

A Comprehensive Study on Cluster Based Routing Protocols for Wireless Sensor Networks

C. Deepa^{1*} and B. Latha²

¹Department of Computer Science and Engineering, Faculty of Computing, Sathyabama University, Chennai - 600119, Tamil Nadu, India; depmca@gmail.com

²Department of Computer Science and Engineering, Sri Sai Ram Engineering College, Chennai - 600044, Tamil Nadu, India; sivasoorya2003@yahoo.com

Abstract

Background/Objectives: Wireless Sensor Networks (WSNs) have emerged as a new powerful tool and a rapidly growing technology, which consume a lesser amount of energy for processing and communication. **Methods/Statistical Analysis:** Most state-of-art reviews have concentrated on look over the various routing methods which have been suggested depends on the energy effectiveness and lifetime. This paper presents an extensive survey and performance analysis of cluster based routing methods for Wireless Sensor Networks and aims to identify current research issues in this area. **Findings:** There are number of routing procedures have been discussed, to progress their performance in wireless networks. In this study, we present a cluster based routing algorithms for WSNs which is highlighted with their features and objectives. **Improvements/Applications:** These algorithms were compared based on the metrics such as energy efficiency, data aggregation, route selection etc.

Keywords: Cluster based Routing, Energy Efficient, Reliability, Wireless Sensor Networks

1. Introduction

Wireless Sensor Network (WSN) is a collection of small sensor nodes that are connected via wireless medium involved of sensing, computations and other communication features, which provide consumer or administrator the capability to device, sense and respond to events in a precise environment¹⁻⁴. WSNs have been emerging speedily in recent decades and assurance to be one of the rudimentary infrastructures which support ambient intelligence⁵. WSNs are applicable in an extensive spectrum of applications, like healthcare, environment and weather monitoring, traffic and video surveillance, combat field surveillance, industrial automation, process control, inventory management, border security, where they accomplish highly subtle information at minimum deployment cost⁶⁻¹¹. Recently, WSNs have been renowned as a promising methodology to attain seamless, reliable,

energy efficient and low-cost remote surveillance and control in smart grid applications¹². A routing protocol for WSN should have less computational complexity, efficient in power consumption, increase the network lifetime and less latency for data diffusion from the Sensor Node (SN) to the sink¹³. As the SNs are battery-operated devices and predictable to function and perform their responsibilities without attending for a long duration of time throughout the application^{10,14}. The critical topographies to face concern how to diminish the energy utilization of nodes, so that the network lifespan can be prolonged to reasonable times¹⁵. Considering the emerging tendency of long detecting range for cost-effective sensor distribution, discovering events within area much lesser than the detecting region of a single sensor is important¹⁶. Unlike traditional networks WSNs can communicate with one another using multi-hop wireless communication¹⁷. Each node of the WSN contains a sensor, embedded proces-

*Author for correspondence

sors, limited memory, and it is answerable for detecting a preferred incident locally and communicating an isolated incident identified by another SNs, which implies that the incident is conveyed to its endpoint through the Base Station (BS). As sink nodes have restricted energy, applications and procedures for WSNs must be prudently planned for enhanced energy utilization for extending the lifetime of the network¹⁸.

2. Background

A survey related to the design issues in the routing process has been performed based on the network construction and the procedure operation^{2,19}. An extensive review on routing protocols has been carried out by Obaisat²⁰, who described their design objectives, procedures, features and challenges. A survey has been conducted based on the classification of the routing procedures and their applications in different fields²¹. A review has been performed relating to various issues in WSN routing protocols and it has been reported how an energy proficient path can be designated and how the various routing methods are suggested for the WSNs^{1,14}. There are many reviews on WSN related to the network's structure and security problems and a few methods for securing the routing procedures has been provided by various researchers²²⁻²⁸. A survey has been conducted on reliability protocols depends on redundancy and retransmission methods using various combinations of packet or incident consistency in terms of refining the missing data by end-to-end or hop-by-hop mechanisms²⁹.

