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Survey on Cluster–based Routing Protocols in Wireless Sensor Networks

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Summary

As the sensor nodes in Wireless Sensor Networks (WSNs) are powered by battery that is usually not rechargeable or replaceable, efficiently utilizing the sensor node energy to improve the network lifetime becomes the first consideration in the design of WSNs. Routing plays the key role in WSN, because it is the most significant energy–saving factor. Among the different routing protocols based on network structure, cluster–based routing protocols are more suitable for saving and using energy in WSNs efficiently.

In this paper, such cluster–based routing protocols have been reviewed comprehensively. Firstly, the main factors of routing protocols affecting the performance of WSNs are considered. Several cluster–based routing protocols including proposed ones recently are also analyzed with their objectives, advantages and disadvantages and compared with the various important metrics in detail. Finally, the study is summarized and concluded with some directions for future cluster–based routing protocols.

Keywords: wireless sensor network; cluster–based routing protocols; cluster formation; cluster head; base station; intra–and inter–cluster communications

1. Introduction

Recently, WSNs have attracted a significant amount of attention because of their benefits of sensing, gathering, processing and transmitting the different kinds of data in many applications.

A WSN is composed of a large number of low–cost, low–power, small size and multi–functional sensor nodes with finite battery life that can sense, gather and process the property data from environment and transmit the collected data to the Base Station(BS) [6].

WSNs are being used in a wide range of applications, such as disaster relief operations, biodiversity mapping, agriculture, medicine and health care and facility management [11]. However, as sensor nodes of WSNs have limited capabilities, WSNs have many constrains such as limited computational ability, low memory, limited transmission range that leads to multi–hop relay, limited battery power due to non–replaceable feature after deployment. As sensor nodes of WSNs have limited and non–rechargeable energy, energy efficiency is a very critical issue in designing WSNs, which affects the lifetime of sensor networks greatly. Thus, it is a main concern how to minimize energy consumption and maximize network lifetime when designing protocols for WSNs [3].

Routing protocols in WSNs are responsible for finding and maintaining energy–efficient routes so as to make the reliable and effective communications [8]. However, routing in WSNs differs from the conventional routing in the fixed networks in terms of several aspects. That is, there is no infrastructure for communications, wireless links are unreliable, sensor nodes may fail, and routing protocols have to meet the strict energy saving requirements [18].

A number of routing protocols proposed for WSNs can be divided according to several classification criteria such as path establishment, network structure, protocol operation and initiator of communication.

Among the different classification criterions of routing protocols for WSNs, the category of routing protocol based on network structure is the most greatly concerned by researchers of WSNs. In addition, among the various routing protocols based on network structure, hierarchical cluster–based routing protocols are more energy efficient and increase the scalability as well as prolonging the network lifetime compared to other protocols [20].

The common objective of designing routing protocol for WSNs is to get the ideal trade–off between energy consumption, latency and bit data rate [11, 12]. Many cluster–based routing protocols have been proposed for WSNs recently.

In this paper, we firstly consider the main factors of routing protocols affecting the performance of WSN to become the challenges related to the design of new routing protocols. We also try to review the predominant cluster–based routing protocols developed for WSNs comprehensively, discussing their objectives, advantages and disadvantages. Then, these protocols are compared based on the important metrics which have been already considered. We aim to provide a deeper understanding of the methods used in design of the cluster–based routing protocol through this study.

2. Challenges for routing protocol design in WSNs

As mentioned above, Routing protocols in WSNs are responsible for finding and maintaining energy–efficient routes so as to make the reliable and effective communications. Due to the several constraints of WSNs, the main purpose of routing protocol design is to extend the network lifetime by keeping the sensor nodes alive as long as possible [5].

There are some challenging factors which are important in designing routing protocols. These include energy consumption, node deployment, clustering methodology, type of clustering algorithms, scalability, coverage, location awareness, nature of nodes, overhead of the control messages, Quality of Service (QoS) and application. These factors are the design challenges of routing protocols which affect the performance of WSN. It should be noted once again that routing protocols in WSNs are very application specific and, thus, all of these factors affect routing protocols greatly. Table 1 shows the symantics of the challenging factors related to WSN routing

protocols' design in essentials.

