

A Multi-hop Uneven Hierarchical Routing Protocol for Wireless Sensor Networks Using a Controlled Mobile Sink

Feng Ruan¹, Chuanyang Yin¹, Jinhui Chen¹, Ning Ma² and Shengjun Xue³

¹*School of Information & Control, Nanjing University of Information Science & Technology, Nanjing 210044, China*

²*College of Meteorology and Oceanography, PLA University of Science & Technology, Nanjing 210007, China*

³*School of Computer & Software, Nanjing University of Information Science & Technology, Nanjing 210044, China*

Abstract

Use of mobile devices for data collection in wireless sensor networks (WSNs) has recently drawn much attention. Controlled sink mobility has been shown to be beneficial in energy conservation and lifetime prolongation. In this paper, we aim at studying the multi-hop uneven hierarchical routing protocol (MUHRP) using different mobile sink strategies. We first analyze the performance of multi-hop uneven hierarchical routing protocol with a fixed sink node. Then to measure the network performance, we use a mobile sink node, replacing the fixed sink node, to collect fused data packets from cluster heads. Network performance using our proposed protocol is validated through simulation experiments using MATLAB.

Keywords: wireless sensor networks, mobile sink, hierarchical routing, residual energy, network lifetime

1. Introduction

Composed of a large number of sensor nodes, wireless sensor networks (WSNs) have been proposed for the observation of various environments in sensing fields. Those sensor nodes sense, process and transmit their sensed data to certain remote sink node (SN) or base station (BS) in a direct or multi-hop transmission manner. And because the resource of sensor nodes is limited, how to minimize the energy consumption and the traffic load becomes one of the key issues in routing protocol design [1, 2]. Recently, many energy efficient protocols, in which the sink node is static, have been proposed for WSNs to improve energy efficiency and prolong network lifetime. Since the traffic pattern usually follows a many-to-one model, those nodes near the sink node will suffer high traffic load to forward and thus inevitably cause hot-spot problem, which has a severely impact on network connectivity and network lifetime [4, 5, 7]. To mitigate hot-spot problem, exploiting mobility strategies have attracted much attention. Several studies have shown that mobility significantly reduces energy consumption at each sensor node and balances traffic load of sensor nodes near SN, thus prolongs the network lifetime.

In this paper, multi-hop uneven hierarchical routing protocol (MUHRP) [4, 5] is firstly studied where clusters have different cluster sizes to reduce energy consumption of intra-cluster communication. In MUHRP, we assume that the sink node is fixed in the center of a rectangular network area and then analyze the performance of MUHRP. To mitigate the hot spot problem, we use a mobile sink node instead of fixed sink node and study the sink mobility strategies for sensor networks. Here, the mobile sink node first moves randomly and

we analyze the energy consumption of the network. Then we assume the mobile sink node moves along a predefined path inside the sensor network. The mobile sink node will sojourn at some locations to collect fused data from CHs in its communication range and other CHs far away from the sink node will communicate in a multi-hop manner.

The rest of the paper is organized as follows. Section 2 presents a literature survey about related clustering protocols and sink movement strategies for sensor networks. In Section 3, our protocol is explained in details. Section 4 provides simulation results and Section 5 concludes this paper.

2. Related Work

Hierarchical routing protocols are suitable for WSNs since they can effectively schedule and manage sensor nodes. Low-energy adaptive clustering hierarchy (LEACH) [3] utilizes randomized rotation of local CHs to evenly distribute energy load across network. Each sensor node takes turn to be cluster head at different round, and thus energy will be balanced among network. However, the 5% of CHs are randomly selected and CHs communicate with SN directly which will easily cause hot spot problem.