3. Cluster based Routing Protocols

In this method, SN can interconnect with the BS directly or via the Cluster Head (CH) or via other transmitting nodes. In direct communication, each and every SN links directly to its BS. When their network is enormous, the energy for collaborating with the BS is relatively large. Therefore, certain nodes far away from the BS will speedily run out of energy³⁰. The other method is the clustering; where the SNs are formed into clusters based on the sensing area and one SN of the cluster act as Cluster Head which receives the information from the other SNs in the cluster and send it to BS³¹.

3.1 Cluster based Congestion Control Scheme (COMUT)

COMUT³² is a congestion control method which supports multi-classes of congestion in WSNs. By using the traffic intensity estimation, the level of congestion is determined within and across the clusters. The control information is communicated between the cluster nodes to regulate the sending rates of the sensors. Depends on the significance of the information, sending rates are adjusted by the sensor to support the multi class of traffic. This technique requires the CH to observe the traffic intensity statistics within their cluster and from time to time forward it. The proactive congestion control technique used to raises the amount of control information communicated among the nodes in the cluster to preserve the traffic level of the network under control. However, this protocol sustains useless devour of SN's battery power, if WSN is not affected from congestion. In addition, this protocol uses the back pressuring mechanism to avoid congestion.

3.2 Distribute and Effective Cluster Routing Protocol (DECROP)

DECROP³³ is a cluster based routing technique that includes four phases: Initialization phase, distributed cluster forming phase, data transmission phase and the route/path maintenance phase. After the completion of node deployment, initialization process starts from BS. It broadcast an initial setup message. When a node obtains this setup message will select convey node as their pre-hop-node then re-broadcast the message. During initialization process a tree network with BS as its root has been formed. When a node's neighbor reaches some threshold value it announces itself as a CH during the distributed cluster forming process. When a node is near to the sink or BS, can directly transfer information to sink. Else the information has been forwarded through CH. Node which is unreachable can be handled by route maintenance process.

3.3 Energy Aware Routing for Cluster based Sensor Networks (EAR-CSN)

EAR-CSN³⁴ is a protocol depends on three tier system architecture, forming of SNs called as clusters, CHs formation which are a lesser amount of power restraint and be likely to identify another SNs position and care the

conditions of the nodes while forming up hop-by-hop paths for information gathering. This algorithm uses Medium Access Control (MAC) in interconnecting with the CHs or gateway. In this method, the cluster SNs states might be relaying only, sensing only and relaying sensing or inactive states delay. Depends on the energy utilization, throughput, delay optimization and other performance parameter between any pair of nodes, the cost function is defined. This method affects in communication range even though used many CHs, this leads additional overheads and therefore it utilizes abundant energy.

3.4 Energy Conserving Passive Clustering (ECPC) Algorithm

ECPC³⁵ is a residual energy and distance based cluster formation algorithm. In the beginning of cluster formation all SNs will be in normal state and the sink will send query to the network. After receiving the query message, nodes in ordinary state will change its state to CH ready state, then calculate the waiting time before transmitting ADV-CH (Advertise new data-Cluster Head) message, contain residual energy, node ID and forward their query. Normal node which receives ADV-CH information will modify its status to gateway-ready status and forward the query and also store the node ID, distance from the CH. A node which is in the gateway ready status will transmit ADV-CH message contain its own ID and the ID of CH. Node which receive this message will store the node ID of the CH and the own ID of gateway node. Gateway node and the ordinary node which are not participating in communication will become the cluster member. This algorithm produces some overhead for cluster creation.

3.5 Energy Efficient Clustering Routing (EECR)

EECR³⁶ is a method which can divide a SN into little clusters then select a CH based on weight value that leads to more identical energy dissipation uniformly among all SNs. The results showed that this method can protect overall energy utilization, increase evenness of dissipated network energy and has the capacity of increasing the life span of the sensor network.

3.6 Energy Neutral Clustering (ENC) Protocol

ENC³⁷ protocol used to form a group of energy gathering WSN into an equal number of clusters, aims to provide

uninterrupted network process. This ENC protocol works an innovative Cluster Head Group method (CHG), permits more than one CH to share the heavy congestion in one cluster. In each cluster, the size of CHG is calculated locally and it has adequate energy in order to handle the data which is sent by their cluster members. This ENC method, data detected by their cluster members can be reliably conveyed to the sink or BS. Extensive experimental studies confirm that ENC method can effectively avoid the cluster failures by confirming the network extensive energy process. This method is compared with LEACH, provide greater amount of data collected by the sensor network while imposing a lesser control information overhead.