3. Cluster–based routing protocols of WSNs

Many researchers have demonstrated that cluster–based routing protocols are more energy–efficient than non–cluster based routing protocols such as flat or location–based routing protocols, so that they increase the scalability and network lifetime [12, 17]. This section describes a comprehensive survey on the predominant cluster–based routing protocols.

3.1 EEUC (Energy Efficient Unequal Clustering)

The EEUC [10] was proposed by Li et al (2005) for solving the problem of hot spots. The hot spot or energy hole problem is related to the earlier death of CH nodes which are close to the BS. The CHs near the BS need to relay more load in addition to the data of their own cluster. Consequently, they run out of power earlier. The EEUC is a distributed CH competitive algorithm. However, EEUC has some drawbacks. Firstly, the CH selection (i.e. selection of tentative CH until final stage) requires broadcasting a significant amount of control messages, which increases energy consumption. Secondly, the EEUC increases the completion of the setup phase as it needs to determine the neighbor nodes and gather resource information. Finally, it increases the overhead and declines the performance of the network due to extra global data aggregation [13].

Table 1. Challenging factors and their semantics

№	Challenging factors	Semantics
1	Energy consumption	This factor should be needed to prolong the network lifetime as long as possible by minimizing energy consumption, and represents the energy–efficiency.
2	Node deployment	It represents the location–distribution of nodes deployed in monitoring field, and has the close relations to other factors.
3	Clustering methodology	A factor explaining clustering methods such as centralized, distributed or hybrid.
4	Type of Clustering algorithms	It describes a method of clustering process that is probabilistic or non–probabilistic.
5	Scalability	This factor guarantees routing protocol's stable operation no matter in network size.
6	Coverage	In the whole monitoring field, it helps routing protocols to transmit the monitored or gathered data to BS.
7	Location awareness	A factor reflecting location information of nodes to routing protocol.
8	Nature of nodes	This factor represents homogeneity or heterogeneity of all nodes in a WSN.
9	Control messages	Overhead amount of control messages used in the clustering phase of routing protocol.
10	QoS	It constrains routing protocol to satisfy QoS in some applications.
11	Application	According to applications, among time–driven, event–driven and query–driven routing protocols, which is chosen.

3.2 EEHC(Energy Efficient Heterogeneous Clustered)

The EEHC [9] protocol proposed by Kumar et al (2009) considers a network with heterogeneous nodes in terms of energy. There are three heterogeneity levels in EEHC: super nodes, advanced nodes and normal nodes. To be more specific, this protocol extends the network lifetime by using heterogeneous sensor nodes. It elects CH in a distributed fashion. CH selection is based on the weighted election probabilities of each node in accordance with the residual energy. The EEHC considered the residual energy of nodes, but it did not consider the initial energy of nodes. The phases in EEHC are identical to LEACH.

However, single hop communications with the BS results in quick energy depletion of the CHs [13].

3.3 EADC(Energy Aware Distributed Clustering)

The EADC[24] routing protocol was proposed by Yu et al (2012) for networks with non–uniform node distribution. This cluster–based routing protocol consists of an energy aware clustering algorithm and a cluster–based routing algorithm. In the routing algorithm, EADC chooses the CHs with more residual energy and less CMs as the relay nodes for the next hops. In the cluster–based routing protocol, a routing tree based on the CHs is constructed. The energy consumption of the CHs in multi–hop communication is divided into intra–cluster energy consumption and inter–cluster energy consumption.

However, due to the different density of the nodes in some regions, in dense areas, there will be redundancy and duplication in data. This redundancy in data transmission is energy consuming and not considered in EADC.

3.4 EAUCF(Energy–Aware Unequal Clustering Algorithm)

The EAUCF [4] proposed by Hakan Bagci et al (2013) aims to decrease the intra–cluster work of the CHs that are either close to the BS or have low remaining battery power. EAUCF is a distributed competitive unequal clustering algorithm.

EAUCF that aims to distribute the workload among all sensor nodes, in terms of half of the nodes alive(HNA) metric, outperforms all of the other tested algorithms and its total remaining energy level at a certain round is higher than the other algorithms. However, in CH competition, only the residual energy and the distance to the BS of the tentative CHs are taken into account. Some parameters such as node degree, density and local distance have not been utilized to improve its performance.

