Cluster Routing Protocol for Coal Mine Wireless Sensor Network Based on 5G

Wei Chen[1], Xiao Yang[1], Weidong Fang[2](✉), Wuxiong Zhang[2], and Xiaorong Jiang[1]

[1] School of Computer Science and Technology, Mine Digitization Engineering Research Center of the Ministry of Education, China University of Mining and Technology, Xuzhou 221116, Jiangsu, China

[2] Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, Shanghai 201899, China

weidong.fang@mail.sim.ac.cn

Abstract. In coal mine, the routing protocol in Wireless Sensor Network (WSN) based on fog computing can effectively achieve combination the monitoring task with the computing task, and provide the correct data forwarding path to meet the requirements of the aggregation and transmission of sensed information. However, the energy efficiency is still taken into account, especially, the unbalance of energy consumption. 5G is a technical system of high frequency and low frequency mixing, with characteristics of large capacity, low energy consumption and low cost. With the formal freeze on 5G NSA standards, 5G networks are one step closer to our lives. In this paper, a centralized non-uniform clustering routing protocol based on the residual energy and communication cost. The protocol considers all nodes as candidate cluster heads in the clustering stage and defines a weight matrix P. The value of the matrix elements takes into account the residual energy of nodes and the cost of communication between nodes and cluster heads, selected as the basis for the cluster head. When selecting a cluster head, each time a node with the largest weight is selected from a set of candidate cluster heads, other candidate cluster heads within the competition range abandon competition, and then updates the candidate cluster head set. Experimental results show that the protocol optimized in this paper can effectively extend the network life cycle.

Keywords: Wireless sensor network · Cluster-based routing protocol · Non-uniform clustering · Multi-cluster-head cluster · 5G

1 Introduction

The deployment of wireless sensor network does not require basic infrastructure, Nodes can form a network in a self-organized manner instead of using linear circuits. which gives the wireless sensor network in mine monitoring a broad application space.

Wireless sensor network is a network that deployed by a large number of sensor nodes deployed in a certain area in an ad-hoc manner. The energy in the sensor node is provided by the battery. The wireless sensor network is generally deployed in the

V. C. M. Leung et al. (Eds.): 5GWN 2019, LNICST 278, pp. 60–67, 2019.
https://doi.org/10.1007/978-3-030-17513-9_5

unreachable area, so the sensor node cannot be replenished by replacing the battery. This makes the energy factor determine the life cycle of the wireless sensor network.

This paper proposes a centralized non-uniform clustering routing protocol based on the residual energy and communication cost based on the protocol proposed by Professor Li et al. [1]. This paper defines the weight matrix P, its element P[i, j] represents the node i as the weight of the cluster head node j. This paper also defines the weight of the node i is the sum of the row of the matrix P. When the nodes compete for the final cluster head, the node with the largest weight is selected as the optimal. The other nodes within the competition radius abandon the competition as ordinary nodes. This method has improved the life cycle of the network and reduced the residual energy variance of the nodes in the network.

2 Related Works

A Wireless Sensor Network (WSN) consists of enormous amount of sensor nodes. These sensor nodes sense the changes in physical parameters from the sensing range and forward the information to the sink nodes or the base station [2, 3]. Fog computing (FC) has received a great deal of attention in current period [4, 5]. FC can be viewed as an extension of cloud computing that services the edges of networks. Current research trends from areas [6–8], such as from Internet of Things and fog computing use sensors as the source of data [9–11]. Sharma, Suraj et al. [12] proposed a method which builds a routing path using each active grid head which leads to the sink. Data packets generated at any source node are routed directly through the data disseminating grid head nodes on the routing path to the sink. Li et al. [13] proposed a cooperative-based model for smart phone tasks. The rewards to each user with a smart sensor are distributed according to the region density. Lee et al. [14] presented a gateway based fog computing architecture for WSANs and argue that the key requirements of this architecture. This architecture mainly consists of master nodes and slave nodes, and manages virtual gateway functions, flows, and resources. Chakraborty et al. [15] presented the dynamic Fog, a high level programming model for time-sensitive applications that are geospatially distributed, large-scale, and latency sensitive. They analyzed the fog model with healthcare datum, more specifically with heart rate datum that is one of the most time-sensitive medical data which deals with life and death situations. Nunes et al. [16] anticipated the future by discussing a new generation of security and privacy mechanisms targeting specifically.