Thus, current studies on hierarchical routing protocols mainly concentrate on residual energy and forming clusters with different sizes [4, 5]. In [4], authors proposed a multi-hop routing protocol with unequal clustering algorithm. In this algorithm, sensor nodes with more residual energy will act as CHs, and clusters have different cluster sizes. The close distance, the smaller cluster sizes. Thus they can preserve some energy during intra-cluster communication for inter-cluster packets forwarding. Besides, when regular nodes need to join clusters, they consider the distance to CHs and the residual energy of CHs. Those nodes with minimum energy consumption will be chosen to act as relay nodes to forward. In [5], authors proposed an unequal cluster-based routing protocol. A greedy geographic and energy-aware routing protocol is designed for the inter-cluster communication, which considers the trade-off between energy cost of relay paths and residual energy of relay nodes.

To improve network performance, exploiting sink mobility has attracted more attention, and mobility management also receives extensive research efforts [6-13].

In [6], the basic idea of mobile sinks was proposed, and authors called them “data MULEs”. MULEs use random walk to pick up data in their close range and then drop off the data to some access points. Energy consumption for sensor nodes can be largely reduced since the transmission range is short. However, a random moving sink node is insensitive to the residual energy, and thus might threaten the energy balance among sensor nodes.

In [7], authors considered a wireless sensor network with a mobile BS which repeatedly relocates to change the bottleneck sensor nodes near BS. Various predetermined trajectories were considered in the search for a combined optimum on the moving and routing strategies.

In [8], authors also considered a BS which moves along a predetermined path in the sensor network. CHs are those nodes closest to the mobile node trajectory, and normal sensor nodes will be organized in each cluster. Besides, CHs are in charge of collecting data from their clusters and sending them to the mobile node when it passes by.

In [9], authors first explored and categorized the general problem of sink mobility in the context of trade-offs between data delivery delay and network lifetime, and then studied a novel mobility control solution in which nodes cooperatively determine the sink trajectory, and navigate the mobile sinks for delay and energy optimized data collection.

In [10], authors proposed theoretical results about the optimal movement of a mobile base station. They showed that when base station location is un-constrained, the network lifetime can be at least $(1 - \varepsilon)$ of the maximum network lifetime under their designed joint mobile base station and flow routing algorithm.

Recently, a mobile sink based routing protocol (MSRP) was proposed in [11] to addressed hot spot problem. In MSRP, the mobile sink node moves in clustered sensor network to collect fused data from CHs within its vicinity. To measure that the mobile sink node can move to CHs with higher residual energy, the residual energy of CHs needs to be known by the mobile sink node.

In [12], authors proposed a novel data collection scheme, called the maximum amount shortest path (MASP), which increases network throughput as well as conserves energy by optimizing the assignment of sensor nodes. MASP was formulated as an integer linear programming problem and solved with the help of a genetic algorithm.

In [13], authors provided a simulation-based analysis of the energy efficiency with static and mobile sinks where the focus was on two important configuration parameters: mobility path of the sink node and duty cycling value of sensor nodes. They quantitatively analyze the influence of duty cycling and the mobility radius of the sink node as well as their interrelationship in terms of energy consumption for a well-defined model scenario. The analysis starts from general load considerations and is refined into a geometrical model which is validated by more realistic simulations.

3. Our Proposed Multi-hop Uneven Hierarchical Routing Protocol (MUHRP) Using a Mobile Sink

3.1. Cluster Formation and Multi-hop Routing Setup

In MUHRP, sensor node is aware of its approximate distance d to current location of SN, the minimum distance d_{\min} and the maximum distance d_{\max} . Thus, the competition range R_i , which is used to form clusters having different cluster sizes, can be calculated according to the Formula (1) [4, 5]. CHs are selected mainly based on their competition range and residual energy.

Sensor nodes are randomly selected with the same probability to act as temporary CHs, where the final CHs will be chosen. Each temporary CHs need to broadcast a message to its neighbor temporary CHs, including its competition range, its residual energy and its own ID. Besides, each temporary CHs need to keep a table to save those received messages to proceed. Those temporary CHs within the limits of competition range R_i will be the neighbor temporary CHs of C_i . At the end of the CHs competition, there will not be another temporary CHs C_j existing in competition range of C_i that becomes a final cluster head. We use competition range to decide the neighbor temporary CHs of each temporary nodes. If C_i has largest residual energy in its neighbors, it will broadcast a message to declare that it becomes CHs. And if their residual energy is equal, C_i with the smaller ID will be chosen.