3.5 HSACP(Harmony Search Algorithm–based Clustering Protocol)

The HSACP [1] proposed by Duc Chinh Hoang et al (2014) is a centralized cluster–based protocol using harmony search algorithm. In the HSACP centralized cluster–based protocol for WSN, the BS needs to select the CHs with higher residual energy among the sensor nodes and then forms the clusters with equal distribution of the sensor nodes based on their information of location and residual energy. This process is referred as an optimization problem. The operation of this protocol includes two phases: clustering setup phase and data transmission phase.

This protocol using harmony search algorithm, a music–based meta–heuristic optimization method, minimizes the intra–cluster distances between the cluster members and their CHs and optimizes the energy distribution of the WSNs. However, research works such as investigation of an adaptive coefficient in the objective function and optimization of the frequency of re–clustering the WSNs and transferring data should be carried out to further improve the performance of the overall networks.

3.6 ERA(Energy–aware Routing Algorithm)

The ERA [22] algorithm proposed by Tarachand Amgoth et

al (2015) aims to minimize the overhead of control messages. The algorithm consists of two phases: clustering and routing. In clustering phase, sensor nodes are grouped into clusters. Each sensor node sets its own timer independently before it starts the competition for CH selection. In routing phase, to route the data to the BS, a Directed Virtual Backbone (DVB) to be the routing tree of the CHs rooted at the BS is constructed.

ERA algorithm has some advantages: non–exchange of control message for CH selection, energy efficient construction of the routing tree called the directed virtual backbone to facilitate data routing toward the BS, relay load balancing, O(1) message complexity per sensor node and O(n) time complexity for a WSN with n sensor nodes. However, this algorithm has not considered the dynamic scenario and fault tolerant aspects of the sensor network.

3.7 DFCR (Distributed Fault–tolerant Clustering and Routing)

The DFCR [15] algorithm was proposed by Md Azharuddin et al (2015) in order to address the problem of designing energy efficient clustering and routing algorithms for WSNs which are fault tolerant. Network setup consists of a setup phase followed by the steady–state phase as shown in Fig. 1.

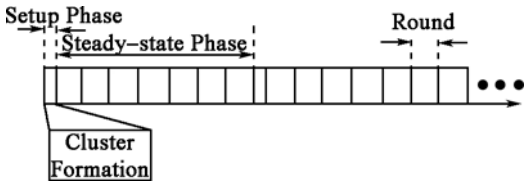

Figure 1. Network setup

DFCR is energy efficient as well as fault tolerant. The cluster formation is based on residual energy of the CHs, distance between the member sensor nodes to their CHs and also the distance from the CHs to the BS. However, for fault tolerance of DFCR algorithms, only permanent failure of the CHs has been considered. In other words, the energy aware distributed clustering and routing algorithm emphasizing partial and transient failure of the sensor nodes has not been designed yet [15].

3.8 DHCR (Decentralized energy efficient Hierarchical Cluster–based Routing)

Main objective of the DHCR [14] algorithm proposed by Maryam Sabet et al (2015) is to reduce the energy consumption caused by extra control message transmissions. This protocol contains a multi–criterion clustering algorithm and a cluster–based routing algorithm which are performed concurrently. In multi–criterion clustering algorithm, the set of CHs for data aggregation and relay transmission bourgeon is specified. In order to select CH nodes, DHCR algorithm utilizes each node's local information such as residual energy, distance to the BS and proximity to its neighbors.

This clustering and multi–hop routing algorithm are performed at the same stage to decrease control packets and in respect of energy consumption and network lifetime are predominant than the other one. However, the successful data delivery was not investigated in terms of throughput.

3.9 ECACD (Energy–efficient Clustering Approach based on Convergence Degree chain)

The ECACD [23] proposed by Xiao–Hui Kuang et al (2015) aims to decrease energy consumption of sensor node and increase WSNs stability. ECACD algorithm includes three stages: initialization, CH election and cluster formation, cluster maintenance. ECACD protocol can improve stability of topology by using convergence degree and residual energy for CH election, reduce energy consumption of cluster member node by cluster joining policy for cluster formation, and decrease communication cost by rotating CH according to convergence degree chain generated at initial stage. However, authors have not varied different parameters to more comprehensively evaluate the performance of WSN system and experiments on real platforms. In addition, research on data aggregation of messages and routing protocol based on ECACD have not been addressed [23].

