *the 33rd Hawaii International Conference on System Sciences*. IEEE.

Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2002). An Application-Specific Protocol Architecture for Wireless Microsensor Networks. *IEEE Transactions on Wireless Communications, 1*(4), 660- 670.

Huang, C.-F., Tseng, Y.-C., & Wu, H.-L. (2007). Distributed protocols for ensuring both coverage and connectivity of a wireless sensor network. *ACM Transactions on Sensor Networks (TOSN), 3*(1), 5.

Intanagonwiwat, C., Govindan, R., & Estrin, D. (2000). *Directed diffusion: a scalable and robust communication paradigm for sensor networks.* Proceedings from *the 6th Annual International Conference on Mobile computing and networking*. ACM.

Jin, Z., Jian-Ping, Y., Si-Wang, Z., Ya-Ping, L., & Guang, L. (2009). A survey on position-based routing algorithms in wireless sensor networks. *Algorithms, 2*(1), 158-182.

Katiyar, V., Chand, N., Gautam, G. C., & Kumar, A. (2011). *Improvement in LEACH protocol for large-scale wireless sensor networks*. Proceedings from *International Conference on Emerging Trends in Electrical and Computer Technology* (*ICETECT).* IEEE.

Katiyar, V., Chand, N., & Soni, S. (2011). A survey on clustering algorithms for heterogeneous wireless sensor networks. *International Journal of Advanced Networking and Applications, 2*(4), 745-754.

Kuhn, F., Wattenhofer, R., & Zollinger, A. (2003). *Worst-case optimal and average-case efficient geometric ad-hoc routing.* Proceedings *from the 4th ACM International Symposium on Mobile Ad hoc Networking & Computing*. ACM.

Kulik, J., Heinzelman, W., & Balakrishnan, H. (2002). Negotiation-based protocols for disseminating information in wireless sensor networks. *Wireless Networks, 8*(2), 169-185.

Kumar, D., Aseri , T. C., & Patel , R. B. (2009). EEHC: Energy efficient heterogeneous clustered scheme for wireless sensor networks. *computer communications, 32*(4), 662-667.

Kumarawadu, P., Dechene, D. J., Luccini, M., & Sauer, A. (2008). *Algorithms for node clustering in wireless sensor networks: A survey.* Proceedings from *4th International Conference on Information and Automation for Sustainability*. IEEE.

Lai, W. K., Fan, C. S., & Lin, L. Y. (2012). Arranging cluster sizes and transmission ranges for wireless sensor networks. *Information Sciences, 183*(1), 117-131.

Li, C., Ye, M., Chen, G., & Wu, J. (2005). *An energy-efficient unequal clustering mechanism for wireless sensor networks*. Proceedings from *Mobile Adhoc and Sensor Systems Conference.* IEEE.

Li, L., & Halpern, J. Y. (2001). *Minimum-energy mobile wireless networks revisited.* Proceedings from *IEEE International Conference on Communications*. IEEE.

Lindsey, S., Raghavendra, C., & 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, M., Cao, J., Chen, G., & Wang, X. (2009). An energy-aware routing protocol in wireless sensor networks. *Sensors, 9*(1), 445-462.

Liu, M., Cao, J. N., Chen, G. H., Chen, L. J., Wang, X. M., & Gong, H. G. (2007). EADEEG: An energy-aware data gathering protocol for wireless sensor networks. *Ruan Jian Xue Bao(Journal of Software), 18*(5), 1092-1109.

Liu, X. (2012). A survey on clustering routing protocols in wireless sensor networks. *Sensors (Switzerland), 12*(8), 11113-11153.

Liu, X., & Shi, J. (2012). Clustering routing algorithms in wireless sensor networks: An overview. *KSII Transactions on Internet and Information Systems, 6*(7), 1735-1755.

Morais Cordeiro, C. D., & Agrawal, D. P. (2011). *Ad Hoc and Sensor Networks: Theory and Applications*. World Scientific.

Murthy, C. S. R., & Manoj, B. S. (2004). *Ad Hoc Wireless Networks: Architectures and Protocols*. Pearson Education.

Muruganathan, S. D., Ma, D. C. F., Bhasin, R. I., & Fapojuwo, A. O. (2005). A centralized energy-efficient routing protocol for wireless sensor networks. *IEEE Radio Communication, 43*, S8-S13.

Naeimi, S., Ghafghazi, H., Chow, C. O., & Ishii, H. (2012). A survey on the taxonomy of cluster-based routing protocols for homogeneous wireless sensor networks. *Sensors (Switzerland), 12*(6), 7350-7409.

Rodoplu, V., & Meng, T. H. (1999). Minimum energy mobile wireless networks. *IEEE Journal on Selected Areas in Communications, , 17*(8), 1333-1344.

Roseline, R. A., & Sumath, P. (2011). Energy Efficient Routing Protocols and Algorithms for Wireless Sensor Networks-A survey. *Global Journal of Computer Science and Technology, 11*(21), 60-067.