3.7 Grid-based Routing and Aggregator Selection Scheme (GRASS)

GRASS³⁸ is an algorithm which combines fixed cluster type routing method with the application precise data accumulation in order to improve the performance of the WSN in terms of increasing the sensor network life time. It is a heuristic as well as optimal algorithm which solves the optimal routing's joint problem with data aggregation. The experimental results exhibited that, GRASS is accomplished of improving the network life time while it deserve the adequate levels of potential and without losing the quality of data.

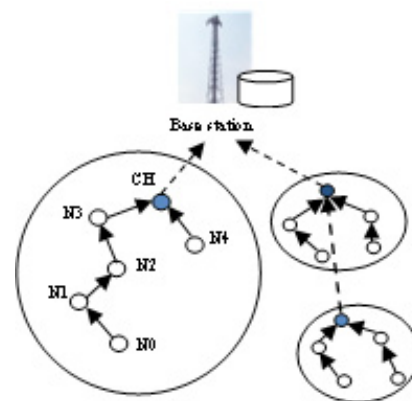


Figure 1. Chains cluster organization in HEEP.

3.8 Hybrid Energy Efficient Distributed Clustering (HEED)

HEED^{39,40} is an improvement of the LEACH technique, applies residual energy and SN's density as a metric to its cluster formation which is to balance sensor network energy. It is a hybrid multi-hop routing method, which

increases the lifetime of the network by managing with the hotspot problem. The execution of HEED is take place in three phases; 1. In initialization phase, depends on SNs remaining energy and intra-cluster communication cost, the CHs are selected. 2. In repetition phase, selection of CH is repeated based on some parameters. 3. In finalization phase, the selected CH is confirmed. The power utilization of HEED has been examined with respects to various metrics and found that this method is a capable technique to handle the hotspot problem also prolong the lifetime of the network.

3.9 Hybrid Energy Efficiency Protocol (HEEP)

HEEP⁴¹ is an energy efficient routing method in which a series of SNs in an identical cluster is created with their closest neighbors and to increase energy dissipation. CH in each cluster sends their collected information to sink or BS via the nearest CH based on multi-hop technique, which reduces the energy consumption. Figure 1 which is redrawn from⁴¹ shows the node organization within clusters. The first node transmits it to nearest neighbor, until reaches its CH that communicates to their sink or BS. Therefore, in this formation, the communication range and the total number of SNs interconnecting with the CH is decreased. It suggests enhanced energy saving and extends CHs lifespan.

3.10 Power Efficient and Adaptive Clustering Hierarchy (PEACH)

PEACH⁴² is a routing method which reduces energy consumption of each node and improves life time of the network. PEACH creates cluster depends on overhearing characteristics of medium and it avoids additional overheads. By using overhearing a SN can know the sender and receiver of the information which is transferred by surrounding nodes of WSN. This protocol is suitable for both locations aware and unaware. It is aimed to function on probabilistic routing method and which is efficient to the different circumstance. PEACH can considerably save the energy utilization of the nodes and improve the life time of the network.

3.11 Route Optimization and Load-Balancing Protocol (ROL)

ROL⁴³ is based on cluster type routing protocol that uses various QoS metrics which satisfy the application

requests. It groups several application requests; especially it gives an extensive clarification to extend the sensor life time of the network, increase network robustness and gives timely message delivery. ROL uses priority type routing metrics to rise the performance of the network. The results showed that ROL increases the network lifetime compare to the other similar methods. From simulation results, compared to Mires++, there is a 7% deviation from the population of cluster, the amount of set-up information reduced as 60%, delay is reduced as 56% and the delivery ratio of data is improved by 0.98%.

3.12 Secure Routing Protocol based on Cluster-Gene (SRPBCG)

SRPBCG⁴⁴ is based on cluster gene and secure routing method for WSNs. The CH selection procedure is similar to LEACH and main aim of this system is to maintain trust and reputation locally and to validate identity of SN with negligible time delay and overhead. An effective biological authentication technique is used, uses biological gene for encryption key and efficient key distribution method that needs only little memory and transmitting overhead. This method only handles with the intruder's attack and compromised nodes. Computation and transmitting problem are high in this protocol.