3.10 DECAR (Distributed, Energy and Coverage Aware Routing)

The DECAR [21] algorithm main objective is to design energy efficient algorithm to maximize the coverage lifetime in a large–scale WSN, was proposed by Tarachand Amgoth et al (2015). This algorithm is divided into the following phases: information update, clustering, virtual backbone network (VBN) and data routing.

DECAR algorithm has some advantages: clever strategy for CH selection, efficient node scheduling, coverage–aware routing and energy balancing. However, this algorithm has not considered the dynamic scenario and non–uniform distribution of the sensor nodes.

3.11 TPSO–CR (Two–tier Particle Swarm Optimization for Clustering and Routing)

The TPSO–CR [19] is the centralized two tier Particle Swarm Optimization (PSO) protocol proposed by Riham S.Y. Elhabyann et al (2015). In TPSO–CR, the network operating time is divided into rounds. Each round consists of two phases: the set–up phase and the steady–state phase. In the set–up phase, the network is configured. The BS will choose the best set of CHs and relay nodes. The set–up phase consists of four steps: neighbor discovery, control data broadcasting, network configuration and configuration broadcasting. In the steady–state phase, each non–CH node uses its TDMA schedule to transmit its data to its respective CH. When a CH receives this data, it uses its next relay node to forward the data to the BS. When a non–CH node finishes its data transmission slot, it enters the sleep state to save its energy.

In TPSO–CR, the network operating time is divided into rounds as shown in Fig. 2.

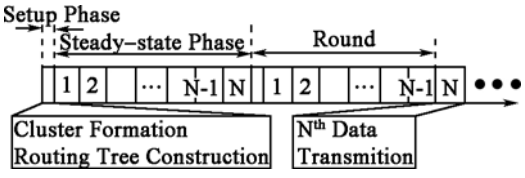

Figure 2. Network operating time in TPSO–CR

TPSO–CR with a novel particle encoding scheme and fitness function identifies the optimal routing tree to improve the packet delivery rate. However, network lifetime remains unaddressed [16].

3.12 NFEACS (Neuron–Fuzzy Energy Aware Clustering Scheme)

The NFEACS that was proposed by Golden Julie et al (2016), aims to form optimum and energy aware clusters. The NFEACS is consisted of two parts: fuzzy subsystem and neural network system which achieve the energy efficiency in forming the clusters and CHs in WSNs. This scheme uses Energy Aware Unequal Clustering Fuzzy (EAUCF) scheme [7] with some modifications. Neural network system is integrated in EAUCF for training network related to the energy and the received signal strength of all nodes. Therefore, NFEACS provides the effective training set to estimate the anticipated energy for the tentative CHs.

However, the weighted metrics like the node degree and the received signal strength is not used in the neural network training set.

3.13 GCR (Greedy Cluster–based Routing)

The GCR [16] was proposed by M. Parthasarathi et al (2017) in order to improve the network lifetime. This scheme is the cluster–based local route search method in WSNs. The GCR method uses arbitrary timer in order to participate CH selection process with maximum neighbor nodes and the minimum distance between the source and the BS. The GCR constructs dynamic routing improving the network lifetime through Mass Proportion value. Also, GCR uses a greedy route finding strategy for balancing energy consumption.

However, an adaptive power control method has not be adapted to much more enhance the network energy efficiency.

4. Comparison of cluster–based routing protocols in WSNs

Table 2 summarizes the comparison between cluster–based routing protocols on the basis of the importance metrics such as energy consumption, scalability, clustering method, node mobility, delivery delay, coverage, control messages complexity, node distribution, location awareness, nature of nodes or sensor type, load balancing, and application. These main metrics affect the design and performance of routing protocols in WSNs.

From table 2, we can know that it is very difficult for a routing protocol in WSNs to satisfy the requirements of all the metrics and thereby, per application specific routing protocol should be designed and used appropriately.