3 Clustering Routing Protocol

In this paper, the centralized unequal clustering routing protocol based on energy of node left and communication cost is an improvement of the protocol, which mainly improves in cluster head competition algorithm. The protocol considered the energy of node left when selecting the final cluster head, but the selection of the candidate cluster heads was random. While if candidate cluster heads selected do not contain higher residual energy, it is impossible to guarantee that the final cluster head has a higher residual energy, thus affecting the balance of energy consumption of the network. The Cluster Head Competition Algorithm proposed in this paper has made two improvements to the algorithm: ① all nodes were treated as candidate cluster heads. ② When selecting the final cluster head consider energy of node left and communication cost between member nodes and cluster heads. Multi-hop routing in clusters is the same as EEUC.

3.1 Cluster Head Competition Algorithm

The algorithm assumes that the node knows its own location. In the initialization phase after network deployment, all nodes and sink nodes communicate at once, and the nodes report their location and residual energy to the sink node. Cluster Head Selection Algorithm is performed by the sink node.

The Cluster Head Selection Algorithm proposed in this paper makes the following assumptions about wireless sensor networks:

(1) Each sensor node has unique ID, and all nodes are randomly distributed in the test area;
(2) After the node is deployed, it is location no longer changes and the energy cannot be replenished again. The location of the sink node has been fixed, with strong computing power and infinite energy.
(3) All nodes are homogeneous, that is to say, all nodes share the same computing power and communication capacity, and have the probability to be cluster head nodes or member nodes.
(4) The node has the ability to perceive position;
(5) Each node in the network collects data periodically and always has to send data;

The paper assumes that each node has data to send in each round, and the length of each data packet is constant. As a result, if the initial energy of sensor node is known the residual energy of sensor nodes based on clustering situation can be estimated.

Cluster Header Selection Algorithm is performed by the sink node. In Cluster Building Phase, sink node send clustering information to all the nodes in the network, clustering information includes whether the node is cluster head, and should also include the next-hop routing information of the node if it is, include it's cluster head nodes if not.

In Communication Phase, member nodes report the finish of data collection to cluster head node. The cluster head communicates with the sink node in a multi-hop method. The selection of the next hop routing node of the cluster head node is the same as that of propose protocol.

3.2 C-EEUC Protocol

Firstly, the paper analyzes the energy consumption of nodes in the protocol theoretically. The sensor node consists of four parts: sensor module, processor module, wireless communication module and energy supply module. Sensor modules and processor modules consume only a small amount of energy [17, 18]. The paper only considers the energy consumption of communication modules.

When the sensor node is sending data, the relation between energy consumption and communication distance of wireless communication is [19]:

$$E = kd^n \tag{1}$$

Where, d is the distance between the transmitting node and the receiving node, and the parameter n is the signal reduction factor, which generally is the real number ranges from 2 to 4.

Assuming that the model of free-space path consumption is adopted when the distance between two nodes is less than d_0, the model of multi-path fading is adopted when the distance is greater than d_0 [20], and d_0 is the distance, which is a constant variable, $d_0 = \sqrt{\varepsilon fs/\varepsilon mp}$, εfs is the energy consumption coefficient of power amplifier in the model of free-space path consumption, εmp is the energy consumption coefficient of power amplifier in the multi-path fading model.

When the sensor node is receiving data, the energy consumed by receiving data of k bit is as follows:

$$E = Eelec \times k \tag{2}$$

Where, $Eelec$ is the energy consumed by accepting one digit of data in the receiver circuit.

4 Experimental Simulation

4.1 Network Model

In order to compare the EEUC protocol with the protocol proposed in this paper, two sets of experiments are carried out in this paper. In the first experiment, 100 wireless sensor nodes are randomly deployed in the region. Suppose the coordinates of the lower left corner of the region are (0, 0) and the coordinates of the sink node are (150, 50). In the second experiment, 200 wireless sensor nodes are randomly deployed in the 200 * 200 region. Suppose the coordinates of the lower left corner of the region are (0, 0) and the coordinates of the sink node are (250, 100). In reference [1], the network performance is optimal when T = 0.4, $R_c^0 = 90$ and c = 0.5. Therefore, we initiate the parameters in the same way. The value of p in the LEACH protocol is 0.03. The influence of R_c^0 and c on the network performance in C-EEUC protocol is the next research goal of this topic. In this paper, the experimental parameters are chosen as the experimental contrast. We use MATLAB as the experiment platform.

4.2 Simulation Experimental Parameters

The experimental parameters of first group are shown in Table 1.

Table 1. Parameters in the first group experiments

Network parameters	Value
Range	(0, 0) to (100, 100)
Number of sensor nodes	100
Coordinates of sink node	(150, 50)
Node initial energy	0.5 J
Packet length	4000 bit
Eelec	50 nJ/bit
EDA	5 nJ/bit
Efs	10 pJ/(bit * m^2)
Emp	0.0013 pJ(bit * m^4)

The experimental parameters of second group are shown in Table 2.

