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Removing the Energy Hole Problem in Wireless Sensor Networks

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Abstract

Users employ wireless sensor networks (WSNs) to monitor various environments. Since nodes in WSNs are usually powered by batteries, which can not be charged or replaced in most cases. In order to let the network operate as long as possible, the energy consumption of nodes in the network should be reduced and balanced. Since data transmission in WSNs adopts a many-to-one mode, the nodes close to the base station deplete their energy more quickly, which results in energy hole. After the energy hole appears, the data from some parts of the observation area can not be transmitted to the base station. In this paper, we classify the approaches to address the energy hole problem and then describe the classical applications in each category.

Keywords

Wireless sensor network, energy hole, energy consumption.

1. Introduction

Recently, wireless sensor networks has been widely used in smart agriculture, smart city and intelligent medical to sense and collect data from various environments[1,2,3,4]. Usually, a wireless sensor network consists of a many tiny nodes, which are able to communicate with each other. Since these nodes are powered by batteries and often are not easy to replace their batteries, it is necessary to prolong the network lifetime by reducing and balancing the energy consumption of nodes.

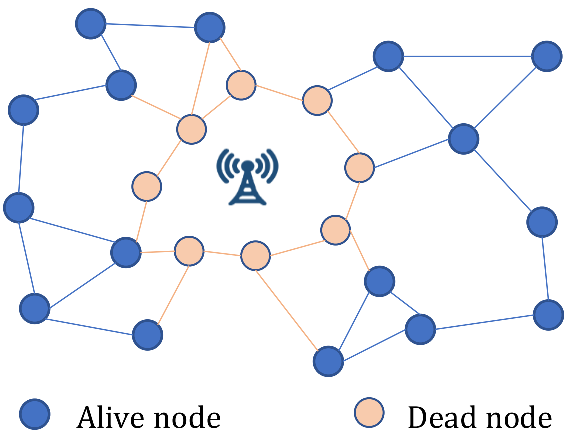

Figure 1: Energy hole problem in wireless sensor networks

Because of the short transmission radius of nodes, the nodes which have long distance to the base station have to use multihop method to send data to the base station. Therefore, the nodes close to the base station have to relay more data than the other nodes, and those nodes deplete their energy more quickly, and then, energy hole appeares. After the energy hole is created, the sensor data from some parts or the whole observation area can not be sent to the base station,

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which shortens the network lifetime although the majority of nodes have not yet become dead. Figure 1 shows the energy hole problem caused by the batteries' depletion of nodes within the base station coverage. Thus, it is necessary to raise approaches to remove the energy hole problem in WSNs. In this paper, we first classify the approaches to overcome the energy hole problem into several categories in Section 2. Then, we discuss the typical applications in each category in Section 3. In the end, we conclude this paper in Section 4.

2. Classification of Removing Energy Hole Approaches

The techniques to remove the energy hole problems in wireless sensor networks can be classified into several categories as follows:

The first method is adaptive cluster head selection. In this method, the network are partitioned into several clusters. In each cluster, one node is selected out as cluster head, and the other nodes are regarded as cluster members. In the sensor data retrieval phase, cluster head receive all the data from the cluster members in the local cluster and then send these data to the base station with single or multi hop routing method. Since the energy load of cluster heads is more heavier than other nodes, the cluster heads deplete their energy more quickly. To balance the energy consumption among nodes, adaptive cluster head selection is utilized.

Using mobile sink nodes (small base stations) is another good method to remove energy hole problem. Because of heavier relay data task of nodes in the sites near to the base station, those nodes depelete their energy more quickly. If the sink node is mobile, and can move from one place to another, the energy load among nodes can be balanced.

Adaptive distribution of nodes is the effective method. In the WSNs, the nodes near to the base station have much heavier energy load than the other nodes. Then, we can deploy more nodes in the sites near to the base station, and then, the energy load of nodes can be lessened. Figure 2 illustrates the category of removing energy hole problem schemes.