Table 2. Comparison of clustering algorithms in WSN

Protocol	Energy efficiency	Scalability	Clustering method	Delivery delay	Mobility	Control message complexity	Node distribution	Location awareness	Sensor type	Coverage	Application
EEUC	High	High	Distributed	Moderate	Stationary	High	Uniform	Required	Homogeneous	Not considered	Time–driven
EEHC	Low	Very low	Distributed	Very small	Stationary	Low	Random	Required	Heterogeneous	Not considered	Time–driven
EADC	High	High	Distributed	Moderate	Stationary	High	Non–uniform	Not required	Heterogeneous	Not considered	Time–driven
EAUCF	High	High	Distributed	Moderate	Stationary	Moderate	Random	Not required	Homogeneous	Not considered	Time–driven
HSACP	Low	Very low	Centralized	Small	Stationary	Low	Random	Required	Homogeneous	Not considered	Time–driven
ERA	Very high	Very high	Distributed	Moderate	Stationary	High	Random	Required	Homogeneous	Not considered	Time–driven
DFCR	Very high	low	Distributed	Small	Stationary	Low	Random	Not required	Homogeneous	Considered	Time–driven
DHCR	Very high	High	Distributed	Moderate	Stationary	Low	Non–uniform	Not required	Heterogeneous	Not considered	Time–driven
ECACD	High	Moderate	Distributed	Moderate	quasi–stationary	Low	Random	Not required	Homogeneous	Not considered	Time–driven
DECAR	Very high	High	Distributed	Small	Stationary	Low	Random	Required	Homogeneous	Considered	Time–driven
TPSO –CR	Low	Very low	Centralized	Very small	Stationary	High	Random	Not required	Homogeneous	Considered	Time–driven
NFEACS	Very high	High	Distributed	Small	Dynamic	High	Random	Not required	Homogeneous	Not considered	Time–driven
GCR	Very high	High	Distributed	Small	Stationary	Low	Random	Not required	Homogeneous	Not considered	Time–driven

5. Conclusion and open issues

In this paper, a comprehensive review on cluster–based routing protocols in WSNs is presented. Firstly, we have discussed the design challenges of routing protocols which affect the performance of WSNs. Several cluster–based routing protocols including recent proposed ones have been also analyzed with their objectives, advantages and drawbacks in detail and compared with the various important metrics.

Although, in the past few years, clustering routing protocols for WSNs were proposed to not only be very application

specific, but also fulfill the various performance requirments of WSNs, some challenges should be addressed in the design of clustering routing protocols. First of all, in aspect of the comprehensive study on clustering routing protocols for WSNs, metaheuristic optimization–based, QoS–based, coverage preservation of network by which follows failure detection and tolerence–based, and node mobility consideration based ones should be reviewed respectivly and comprehensively. Next, individual routing protocol should be developed according to specific application. Metaheuristic optimization–based algorithms are quickly replacing the classical methods in solving practical problems. QoS–based routing protocols developed so far are mainly location–based; a little work has been done on clustering–based QoS protocols. Coverage preservation is one of the most essential issues to guarantee the QoS of networks. However, in previous works, these two issues of energy efficiency and coverage awareness have not been extensively studied in a joint way. If network topology is changed according to the node mobility in network, clustering routing protocol should handle the challenges related to the node mobility.

Conclusively, since the routing protocols in WSNs are very application specific and each application has its own requirements, the above–mentiond challenges should be sufficiently addressed in the design of routing protocols of future works.

References

1. Duc Chinh Hoang, Parikshit Yadav, Rajesh Kumar, Sanjib Kumar Panda, 2014. Real–Time Implementation of a Harmony Search Algorithm–Based Clustering Protocol for Energy–Efficient Wireless Sensor Networks, *IEEE Trans. on Industria Informatics*, 10, 774–783.

2. E. Golden Julie & S. Tamil Selvi, 2016. Development of Energy Efficient Clustering Protocol in Wireless Sensor Network Using Neuron–Fuzzy Approach, *Scientific World Journal*, 8, 234–243.

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

4. Hakan Bagci & Adnan Yazici, 2013. An energy aware fuzzy approach to unequal clustering in wireless sensor networks, *Applied Soft Computing*, 13, 1 741–1 749.

5. Haneef, M. & D. Zhongliang, 2012, Design challenges and comparative analysis of cluster based routing protocols used in wireless sensor networks for improving network lifetime, *Adv. Inform. Sci. Service Sci*., 4, 450–459.

