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Optimizing the Energy Efficiency of Wireless Sensor Networks with Intelligent Clustering Protocols

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Abstract

With the advances in sensor and wireless communication technology, wireless sensor networks (WSNs) have been widely used in various fields, such as military, environmental monitoring, smart city and smart agriculture, to sense and obtain data. A WSN usually consists of a number of sensor nodes that have limited computational, storage, and especially energy resources. In many cases, it is very difficult to change the power unit of the sensor node, and thus, when nodes deplete their energy, the network can not operate anymore. To address the above issue, many techniques have been proposed for energy saving, and clustering protocol has become one of the most promising techniques to improve the energy efficiency of WSNs. In this paper, we first present the classification of clustering protocols, and then, discuss how these existing protocols work in order to increase the network lifetime in each category.

Keywords

Wireless Sensor Network, Clustering Protocol, Energy Efficiency.

1. Introduction

In recent years, wireless sensor networks (WSNs) have become one of the basic components of Internet of Things (IoT) [1]. When a sensor node detects the environmental changes, it will produce an event message, and transmit this message to the end-users through the relay transmission of sensor nodes and the base station (BS). A simplified scenario of a wireless sensor network is shown in Figure 1. Generally, WSN consists of a number of sensor nodes, which have limited computational, storage, and energy resources. In particular, when nodes in the network deplete their energy, it is possible to change their power unit in many cases. Therefore, it is necessary to develop energy-efficient clustering protocols to prolong the lifetime of the network.

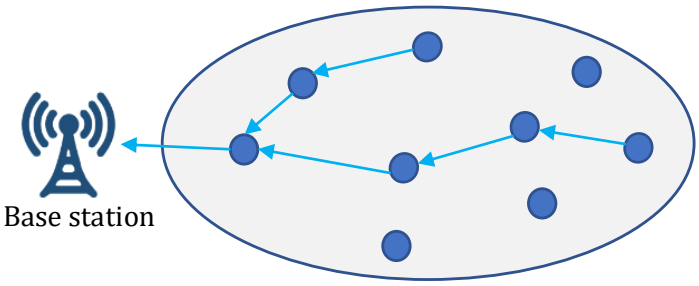

Figure 1. Sample scenario of wireless sensor network

Various techniques [2-4] have been proposed to improve the energy efficiency of wireless sensor network. Compressive sensing [2] employs time correlation of nodes and space correlation among nodes to reduce the number of messages transmitted to the BS, and thus, the lifetime of the network is increased. With the help of TDMA (time-division multiple access) MAC

protocols [3], the nodes having no data to transmit in some period can be kept in sleep state, and therefore, the energy consumption can be greatly reduced. In clustering protocols [4], the nodes which have short distances from each other form a cluster, since the above clustering structure has the advantages of bandwidth reuse and good resource allocation, it greatly improves the network power control. Among the above energy-saving techniques, clustering protocols have become one of the most promising protocols used in wireless sensor networks.

In this paper, we focus on the typical techniques to optimize the energy efficiency of networks in clustering protocols. In Section 2, we classify the clustering protocols into two categories: distributed clustering and centralized clustering. Then, representative methods in each category to raise the energy efficiency of the network are presented in Section 3. We conclude this paper in Section 4.

2. Classification of Clustering Protocols

In clustering protocols, based on different ways of node clustering strategies, the clustering protocols can be classified as centralized clustering [ ] and distributed clustering [ ]. As for the centralized clustering protocols, there exists a powerful node that is responsible to run classical clustering algorithms. Different from the centralized clustering algorithms, in the distributed clustering protocols, the clustering algorithms are performed in a fully distributed way, and each node only performs a fraction of the algorithm.

According to the network size, centralized clustering can be furtherly classifed as centralized clustering with one-hop network [11,12] and centralized clustering with multi-hop network [13,14]. Similarly, distributed clustering can be categorized as distributed clustering with one-hop network [5,6] and distributed clustering with multi-hop network [8,9]. The classification of clustering protocols is shown in Figure 2. In one-hop network, when the cluster head (CH) collects data from its cluster members, it directly sends this data to the BS. In multi-hop network, after the CH aggerates data from the cluster members, it will transmit the data to the BS with multi-hop routing algorithm.