After completing the selection of CHs, normal sensor nodes need to join CHs according to the signal strength. Member sensor nodes will transmit their sensed data packets to their CHs directly. To reduce the cost of long distance communication and improve the efficiency of network, we adopt a multi-hop manner in inter-cluster communication. If the distance between CHs and SN is smaller than the threshold d_{th} , which is predefined, CHs will transmit fused data to SN directly; otherwise, it will find an adjacent cluster head node to act as its relay sensor node, which is chosen based on their distance and residual energy. The cost of the relay node can be computed by the

Formula (2), and CHs with minimum cost will be selected. After all the relay nodes have been selected, data transmission can be conducted.

$$R_i = ((d_{\max} - d_{\min}) / d_{\max}) \times d_{(s_i, SN)} + d_{\min} \quad (1)$$

$$\cos t(j) = \omega * \frac{d(s_i, s_j)^2 + d(s_j, SN)^2}{\max(d(s_i, s_j)^2 + d(s_j, SN)^2)} + (1-\omega) * \frac{\max(E(j) - E(j))}{\max(E(j))}, \omega \in [0,1] \quad (2)$$

3.2 Sink Mobility Strategy

To improve network performance and mitigate hot spot problem, we study the sink mobility strategies for sensor networks. The entire sensor network consists of one mobile sink node and a large number of sensor nodes, which are static after being deployed. In our paper, we first study the random movement of the sink node. The mobile sink node initially locates in the centre of the network and then moves to different locations at each round. Then the mobile sink node moves at a certain speed along a predefined movement path and sojourn at some predefined locations to collect fused data packets from CHs.

To effectively gather data packets, CHs will be chosen from all sensor nodes based on the uneven clustering algorithm, as small blue dots in Figure 1. Each sensor node will generate 1-bits data packets and need to participate in the CHs competition. CHs will aggregate data packets from their member nodes and forward fused data packets to the mobile sink node. The sink movement path is predefined in the sensor network and several sojourn positions are also predefined in the movement path, as the gray line and the small black square in Figure 1.

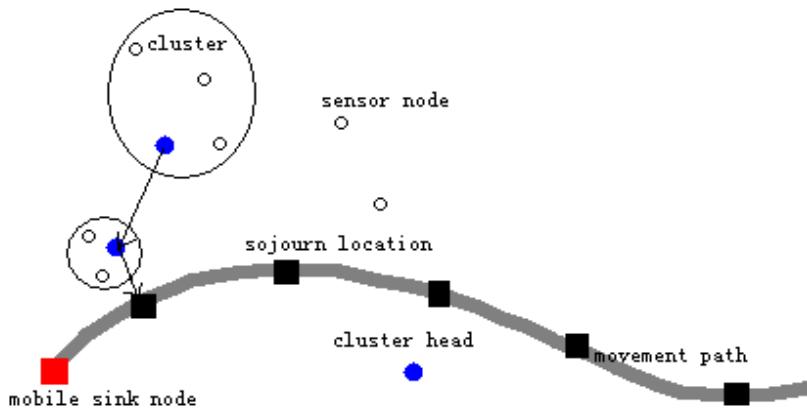


Figure 1. Network Model

Thus, CHs can find the optimal sojourn position of the mobile sink node. Thus when the mobile sink node moves to the communication range, CHs will transmit their fused data packets and send a message including its ID, residual energy and the position to

the mobile sink node. If cluster head C_i choose the sojourn position P_i as its destination, the cluster head C_i is taken as the neighbor of the position P_i . Once the mobile sink node reaches the predefined sojourn position, it will broadcast an arrival message to its neighbors. Then neighbor CHs will forward their fused data packets within sojourn time. The mobile sink node will move along the predefined path back and forth to collect data packets.

4. Performance Evaluation

4.1 Simulation Environment

We use MATLAB simulator to evaluate the network performance. Some relevant simulation parameters are listed in Table 1, where 100 sensor nodes with the same initial energy are distributed randomly and each of them will generate 2000-bits data packets.