Schurgers, C., & Srivastava, M. B. (2001). *Energy efficient routing in wireless sensor networks.* Proceedings from *Military Communications Conference, 2001. MILCOM 2001. Communications for Network-Centric Operations: Creating the Information Force.* IEEE.

Shah, R. C., & Rabaey, J. M. (2002). *Energy aware routing for low energy ad hoc sensor networks.* Proceedings from *Wireless Communications and Networking Conference*. IEEE.

Shen, H. (1999). Finding the k most vital edges with respect to minimum spanning tree. *Acta Informatica, 36*(5), 405-424.

Shin, H., Moh, S., & Chung, I. (2011). *A Balanced Clustering Algorithm for Non-uniformly Deployed Sensor Networks.* Proceedings *from the 2011 IEEE Ninth International Conference on Dependable, Autonomic and Secure Computing (DASC)*. IEEE.

Sohrabi, K., Gao, J., Ailawadhi, V., & Pottie, G. J. (2000). Protocols for self-organization of a wireless sensor network. *IEEE Personal Communications, 7*(5), 16-27.

Soro, S., & Heinzelman, W. B. (2005). *Prolonging the lifetime of wireless sensor networks via unequal clustering.* Proceedings from *the 19th IEEE International Parallel and Distributed Processing Symposium*. IEEE.

Soro, S., & Heinzelman, W. B. (2009). Cluster head election techniques for coverage preservation in wireless sensor networks. *Ad Hoc Networks, 7*(5), 955-972.

Tang, F., You, I. Y., Guo, S., Guo, M., & Ma, Y. (2012). A chain-cluster based routing algorithm for wireless sensor networks. *Journal of Intelligent Manufacturing 23*(4), 1305-1313.

Tian, D., & Georganas, N. D. (2002). *A coverage-preserving node scheduling scheme for large wireless sensor networks.* Proceedings from *the 1st ACM International Workshop on Wireless Sensor Networks and Applications*. ACM.

Tian, D., & Georganas, N. D. (2003). A node scheduling scheme for energy conservation in large wireless sensor networks. *Wireless Communications and Mobile Computing, 3*(2), 271-290.

Wang, B. (2010). *Coverage control in sensor networks*. Springerverlag London.

Wang, B. (2011). Coverage problems in sensor networks: A survey. *ACM Computing Surveys (CSUR), 43*(4), 32.

Wang, J., Zhang, Z., Xia, F., Yuan, W., & Lee, S. (2013). An Energy Efficient Stable Election-Based Routing Algorithm for Wireless Sensor Networks. *Sensors, 13*(11), 14301-14320.

Xing, G., Wang, X., Zhang, Y., Lu, C., Pless, R., & 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., & Estrin, D. (2001). *Geography-informed energy conservation for ad hoc routing.* Proceedings from *the 7th Annual International Conference on Mobile Computing and Networking.* ACM.

Ye, M., Li, C., Chen , G., & Wu, J. (2005). *EECS: An Energy Efficient Clustering Scheme in Wireless Sensor Networks*. Proceedings from *24th IEEE International Performance, Computing, and Communications Conference*. IEEE.

Yick, J., Mukherjee, B., & Ghosal, D. (2008). Wireless sensor network survey. *Computer Networks, 52*(12), 2292-2330.

Yoo, S. (2012). *Improve Far-Zone LEACH Protocol for Energy Conserving.* Proceedings from *8th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM).* IEEE.

Younis, M., & Akkaya, K. (2008). Strategies and techniques for node placement in wireless sensor networks: A survey. *Ad Hoc Networks, 6*(4), 621-655.

Younis, O., & Fahmy, S. (2004). HEED: A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks. *IEEE Transactions On Mobile Computing, 3*, 366-379.

Yu, Qi, Y., Wang, G., Guo, Q., & Gu, X. (2011). An Energy-Aware Distributed Unequal Clustering Protocol for Wireless Sensor Networks. *International Journal of Distributed Sensor Networks, 2011*(9), 133-139.

Yu, J., Qi, Y., & Wang, G. (2011). An energy-driven unequal clustering protocol for heterogeneous wireless sensor networks. *Journal of Control Theory and Applications, 9*(1), 133-139.

Yu, J., Qi, Y., Wang, G., & Gu, X. (2012). A cluster-based routing protocol for wireless sensor networks with nonuniform node distribution. *AEU - International Journal of Electronics and Communications, 66*(1), 54-61.

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

Yuan, H., Liu, W., & Xie, J. (2011). *Prolonging the Lifetime of Heterogeneous Wireless Sensor Networks via Non-Uniform Node Deployment.* Proceedings from *International Conference on Internet Technology and Applications (iTAP)*. IEEE.

Zungeru, A. M., Ang, L.-M., & Seng, K. P. (2012). Classical and swarm intelligence based routing protocols for wireless sensor networks: A survey and comparison. *Journal of Network and Computer Applications, 35*(5), 1508-1536.