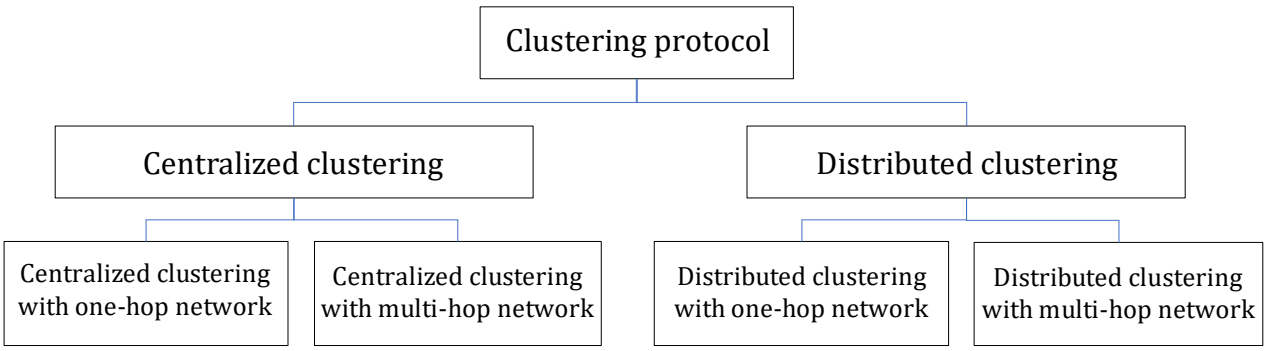

Figure 2. Classification of clustering protocols in wireless sensor network

3. Distributed Clustering Strategy

3.1. Distributed clustering with one-hop network

LEACH [5] is the pioneering clustering protocol used in WSNs to extend the lifetime of the network. In each round, LEACH performs self-organizing and re-clustering functions, and the nodes with short distances organize themselves into clusters. In every cluster, one of the nodes is selected as a CH and other nodes are regarded as cluster members. In the sensor data retrieval, only CH can communicate with the BS directly. Cluster members use CH as the relay to communicate with BS. CH collects, aggregates and collects the data from cluster members and sends the aggerated information to the BS. Due to these additional responsibilities, CH

dissipates more energy than other nodes and if it remains CH permanently, To address the above issue, LEACH rotates the role of CHs among nodes. In this way, LEACH maximizes the lifetime of nodes in the network and also reduces the energy dissipation by compressing the data before transmitting it to the BS.

In order to avoid the fluctuation of cluster number in LEACH, researchers in [6] proposed LEACH-B, which suggests an extension of LEACH by finding the optimal number of CHs. The work of LEACH-B is almost the same as LEACH by choosing a random number between 0 and 1 and then calculating the threshold value. Nevertheless, LEACH-B employs another selection stage: All candidate CHs, which are selected, will be ordered descendingly based on their residual energy, and only ($\alpha \cdot N$) of them (where α denotes the percentage of CHs, and N is the total number of nodes) will be considered as CH and the rest candidate will resume their cluster member role. By doing this, LEACH-B can guarantee the optimal number of CHs.

The protocol of PEGASIS [7] is another routing scheme for WSNs. PEGASIS does not form clusters but forms a chain from nodes into the BS. Every node runs a greedy algorithm so as to form a chain. Each node sends its event information to a nearby neighbor which is in the chain. In the end, all data are aggregated in one node and only one node transmits the aggregated data to the BS by using a long-distance transmission. PEGASIS saves the clustering overhead but it introduces the chain shaping overhead. Furthermore, it needs multi-hop data transmission from nodes into the BS which results in the problem of the long response time of queries.

3.2. Distributed clustering with multi-hop network

Based on the radio energy model, when the distances between CHs and the BS are longer than a certain threshold, the energy consumption of the CHs is directly proportional to the fourth power of their distances. Thus, in large observation area and far distance between CHs and the BS, CHs dissipate too much energy and become dead very quickly. LEACH protocol can not be used for the above situation. The energy efficiency of the above mentioned network is improved by utilizing multi-hop LEACH routing protocol [8], which employ multi-hop communication between CHs and the BS. In the set-up phase, the operation of multi-hop LEACH protocol is similar to that of LEACH protocol, and the operations in both protocols are performed in a completely distributed way. In the steady state phase, the CHs which have short distances to the BS transmit their data to the BS directly, and the CHs which have long distances to the BS use the CHs near to the BS as relay nodes to transmit their data to the BS.