Table 2. Parameters in the second group experiments

Network parameters	Value
Range	(0, 0) to (200, 200)
Number of sensor nodes	200
Coordinates of sink node	(250, 100)
Node initial energy	0.5 J
Packet length	4000 bit
Eelec	50 nJ/bit
EDA	5 nJ/bit
Efs	10 pJ/(bit * m^2)
Emp	0.0013 pJ(bit * m^4)

4.3 Experiment Results

In this paper, we compare LEACH protocol, EEUC and C-EEUC from three aspects: network life cycle, network energy consumption and node residual energy variance. Experiment results show that the proposed C-EEUC protocol is better than LEACH and EEUC in these three aspects. Define the time when the first sensor node is dead as the life time of the network.

Figure 1 shows the LEACH, EEUC and the number of rounds-remaining nodes of the algorithm proposed in this paper under the condition that 100 nodes are randomly arranged in the network coverage of 100 m * 100 m.

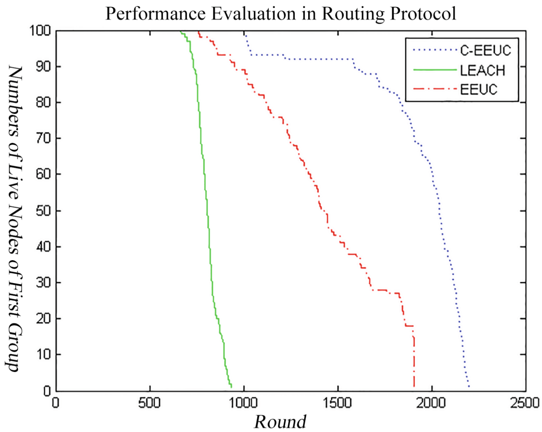

Fig. 1. Round-numbers of live nodes in first group

5 Conclusions

In a coal mine monitoring system, a clustering routing protocol could reduce the volume of data transmitted and the energy consumption in communication that cluster head nodes in WSN based on fog computing framework coalesce the data from cluster members before forwarding. However, cluster head nodes have to manage too many tasks in clustering routing protocols including cluster establishment, communication control in clusters, data coalescence, exchange data with sink nodes, and so on, which causes the imbalance of the energy consumption. In addition, if cluster head nodes communicate with the sink node in a multi-hop routing mechanism, head nodes near the sink node have to forward the data frequently, which makes the energy consumption even more imbalanced. Therefore, clustering routing protocol reduces the energy consumption of the network, but also contributes the imbalance to the network energy consumption. In EEUC protocol, the radius of the cluster close to the sink node is smaller, which reduces the size and increases the number of the clusters, so that more cluster heads could join the forwarding. Besides, the reduction of cluster members also reduces the energy consumption of the cluster heads. The uneven clustering routing protocol proposed in this paper, takes all nodes as candidate cluster head node. The weight matrix P is defined to calculate the residual energy of nodes and the communication cost between the nodes and the cluster head. Experiment results show that the routing protocol is better than LEACH and EEUC in the performance of prolonging network lifetime, reducing network energy consumption and balancing energy consumption.

Acknowledgment. The research is supported by National Natural Science Foundation of China (Grant No. 51874300), the National Natural Science Foundation of China and Shanxi Provincial People's Government Jointly Funded Project of China for Coal Base and Low Carbon (Grant No. U1510115), National Natural Science Foundation of China (Grant Nos. 51874299, 51104157), the Qing Lan Project, the China Postdoctoral Science Foundation (Grant No. 2013T60574), the Ph.D. Programs Foundation of Ministry of Education of China (Grant No. 20110095120008) and the China Postdoctoral Science Foundation (Grant No. 20100481181) and the Scientific Instrument Developing Project of the Chinese Academy of Sciences (No. YJKYYQ20170074).