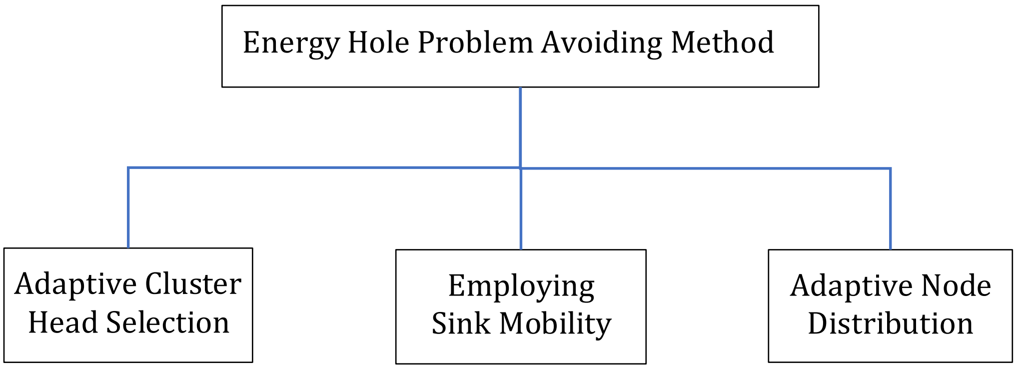

Figure 2: Methods to remove the energy hole problem

3. Typical Applications

In this section, we discuss the typical applications used to migrate the energy hole problem in wireless sensor networks in detail.

3.1. Adaptive Cluster Head Selection

To balnace the energy load of cluster head role in wireless sensor networks, various methods have been proposed. In LEACH [5], the node clustering is performed at every round, and then, every node has the same probability to become the cluster head. Hence, the energy load among nodes can be kept balanced. Its drawback is that the re-clustering cost is very high.

The operation in Modified LEACH [6] is divided into three phases: In set-up phase, all the nodes transmit their location and initial energy information to the base station. The nodes which have more residual energy and are closer to the base station are chosen as cluster heads. The base station chooses the next cluster head for each cluster based on the pre-set threshold and the nodes having more energy than the threshold is picked out as the next cluster heads. Then, the base station broadcasts the cluster head ID to the network. In the steady state phase, the base station checks the remaining energy of the current cluster heads. If the remaining energy of the cluster head remains more than the pre-defined threshold, the current cluster head will continue its role during the next round. If the remaining energy of the current cluster head is less than the threshold, the next cluster head having more energy than the threshold will be chosen as the cluster head. The above process is repeated until there are no nodes that have the residual energy above the threshold, and then, the re-clustering phase is incurred.

Researchers in [7] proposed IEEHCS protocol. In this protocol, cluster heads in the network are chosen by the base station according to node energy, node density and minimum separation distance. After that, the cluster head role is repeated in the same node or shifted to another node instead of re-clustering the whole network at every round in LEACH.

FSC protocol is suggested in [8], and the whole network is divided into several layers. In each layer, many clusters with the same size are formed. During the network runtime, cluster head role is rotated among the nodes in the same cluster. If all the nodes have no ability to serve as the cluster heads, re-clustering is incurred. What's more, the re-clustering is performed is within one layer not the whole network. Thus, the energy load among nodes is balanced, and the overhead is shrinked.

3.2. Employing Sink Mobility

Researchers in [9] have proven that selecting the optimal moving positions for mobile sink nodes is an NP-hard problem, and they also raise a heuristic algorithm to decide the moving directions and distances. In the above protocol, authors proposed a mobile sink moving strategy, in which sink node should move to the position where nodes generate more sensor data, and it also move only when it detects an unacceptable performance.

Authors in [10] proposed a half-quadrant-based moving strategy (HUMS) for the mobile sink. In the proposed strategy, each node in the network first discovers its neighboring nodes. Then, the network begins to collect sensor data periodically. Each sensor data retrieval period can be divided into three phases. Sink node in the first phase is to broadcast its position information to the neighboring nodes. In the second phase, nodes in the network report their data to the sink node with location-based routing algorithm, and sink node stays on and collects data from the neighboring nodes. In the last phase, sink node moves to the new position before the next data retrieval period begins and the nodes in the network can be kept sleep.

Researchers propose Dual-Sink protocol [11] in WSNs. One is the static sink, which broadcasts its location information to the whole network once after network initialization. The other is the mobile sink node. When the mobile sink arrives at a new position, it broadcasts a notification to a subset of nodes in the network. Then, it will be ready to receive data. When it completes all the data, it will move to the new position.

3.3. Adaptive Node Distribution

Researchers in [12] first explored the theoretical aspects of the non-uniform node distribution strategy which addresses the energy hole problem in wireless sensor networks. Then, the authors find that it is impossible to achieve a balanced energy depletion among all the nodes due to the data transmission pattern of wireless sensor networks. Nevertheless, They propose a node distribution strategy to help the energy efficiency reach a high level. The main idea is that the density of nodes in the site near to the sink node shoud has higher node density considering that those nodes not only forward the data generated by the nodes far away from the sink nodes but also send the data generated by themselves. Different sites have different number of nodes depending on their distance to the sink node.