LEACH-1R [9] aims to extend the lifetime of multi-hop WSNs. In this protocol, the CH does not change at every round, and the CH only changes when it runs out of the energy. When the energy level of the current CH goes below the predefined threshold, it will select the strongest received signal node as the CH and then send the new CH message to that node. After receiving the new CH message, the node transmits the CH message to all its neighbors, and this message contains the CH id, positional information and remaining energy.

DL-LEACH [10] protocol removes the limitation of LEACH which is incurred by two-hop transmission distance structure by utilizing two layers of multi-hop routing scheme. The nodes which have shorter distance to the BS reside in the lower layer. In DL-LEACH, the CH selection process is similar to LEACH, and then the whole network is divided into several layers. In the sensor data retrieval phase, the lower layer nodes compare their distances from the CH and the BS. These nodes directly send their data to the BS if the distance is shorter than to the CH, or else it transmits the data with the relay of the other CHs. This protocol has achieved a great improvement in energy consumption of the network compared to LEACH but the drawback is short node lifespan in large-scale networks.

4. Centralized Clustering Strategy

4.1. Centralized clustering with one-hop network

Unlike LEACH, in which nodes configure themselves into clusters, LEACH-C is a centralized protocol [5] where all decisions, including CH selection and cluster formation, are performed by the BS. During the setup phase of LEACH-C, the BS receives information regarding the position and energy level of each node in the network, and thus, the BS in LEACH-C can produce optimal clusters by scattering the CH throughout the sensor network. In LEACH-C, because the complete process is fully managed by the BS, the network performance in terms of energy efficient is greatly improved compared to LEACH. To obtain positional information of nodes, each node requires GPS and must transmit its status information periodically, consuming much energy.

In sLEACH [11], CHs are selected via BS with the help of an optimized centralized control algorithm. BS usually selects solar powered nodes by maximizing residual energy. Authors improve the CH selection algorithm by utilizing LEACH-C. In sLEACH nodes send their solar status and the remaining energy to the BS and nodes with higher energy levels will be chosen as CH. Lifetime of wireless sensor network is increased when the number of solar-aware nodes rises. Moreover, the lifetime of network relies on sunshine duration.

Two fuzzy Logic algorithms are introduced in FL-LEACH [12] to optimize the energy consumption of nodes in WSNs. In both of the above algorithms, CHs are selected in the BS by employing fuzzy logic theories and then the election results are broadcasted to all the nodes in the network. One algorithm of FL-LEACH utilizes nodes' centrality, nodes' density, and nodes' residual energy as their algorithms' inputs. In the other algorithm, the factors, i.e. the distance of nodes from the sink, nodes' density, and nodes' residual energy, are regarded as the input of the algorithm. Both of these algorithms outperformed the basic LEACH algorithm in terms of energy efficiency.

4.2. Centralized clustering with multi-hop network

BCDCP [13] utilizes the powerful BS to calculate optimal clusters and routing paths, perform randomized rotation of CHs, and carry out other energy-intensive tasks. The main ideas in BCDCP are the formation of balanced clusters where each CH serves an approximately equal number of cluster members to avoid CH overload, uniform distribution of CHs throughout the whole observation area, and utilization of CH-to-CH routing to send the data to the BS. Based on the simulation results, BCDCP enhances the network performance compared with other existing clustering protocols.

Researchers in [14] proposed a centralized evolutionary clustering protocol, called WST-LEACH, for WSNs. The proposed protocol chooses the proper nodes as CHs based on the three criteria that greatly affect the network lifetime. Firstly, the remaining energy level of the candidate node must be higher than the average energy level of the nodes in the network. Secondly, a graph between the nodes which are within the radio communication range of each other is constructed. Energy edge of this graph is assigned a weight. Then, the Sum of Weights for Edges (SWE) connected to each node is calculated. SWE must be maximized for a node so that it could be considered as a proper candidate for being CH. Lastly, the node can not be an outlier. This proposed algorithm can be used to search in a complicated search space and select optimum CHs. Furthermore, the authors have proven that the proposed protocol has significantly improved the performance in terms of the number of nodes alive and the total residual energy through simulations.