References

1. Li, C.F., Chen, G.H., Ye, M., Wu, J.: An uneven cluster-based routing protocol for wireless sensor networks. Chin. J. Comput. **30**(1), 27–36 (2007)
2. Jamthe, A., Chakraborty, S., Ghosh, S.K., Agrawal, D.P.: An implementation of wireless sensor networks in monitoring of Parkinson's patients using received signal strength indicator. In: O'Conner, L. (ed.) 2013 9th IEEE International Conference on Distributed Computing in Sensor Systems, Cambridge, Massachusetts, pp. 442–447. IEEE (2013)
3. Suto, K., Nishiyama, H., Kato, N., Huang, C.-W.: An energy-efficient and delay-aware wireless computing system for industrial wireless sensor networks. IEEE Access **3**, 1026–1035 (2015)
4. Bhargava, K., Ivanov, S., Kulatunga, C., Donnelly, W.: Fog-enabled WSN system for animal behavior analysis in precision dairy. In: Yang, L.Q., Muller, P. (eds.) 2017 International Conference on Computing, Networking and Communications, pp. 504–510 (2016)
5. Vaquero, L.M., Rodero-Merino, L.: Finding your way in the definition fog: towards a comprehensive of fog computing. ACM SIGCOMM Comput. Commun. Rev. **44**(5), 27–32 (2014)
6. Zeng, J., Wang, T., Lai, Y., Liang, J., Chen, H.: Data delivery from WSNs to cloud based on a fog structure. In: Tarek, E.G., Christophe, C., Bing, G. (eds.) 2016 Fourth International Conference on Advanced Cloud and Big Data, Chengdu, Sichuan, China, pp. 104–109. IEEE (2016)
7. Zhu, Z., Zhuo, L., Qu, P., Zhou, K., Zhang, J.: Extreme weather recognition using convolutional neural networks. In: Mohan, S.K., Phillip, C.-Y.S., Mei-Ling, S. (eds.) 2016 IEEE International Symposium on Multimedia, San Jose, California, pp. 621–625 (2016)
8. Teerapittayanon, S., McDanel, B., Kung, H.T.: Distributed deep neural networks over the cloud, the edge and end devices. In: Lee, K., Liu, L. (eds.) 2017 IEEE 37th International Conference on Distributed Computing Systems, Atlanta, Georgia, pp. 328–339 (2017)
9. Eriksson, E., Dan, G., Fodor, V.: Radio and computational resource management for fog computing enabled wireless camera networks. In: Cui, S.R., Secci, S. (eds.) 2016 IEEE Globecom Workshops, Washington, DC, USA, pp. 1–6 (2016)
10. Majd, A., Sahebi, G., Daneshtalab, M., Plosila, J., Tenhunen, H.: Placement of smart mobile access points in wireless sensor networks and cyber-physical systems using fog computing. In: Didier, E.B., Julien, B. (eds.) UIC-ATC-ScalCom-CBDCom-IoP-SmartWorld, Toulouse, France, pp. 680–689 (2016)
11. Feng, J., Liu, Z., Wu, C., Ji, Y.: Mobile edge computing for the internet of vehicles: offloading framework and job scheduling. IEEE Veh. Technol. Mag. **14**(1), 28–36 (2019)
12. Sharma, S., Puthal, D., Tazeen, S., Prasad, M., Zomaya, A.Y.: MSGR: a mode-switched grid-based sustainable routing protocol for wireless sensor networks. IEEE Access **5**, 19864–19875 (2017)
13. Li, T., Liu, Y., Gao, L., Liu, A.: A cooperative-based model for smart-sensing tasks in fog computing. IEEE Access **5**, 21296–21311 (2017)

14. Lee, W., Nam, K., Roh, H.-G., Kim, S.-H.: A gateway based fog computing architecture for wireless sensors and actuator networks. In: Chang, M., Chen, N.-S., Huang, R., Kinshuk, M.K., Murthy, S., Sampson, D.G. (eds.) 2016 18th International Conference on Advanced Communications Technology, Bombay, India, pp. 210–213 (2016)
15. Chakraborty, S., Bhowmick, S., Talaga, P., Agrawal, D.P.: Fog networks in healthcare application. In: Cao, J., Carvalho, M.M. (eds.) Proceedings 2016 IEEE 13th International Conference on Mobile Ad Hoc and Sensor Systems, Brasília, Brazil, pp. 386–387 (2016)
16. Nunes, D., et al.: FoTSeC - human security in Fog of Things. In: Ali, A.B.M.S., Yang, X., Albert, Z. (eds.) 2016 IEEE International Conference on Computer and Information Technology (Cit), Nadi, Fiji, pp. 743–749 (2016)
17. Sun, L.M., Li, J.Z., Chen, Y., Zhu, H.S.: Wireless Sensor Networks. Tsinghua University Press, Peiking (2005)
18. Wang, X., Liu, Z., Gao, Y., Zheng, X., Chen, X., Wu, C.: Near-optimal data structure for approximate range emptiness problem in information-centric Internet of Things. IEEE Access **7**, 21857–21869 (2019)
19. Liu, A.F., He, H., Wu, X.Y., Chen, Z.G.: Optimization of parameter selection for wireless sensor network with mobile base station. J. Central South Univ. (Sci. Technol.) **40**(5), 1336–1344 (2009)
20. Heinzelman, W.R., Chandrakasan, A., Balakrishnan, H.: Energy-efficient communication protocol for wireless microsensor networks. In: Jay Jr., F.N., Robert, B. (eds.) Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, vol. 2, p. 8020 (2000). https://doi.org/10.1109/hicss.2000.926982