3.13 Low Energy Adaptive Clustering Hierarchy (LEACH)

LEACH^{18,30,45} is an energy efficient hierarchical routing method which decreases the energy utilization of the SNs. It partition the network region into smaller clusters in which one node act as CH which regulates the channel access and the other node in the cluster act as a cluster member. It uses the received signal quality of the SN to form the cluster and also uses local CHs as routers to route information to Base Station which is directly communicate to the sink. By using this method it saves the energy, since SNs are not involved for transmitting the information whereas CH only participated. Periodically the CH role will be rotated randomly in the cluster to adjust the energy consumption of sensor nodes. In CH, original data are combined depends on data aggregation or fusion method which reduces the original size of the information. This protocol is suitable for smaller area network deployment since it uses single hop routing. However in CH, an amount of energy is wasted for broadcasting the CH selection intimation message and for data aggregation or fusion technique.

Table 1. Comparison of cluster based routing methods

Routing protocol	Energy efficiency	Data aggregation	Location awareness	Route selection	Query based	Simulation environment
COMUT	Moderate	Yes	NO	Proactive	NO	NS-2
DECORP	Weak	Yes	NO	Proactive	NO	Unknown
EAR-CSN	Moderate	Yes	Yes	Proactive	NO	Unknown
ECPC	Moderate	Yes	NO	Reactive	Yes	Unknown
EECR	Moderate	Yes	NO	Proactive	NO	Unknown
GRASS	Weak	Yes	NO	Proactive	NO	NS-2
HEED	Moderate	Yes	NO	Proactive	NO	Math. Model
HEEP	Moderate	Yes	NO	Proactive	NO	Unknown
PEACH	Strong	Yes	Yes	Proactive	NO	Unknown
ROL	Strong	Yes	NO	Proactive	NO	Dingoo
SRPBCG	Weak	Yes	NO	Proactive	NO	Unknown
LEACH	Strong	Yes	NO	Proactive	NO	MATLAB

4. Comparison of Cluster based Routing Protocols

The routing methods are analyzed depends on the energy efficiency, location awareness, data aggregation, route selection and simulation environment and the results are listed in Table 1. In this category all the protocols are mixed response in terms of energy utilization. Data aggregation is possible for all the protocols and the method of route selection is proactive except ECPC. The simulation environment for many protocols is not explained in the previous works.

5. Summary and Conclusion

In this study, we discussed number of cluster based routing protocols and suggest the indications and methods to give some phases about designing of an efficient routing protocols for WSNs. The protocols have been categorized according the aims, the desired cluster properties and clustering process and comparative analysis has been done. In general, from the review and the report presented in Table 1, we found that there are some major short comings existing shared to the great popular of the measured works: 1. The protocols are not assessed over huge set of functioning situations, 2. The simulation environment and tools used are not sufficiently defined and 3. Many of the methods have not been related by other contemporary methods for routing in WSNs. From this study

we observed that, the positive steps have been taken in addressing the methods to develop an efficient and effective cluster based routing protocol for WSNs. Another important point we notice that many methods explained in the literature assumed that the energy utilization is much greater due to data sampling or data processing. Finally, we observed that an increasing interest towards design and progress of energy efficient cluster based routing protocol for WSNs.

6. References

1. Akyildiz IF, Su W, Sankarasubramaniam Y, Cayirci E. A survey on sensor networks. *IEEE Communications Magazine*. 2002; 40:102–14.
2. Akkaya K, Younis M. A survey on routing protocols in Wireless Sensor Networks. *Ad-Hoc Networks*. 2005; 3:325–49.
3. Sohraby K, Minoli D, Znati T. *Wireless Sensor Networks: Technology, protocols and applications*. New Jersey: Wiley; 2007.
4. Zungeru AM, Ang LM, Seng KP. Termite hill: Performance optimized swarm intelligence based routing algorithm for Wireless Sensor Networks. *Journal of Network and Computer Applications*. 2012; 35:1901–17.
5. Stavrou E, Pitsillides A. A survey on secure multipath routing protocols in WSNs. *Computer Networks*. 2010; 54:2215–38.
6. Romer K, Mattern F. The design space of Wireless Sensor Networks. *IEEE Wireless Communications*. 2004; 11:54–61.