Optimized Lifetime Enhancement (OLE) [15] is a centralized algorithm that forms a chain from nodes into the BS. Every node transmits the sensed event information to a nearby node that is in the chain. Different from the greedy algorithm used in PEGASIS, OLE utilized a particle-

swarm-optimization heuristic. OLE allows nodes to communicate with the BS directly a different number of times according to their remaining energy. OLE is executed by the BS and then the results are broadcasted to the network before starting the stable phase. However, in case of nodes' unfrequent communications with the BS, it can also be executed in individual clusters by a local leader and the local information can be transmitted to the BS in order to shape the optimized chain. The performance improvement of the suggested algorithm is validated through experiments.

5. Conclusion

Wireless sensor network is the critical component of the Internet of Thing (IoT), However, due to the limited energy resources of sensor nodes networks, designing energy-efficient routing protocols is necessary to prolong the lifetime of wireless sensor networks. Among existing energy-saving protocols, clustering protocol has become a widely used method to improve the energy efficiency of WSNs. In this paper, we first classified the current clustering protocols into different categories according to the way of node clustering. Then, we present the various techniques of the classical clustering protocols in each category to improve the network performance in terms of energy efficiency.

References

[1] T. D. Nguyen, J. Y. Khan and D. T. Ngo: A Distributed Energy-Harvesting-Aware Routing Algorithm for Heterogeneous IoT Networks, IEEE Transactions on Green Communications and Networking, Vol. 2 (2018), No. 4 p. 1115-1127.

[2] M. C. Vuran and I. F. Akyildiz: Spatial correlation-based collaborative medium access control in wireless sensor networks, IEEE/ACM Transcation on Network, Vol. 14 (2006) No. 2, p. 316-329.

[3] L. Shi and A. O. Fapojuwo: TDMA Scheduling with Optimized Energy Efficiency and Minimum Delay in Clustered Wireless Sensor Networks, IEEE Transactions on Mobile Computing, Vol. 9 (2010) No. 7, p. 927-940.

[4] 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.

[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] M. Tong and M. Tang: LEACH-B: An Improved LEACH Protocol for Wireless Sensor Network, the 6th International Conference on Wireless Communications Networking and Mobile Computing (Chengdu, China, September 23-25, 2010), Vol.1 p.1.

[7] S. Lindsey and C. S. Raghavendra: PEGASIS: Power-efficient gathering in sensor information systems, IEEE Aerospace Conference (MT, USA, March 9-16, 2002) Vol.1p.3.

[8] Y. Lei, F. Shang, Z. Long, and Y. Ren: An energy efficient multiple-hop routing protocol for wireless sensor networks, Int. Conf. Intell. Netw. Intell. Syst. (Wuhan, China, November 1-3, 2008),Vol.1 p.147.

[9] M. Omari and W. H. Fateh: Enhancing multihop routing protocols in wireless sensor networks using LEACH-1R, World Symp. Web Appl. Netw. (Sousse, March 21-23, 2015), Vol.1 p.1.

[10] J. Y. Lee, K. D. Jung, S. J. Moon, and H. Y. Jeong: Improvement on LEACH protocol of a wide-area wireless sensor network, Multimedia Tools Appl., vol. 75 (2016), pp. 1-18.

[11] T. Voigt, A. Dunkels, J. Alonso, H. Ritter, and J. Schiller: Solar-aware clustering in wireless sensor networks, Int. Symp. Comput. Commun. (Alexandria, Egypt, June 28-July 1, 2004), p.238.

[12] F. Al-Maaqbeh, O. Banimelhem, E. Taqieddin, F. Awad, and M. Mowa: Fuzzy logic based energy efficient adaptive clustering protocol, Int. Conf. Inf. Commun. Syst.(Shanghai, China, May 5-8, 2012), Vol.1 p.156.

[13] Muruganathan S D , Ma D , Bhasin R I , et al: A Centralized Energy-Efficient Routing Protocol for Wireless Sensor Networks, IEEE Communications Magazine, Vol 43(2005), No(3), p.S8-13.

[14] H. Zhang, P. Chen, and S. Gong: Weighted spanning tree clustering routing algorithm based on LEACH, Int. Conf. Future Comput. Commun (Wuhan, China, April 3-5, 2010). Vol.1, p.120.

[15] A. Chakraborty, K. Chakraborty, S. K. Mitra and M. K. Naskar: An Optimized Lifetime Enhancement scheme for data gathering in wireless sensor networks, International Conference on Wireless Communication and Sensor Networks (Allahabad, India, 2009), Vol.1 p.1.