Table 1. Simulation parameters

Parameter	Definition	Unit
A	Area of sensor network	$100 \times 100 m^2$
N	Total number of sensor nodes	100
E_0	Initial energy of sensor nodes	2J
E_{elec}	Energy dissipation to run the radio device	50 nJ/bit
\mathcal{E}_{fs}	Free space model of transmitter amplifier	10 pJ/bit/m ²
\mathcal{E}_{mp}	Multi-path model of transmitter amplifier	0.0013 pJ/bit/m ⁴
l	Packet length	2000 bits

4.2 Performance Analysis

In multi-hop uneven hierarchical routing protocol (MUHRP), each sensor node needs to participate in competition for CHs, which are chosen mainly based on competition range and residual energy. To analyze network performance, we compare the energy consumed by the uneven hierarchical routing protocol and LEACH, as shown in Figure 2. We can observe that LEACH consumed more energy than MUHRP. Thus CHs will be selected based on the uneven hierarchical routing protocol.

However, due to the sink node is static, CHs near SN will carry heavier traffic loads and run out of their energy rapidly, causing hot-spot problem. Thus, we study MUHRP using a mobile sink node. The sink node moves randomly or along a predefined fixed path. We first study the random movement of the sink node. We assume it moves at a certain step length and a random angle. The step length is assigned to 15 meters. The sink node will randomly move to a new location in each round. Figure 2 shows the total residual energy of the network from 20 to 35 rounds. We can observe that performance of the network using the random mobile sink node is superior to the others using a fixed sink node.

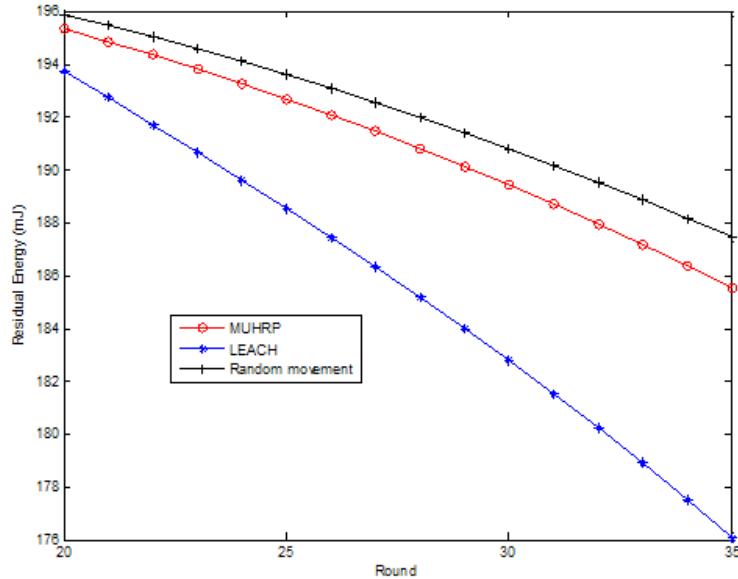


Figure 2. Residual Energy Comparison

Then we predefine a movement path in the sensor network and the mobile sink moves at a certain speed along this movement path and sojourn at some scheduled positions to collect fused data packets from CHs. The distance between sojourn positions is equal and is briefly assigned to 10 meters. Figure 3 shows the residual energy of the three sink placement strategies from 50 to 100 rounds. We can observe that mobile SN can save much energy than fixed SN. Mobile SN moving along a predefined path can conserve more energy than random movement. Thus, we can conclude that MUHRP using a controlled mobile SN can largely reduce energy consumption.