Authors in [13] suggest a Gaussian deployment strategy for the WSN where the sink node is located in the center and all nodes are homogeneous. The proposed strategy can be divided into two main topology, i.e., random Gaussian and engineered Gaussian. The random Gaussian node distribution pattern is like the effect of a shell that is exploded and it also has the pre-defined probability density function for sensor positions in polar coordinates within a distance R from the base station. The density of sensor nodes in engineered Gaussian increases from outer to inner corona according to the traffic load.

In [14], researchers raise a novel non-uniform node deployment method so as to achieve a balanced energy consumption among nodes in the network. In each corona, they set the number of nodes and derived the ratio between ith coronas and the node densities within the adjacent (i + 1)th for energy holes problem.

4. Conclusion

In this paper, various techniques were discussed to remove the energy hole problem in the WSN. We illustrated a general classification of existing energy hole removal schemes, and it can be classified into three categories: adaptive cluster head selection, employing sink mobility and adaptive node distribution. Furthermore, we present the typical applications in each category.

References

[1] Hou, S. Tan, Z. Zhang and N. W. Bergmann: Thermal Energy Harvesting WSNs Node for Temperature Monitoring in IIoT, IEEE Access, Vol. 6 (2018), p. 35243-35249.

[2] A. Mehmood, Z. Lv, J. Lloret and M. M. Umar: ELDC: An Artificial Neural Network Based Energy-Efficient and Robust Routing Scheme for Pollution Monitoring in WSNs, IEEE Transactions on Emerging Topics in Computing, Vol. 8 (2020) No. 1, p. 106-114.

[3] W. Sun, X. Yuan, J. Wang, Q. Li, L. Chen and D. Mu: End-to-End Data Delivery Reliability Model for Estimating and Optimizing the Link Quality of Industrial WSNs, IEEE Transactions on Automation Science and Engineering, Vol. 15 (2018) No. 3, p. 1127-1137.

[4] X. Liu, J. Cao, W. -Z. Song, P. Guo and Z. He: Distributed Sensing for High-Quality Structural Health Monitoring Using WSNs, IEEE Transactions on Parallel and Distributed Systems, Vol. 26 (2015) No. 3, p. 738-747.

[5] W. B. Heinzelman, A. P. Chandrakasan and H. Balakrishnan: An application-specific protocol architecture for wireless microsensor networks, IEEE Transactions on Wireless Communications, vol. 1 (2002), no. 4, p. 660-670.

[6] V. K. Subhashree, C. Tharini and M. Swarna Lakshmi: Modified LEACH: A QoS-aware clustering algorithm for Wireless Sensor Networks, 2014 International Conference on Communication and Network Technologies, (2014), p. 119-123

[7] A. Patra and S. Chouhanz: An approach to improved energy efficient hybrid clustering in wireless sensor networks, 2014 International Conference on Signal Processing and Communications, (2014), p. 1-6.

[8] H. Lin, L. Wang and R. Kong: Energy Efficient Clustering Protocol for Large-Scale Sensor Networks, IEEE Sensors Journal, Vol. 15 (2015) No. 12, p. 7150-7160.

[9] K. Akkaya, M. Younis, and M. Bangad: Sink repositioning for enhanced performance in wireless sensor networks, Computer Networks, Vol. 49 (2005) No. 4, p. 512–534.

[10] Bi, Y., Sun, L., Ma, J. et al. HUMS: An Autonomous Moving Strategy for Mobile Sinks in Data-Gathering Sensor Networks. Journal of Wireless Communication Network, (2007), p.1-15.

ISSN: 2664-9640

[11] X. Wu and G. Chen: Dual-Sink: Using Mobile and Static Sinks for Lifetime Improvement in Wireless Sensor Networks, 16th International Conference on Computer Communications and Networks, (2007), p. 1297-1302.

[12] X. Wu, G. Chen and S. K. Das: On the Energy Hole Problem of Nonuniform Node Distribution in Wireless Sensor Networks, IEEE International Conference on Mobile Ad Hoc and Sensor Systems, (2006), p. 180-187.

[13] Atiq-Ur-Rahman, H. Hasbullah and Najm-us-Sama: Impact of Gaussian deployment strategies on the performance of wireless sensor network, 2012 International Conference on Computer & Information Science (ICCIS), (2012), p. 771-776.

[14] Xiaobing, W., Guihai, C., & Das, S. K.: Avoiding energy holes in wireless sensor networks with nonuniform node distribution. IEEE Transactions on Parallel and Distributed Systems, Vol.19 (2008) No.5, p.710–720.