7. Hernandez CFG, Gonzalez PHI, Hernandez JG, Diaz JAP. Wireless Sensor Networks and application: A survey. *International Journal of Computer Science and Network Security*. 2007; 7:264–73.
8. Sohrabi K, Gao J, Ailawadhi V, Pottie GJ. Protocols for self-organization of a Wireless Sensor Network. *IEEE Personal Communications*. 2000; 7:16–27.
9. Kumari S, Khan MK, Atiquzzaman M. User authentication schemes for Wireless Sensor Networks: A review. *Ad-Hoc Networks*. 2015; 27:159–94.
10. Chong CE, Kumar SP. Sensor Networks: Evolution, opportunities and challenges. *Proceedings of the IEEE*. 2003; 91:1247–56.
11. Tonneau AS, Mitton N, Vandaele J. How to choose an experimentation platform for Wireless Sensor Networks? A survey on static and mobile Wireless Sensor Network experimentation facilities. *Ad-Hoc Networks*. 2015; 30:115–27.
12. Fadel E, Gungor VC, Nassef L, Akkari N, Maik MGA, Almasri S, Akyildiz IF. A survey on Wireless Sensor Networks for smart grid. *Computer Communications*. 2015. Available from: <http://dx.doi.org/10.1016/j.comcom>
13. Misra S, Woungang I, Misra SC. *Guide to Wireless Sensor Networks*. Computer Communications and Networks Series. London, UK: Springer-Verlag; 2009.
14. Akyildiz IF, Su W, Sankarasubramaniam Y, Cayirci E. Wireless Sensor Networks: A survey. *Computer Networks*. 2002; 38:393–422.
15. Anastasi G, Conti M, Francesco MD, Passarella A. Energy conservation in Wireless Sensor Networks: A survey. *Ad-Hoc Networks*. 2009; 7:537–68.
16. Iqbal A, Murshed M. A hybrid Wireless Sensor Network framework for range-free event localization. *Ad-Hoc Networks*. 2015; 27:81–98.
17. Jawhar I, Mohamed N, Agrawal DP. Linear Wireless Sensor Networks: Classification and applications. *Journal of Network and Computer Applications*. 2011; 34:1671–82.
18. Tyagi S, Kumar N. A systematic review on clustering and routing techniques based upon LEACH protocol for Wireless Sensor Networks. *Journal of Network and Computer Applications*. 2013; 36:623–45.
19. Karaki JNA, Kamal AE. Routing techniques in Wireless Sensor Networks: A survey. *IEEE Wireless Communications*. 2004; 11:6–28.
20. Obaisat YA, Braun R. On Wireless Sensor Networks: Architectures, protocols, applications and management. *International Conference on Wireless Broadband and Ultra Wideband Communication (AusWireless)*; 2006.
21. Li Y, Newe T. Wireless Sensor Networks – Selection of routing protocols for applications. *Australian Telecommunication Networks and Applications Conference (ATNAC)*; 2006.
22. Wang YH, Tsai CH, Mao HJ. HMRP: Hierarchy based multipath routing protocol for Wireless Sensor Networks. *Tamkang Journal of Science and Engineering*. 2006; 9:255–64.
23. Pietro R, Mancini L, Law Y, Etalee S, Havinga P. LKHW: A direct diffusion-based secure multicast scheme for Wireless Sensor Networks. *ICPPW '03: Proceedings of the 32nd International Conference on Parallel Processing Workshop*, IEEE Computer Society Press; 2003.
24. Perrig A, Szewczyk R, Wen V, Cullar D, Tygar JD. SPINS: Security protocols for sensor networks. *Proceedings of the Seventh Annual ACM International Conference on Mobile Computing and Networks (MOBICOM)*; Rome, Italy. 2001.
25. Du W, Wang R, Ning P. An efficient scheme for authenticating public keys sensor networks. *MobiHoc '05: Proceedings of the Sixth ACM International Symposium on Mobile Ad-hoc Networks and Computers*; New York: ACM Press; 2005.
26. Walters JP, Liang Z, Shi W, Chaudhary V. Wireless Sensor Networks security: A survey. Book Chapter of *Security in Distributed, Grid and Pervasive Computing*, Auerbach Publications. Yang Xiao, editor. CRC Press; 2006. ISBN: 0-849-37921-0.
27. Deng J, Hang R, Mishra S. INSENS: Intrusion-tolerant routing in Wireless Sensor Networks. *Computer Communications*. 2006; 29:216–30.
28. Tanachaiwiwat S, Dave P, Bhindwale R, Helmy A. Location-centric isolation of misbehavior and trust routing in energy-constrained sensor networks. *The Workshop on Energy-Efficient Wireless Communications and Networks (EWCN 04) in Conjunction with IEEE International Performance, Computing and Communications Conference (IPCCC)*; 2004.
29. Mahmood MA, Seah WKG, Welch I. Reliability in Wireless Sensor Networks: A survey and challenges ahead. *Computer Networks*. 2015; 79:166–87.
30. Heinzelman WR, Chandrakasan A, Balakrishnan H. An application specific protocol architecture for wireless micro sensor networks. *IEEE Transactions on Wireless Communications*. 2002; 1:660–70.
31. Zarei B, Zeynali M, Nezhad VM. Novel cluster based routing protocol in Wireless Sensor Networks. *International Journal of Computer Science Issues*. 2010; 7:32–6.
32. Karenos K, Kalogeraki V, Krishnamurthy SV. Cluster based congestion control for supporting multiple classes of traffic in sensor networks. *2nd IEEE Workshop on Embedded Networked Sensors*; Sydney, Australia. 2005.
33. Chen J, Yin Z, Li D, Sun T. A distributed and effective cluster routing technique of sensor networks. *First International Conference on Intelligent Networks and Intelligent Systems, ICINIS*; 2008. p. 271–5.