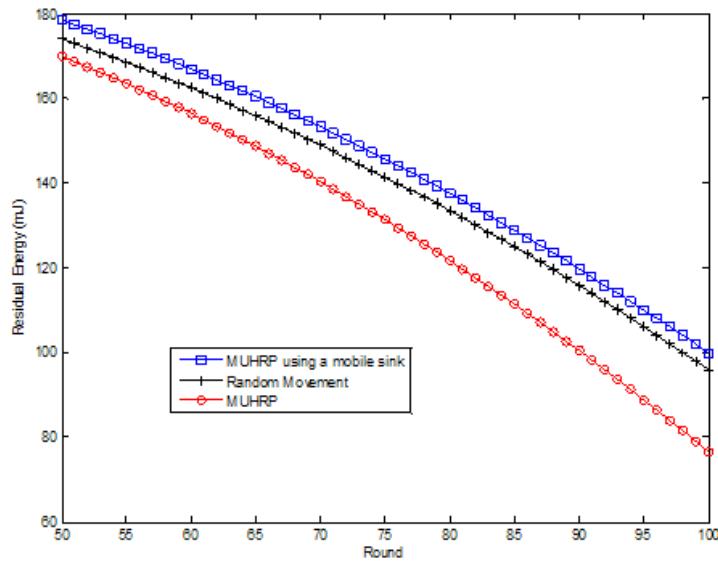


Figure 3. Energy Consumption

The network lifetime of the four strategies is shown in Figure 4. Here, we define the network lifetime as the time when the first node depletes its energy. The initial energy sensor node is 0.5 Joule to reduce simulation time. From Figure 4, we can see that the other three routing protocol are more conducive to the network lifetime prolongation. The first dead node of the four routing protocols respectively appears in the 30, 89, 96 and 99 rounds. MUHRP using a mobile sink node prolong the network lifetime to a certain extent.

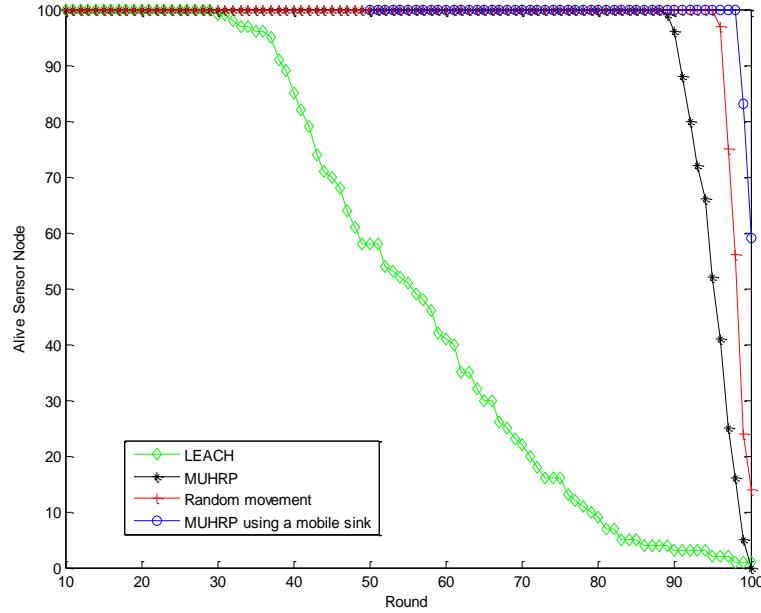


Figure 4. Network Lifetime Comparison

5. Conclusions

In this paper, we study the multi-hop uneven hierarchical routing protocol with a fixed sink node and a mobile sink node respectively and analyze their performance, such as the energy consumption and the network lifetime. Simulation results show that multi-hop uneven hierarchical routing protocol using a mobile sink node can largely improve energy efficiency and extend network lifetime compared with those protocols using a fixed sink node. Besides, sink node moving along a predefined path can conserve more energy than when it moves randomly. However, we have made several assumptions throughout the paper. All the above experiments are conducted in an ideal environment. How to possibly relax certain assumptions we made become further future work. And how to achieve the trade-off between a high network lifetime and a low data transfer delay also need further research.

Acknowledgements

This research was supported by the National Natural Science Foundation of China (41275116). Dr. Chuanyang Yin is the corresponding author.