6. Hassan Oudani, 2017, Energy Efficient in Wireless Sensor Networks Using Cluster–Based Approach Routing, *International Journal of Sensors and Sensor Networks*, 5, 6–12.

7. H. Bagci & A. Yazici, 2013, An energy aware fuzzy approach to unequal clustering in wireless sensor networks, *Applied Soft Computing*, 13, 1 741–1 749.

8. Komal Mehta & Raju Pal, 2017, Energy Efficient Routing Protocols for Wireless Sensor Networks: A Survey, *International Journal of Computer Applications*, 165, 41–47.

9. Kumar. D, T.C. Aseri & R.B. Patel, 2009, EEHC: Energy efficient heterogeneous clustered scheme for wireless sensor networks, *Comput. Commun*., 32, 662–667.

10. Li, C. M. Ye, G. Chen & J. Wu., 2005, An energy–efficient unequal clustering mechanism for wireless sensor networks, *Proceedings of the International Conference on Mobile Adhoc and Sensor Systems Conference*, November 7–10, 1–8.

11. Liu. X. X., 2012. A survey on clustering routing protocols in wireless sensor networks, *Sensor*s, 12, 11 113–11 153.

12. Naeimi, S., H. Ghafghazi, C.O. Chow & H. Ishii, 2012. A survey on the taxonomy of Cluster–based routing protocols for homogeneous wireless sensor networks, *Sensor*s, 12, 7 350–7 409.

13. Nooshin Nokhanji & Zurina Mohd Hanapi, 2014, A Survey on Cluster–based Routing Protocols in Wireless Sensor Networks, *Journal of Applied Science*s, 14(18), 2 011–2 022.

14. Maryam Sabet & Hamid Reza Naji, 2015, A decentralized energy efficient hierarchical cluster–based routing algorithm for wireless sensor networks, *Int. J. Electron. Commun. (AEÜ)*, 69, 790–799.

15. Md Azharuddin, Pratyay Kuila, Prasanta K. Jana, "Energy efficient fault tolerant clustering and routing algorithms for wireless sensor networks, Computers and Electrical Engineering 41, 2015, 177–190.

16. M. Parthasarathi & Karthikeyani Vajravel, 2017, Greedy cluster based routing for wireless sensor networks, *International Journal of Computer Science & Information Technology (IJCSIT)*, 9, 85–99.

17. Pooja Mishra & Sanjiv Sharma, 2016, A Comparative Study of Existing Cluster–Based Routing Protocols in Wireless Sensor Networks, I*nternational Journal of Future Generation Communication and Networking*, 9, 43–52.

18. Puneet Gurbani, Hansa Acharya & Anurag Jain, 2016, Hierarchical cluster based energy efficient routing protpcol for wireless sensor networks: a survey, *International journal of Computer Science and Information Technology*, 7, 682–687.

19. Riham S.Y. Elhabyann & Mustapha C.E. Yagoub, 2015, Two–tier particle swarm optimization protocol for clustering and routing in wireless sensor network, *Journal of Network and Computer Applications*, 52, 116–122.

20. Supriya Bhagat & Kamaljit Kaur, 2017, A Comparative Study of Hierarchical Clustering based Routing Protocols in WSN: A Survey, *International Journal of Computer Applications*, 168, 7, 19–27.

21. Tarachand Amgoth·& Prasanta K. Jana, 2015, Energy and Coverage–Aware Routing Algorithm for Wireless Sensor Networks, *Wireless Pers Commun*, 81, 531–545.

22. Tarachand Amgoth & Prasanta K. Jana, 2015, Energy–aware routing algorithm for wireless sensor networks, *Computers and Electrical Engineering*, 41, 357–367.

23. Xiao–Hui Kuang, LiLiu, Qiang Liu & Xiang Li, 2015, A clustering approach based on convergence degree chain for wireless sensor networks, *Security Comm. Networks*, 8, 1 878–1 889.

24. Yu. J, Y. Qi, G. Wang & X. Gu, 2012, A cluster–based routing protocol for wireless sensor networks with non–unifonn node distribution, *AEU–Int. J. Electron. Commun*, 66, 54–61.