34. Younis M, Youssef M, Arisha K. Energy aware routing in cluster-based sensor networks. *Proceedings of the 10th IEEE/ACM International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems (MASCOTS'02)*; Fort Worth, TX. 2002.
35. Rashid MM, Alam MM, Hong CS. Energy conserving passive clustering for efficient routing in Wireless Sensor Network. *The 9th International Conference on Advanced communication Technology*; 2007. p. 982–6.
36. Li L, Shusong D, Xiangming W. An energy efficient clustering routing algorithm for Wireless Sensor Networks. *The Journal of China Universities of Posts and Telecommunications*. 2006; 13:71–5.
37. Peng S, Wang T, Low CP. Energy neutral clustering for energy harvesting Wireless Sensors Networks. *Ad-Hoc Networks*. 2015; 28:1–16.
38. Karaki JNA, Mustafa RU, Kamal AE. Data aggregation and routing in Wireless Sensor Networks: Optimal and heuristic algorithms. *Computer Networks*. 2009; 53:945–60.
39. Younis O, Fahmy S. HEED: A Hybrid, Energy Efficient, Distributed clustering approach for ad-hoc networks. *IEEE Transactions on Mobile Computing*. 2004; 3:366–9.
40. Abdulla AEAA, Nishiyama H, Kato N. Extending the lifetime of Wireless Sensor Networks: A hybrid routing algorithm. *Computer Communications*. 2012; 35:1056–63.
41. Boubiche DE, Bilami A. HEEP: Hybrid Energy Efficiency Protocol based on chain clustering. *International Journal of Sensor Networks*. 2011; 10:25–35.
42. Yi S, Heo J, Cho Y, Hong J. PEACH: Power Efficient and Adaptive Clustering Hierarchy protocol for Wireless Sensor Networks. *Computer Communications*. 2007; 30:2842–52.
43. Hammoudeh M, Newman R. Adaptive routing in Wireless Sensor Networks: QoS optimisation for enhanced application performance. *Information Fusion*. 2015; 22:3–15.
44. Quan Z, Li J. Secure routing protocol cluster-gene-based for Wireless Sensor Networks. *Proceedings of the 1st International Conference on Information Science and Engineering (ICISE2009)*; 2009. p. 4098–102.
45. Heinzelman W. Application specific protocol architecture for wireless network. [PhD Thesis]. Massachusetts Institute of Technology; 2000.