References

- [1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "Wireless sensor networks: a survey", Computer Networks, vol. 38, no. 4, (2002).
- [2] K. Akkaya and M. Younis, "A survey on routing protocols in wireless sensor networks", in the Elsevier Ad Hoc Network, vol. 3, no. 3, (2005).
- [3] W. R. Heinzelman, A. Chandrakasan and H. Balakishnan, "Energy-efficient communication protocol for wireless microsensor networks", Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, (2002).
- [4] B. Gong, L. Li, S. Wang and X. Zhou, "Multihop routing protocol with unequal clustering for wireless sensor networks", ISECS International Colloquium on Communication, Control, and Management, (2008).
- [5] G. Chen, C. Li, M. Ye and J. Wu, "An unequal cluster-based routing protocol in wireless sensor networks", Wireless Networks, vol. 15, no. 2, (2009).
- [6] R. C. Shah, S. Roy, S. Jain and W. Brunette, "Data MULEs: modeling a three-tier architecture for sparse sensor networks", Proceedings of the First IEEE.2003 IEEE International Workshop on Sensor Network Protocols and Applications (SNPA), (2003).
- [7] J. Luo and J. P. Hubaux, "Joint mobility and routing for lifetime elongation in wireless sensor networks", Proceeding of the 24th Annual Joint Conference of the IEEE Computer and Communications Societies, (2005).
- [8] A. A. Somasundara, A. Kansal, D. D. Jea, D. Estrin and M. B. Srivastava, "Controllably mobile infrastructure for low energy embedded networks", IEEE Transaction on Mobile Computing, vol. 5, no. 8, (2006).
- [9] J. Rao and S. Biswas, "Data harvesting in sensor networks using mobile sinks", IEEE Wireless Communications, vol. 15, no. 6, (2008).
- [10] Y. Shi and Y. T. Hou, "Theoretical results on base station movement problem for sensor network", Proceeding of the 27th Conference on Computer Communications (INFOCOM), (2009).
- [11] B. Nazir and H. Hasbullah, "Mobile sink based routing protocol (MSRP) for prolonging network lifetime in clustered wireless sensor network", Int'l Conference on Computer Applications and Industrial Electronics, (2010).
- [12] S. Gao, H. Zhang and S. K. Das, "Efficient data collection in wireless sensor networks with path-constrained mobile sinks", IEEE Transactions on Mobile Computing, vol. 10, no. 4, (2011).
- [13] M. I. Khan, W. N. Gansterer and G. Haring, "Static vs. Mobile sink: the influence of basic parameters on energy efficiency in wireless sensor networks", Computer Communications, (2012).

Authors



Feng Ruan Lecturer at Nanjing University of Information Science & Technology. He received the B.S. and M.S. degree in the Nanjing University of Information Science & Technology. Now he is PHD student in Computer Science Department of Nanjing University of Information Science & Technology. His research interests mainly include complex system, computer network, routing protocol and algorithm design, data mining, cloud computing.



Chuanyang Yin Lecturer at Nanjing University of Information Science & Technology. Received his Ph.D. degree in 2008 from University of Science & Technology of China. His main research interests include nonlinear science, complex systems and routing protocol on complex networks.



Jinhuai Chen Associate professor and master tutor at the College of Information and Control, Nanjing University of Information Science & Technology. She received her master degree from Nanjing University of Information Science & Technology in 1999. Her research interest covers data mining and cloud computing.



Ning Ma Lecturer at the College of Meteorology and Oceanography, PLA University of Science and Technology. He received his master degree from PLA University of Science and Technology in 2002. Now he is a Ph. D. candidate at the Laboratory of Image Science and Technology, School of Computer Science and Engineering, Southeast University. His research interest covers image processing and pattern recognition.



Shengjun Xue Professor in the Computer and Software Institute, Nanjing University of Information Science and technology. He received his B.S degree in Computer Science and Technology at the College of the Zhejiang University in 1983, and PHD in Huhan University of Science and Technology in 2002. Purdue University in Indiana, postdoctoral in 2007 and 2008. His research interest covers computer network, intelligent traffic, cloud computing, application in meteorology.

