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# A Survey on Cluster Based Routing Protocols in Wireless Sensor Networks

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**Abstract**

Latest advancements in micro-electro-mechanical-system (MEMS) and wireless communication technology, opens the way for the growth in applications of wireless sensor networks (WSNs). Wireless sensor network is comprised of huge number of small and cheap devices known as sensor nodes. The sensor nodes communicate together by many wireless strategies and these communication strategies are administered by routing protocols. Performance of sensor networks largely depends on the routing protocols, which are application based. Keeping this in mind, we have carried out extensive survey on WSN routing protocols. Based on structure of network, routing protocols in WSN can be broadly classified into three categories: flat routing, hierarchical or cluster based routing, and location based routing. Due to certain advantages, clustering is flattering as an active stem in routing technology. In this paper, authors have been reported a comprehensive survey on cluster based routing protocols in wireless sensor networks. We outline the merits and limitations of the clustering schemes in WSNs, and propose a taxonomy of cluster based routing methods. Finally, we summarize and conclude the paper with some future directions.


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*Keywords:* wireless sensor networks; cluster based routing; sensors; taxonomy; communication strategy.

## 1. Introduction

The progression of wireless sensor networks [1,2] was initially motivated by military applications. Though, wireless sensor networks are nowadays used in numerous civilian application areas like: monitoring, tracking, automation, traffic control, and healthcare applications. The WSN is composed of wireless modules called sensor nodes. The architecture of sensor node is shown in figure 1. The key components [3] of a node are: a micro sensor, a microprocessor, a memory, a battery, and a transceiver to communicate with rest of the networks. Because of the


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limitations on the power supply, transmission bandwidth and processing capability, efficient routing becomes a crucial issue in wireless sensor network. Routing protocols [4,5] in WSN are responsible for discovering and maintaining energy efficient routes, in order to make communication reliable and efficient. On the basis of literature review on network structure based routing schemes, WSNs routing protocols can be divided into three categories: flat routing, hierarchical or cluster based routing and location based routing.

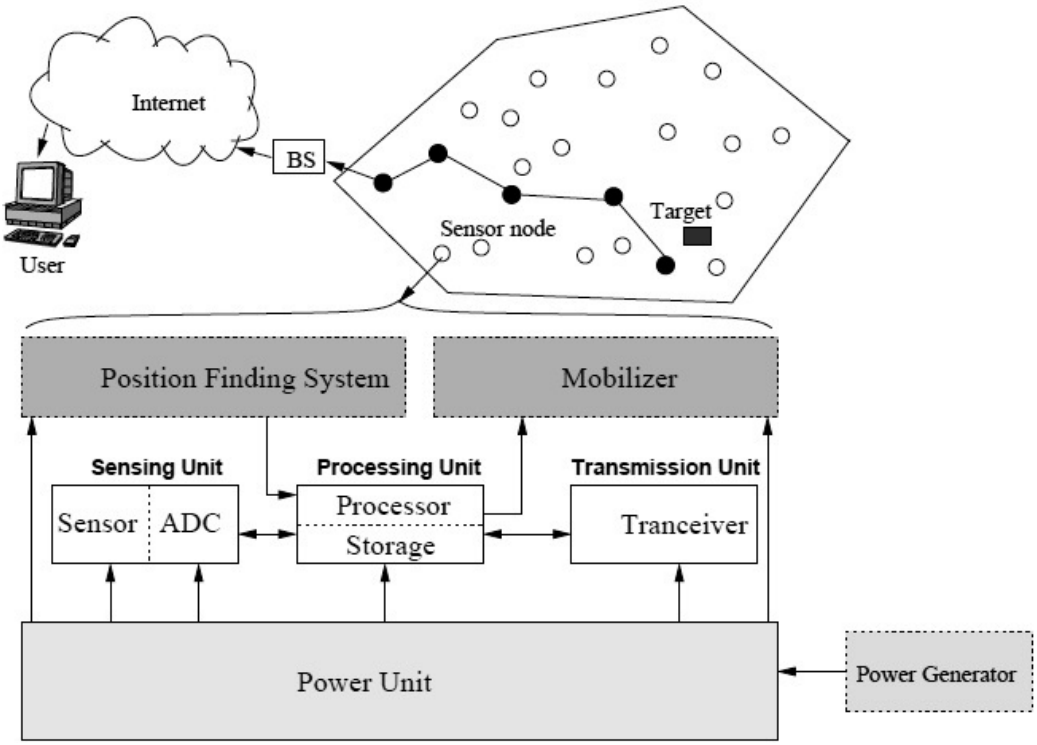


Fig.1. Sensor node architecture (source: [4])

In flat networks, each node plays the same role and nodes work together to perform the sensing task [4]. Flat routing protocols [6,7] are quite effective in small scale networks. However, they are fairly undesirable in large scale networks because of resources limitation. In hierarchical routing, nodes execute dissimilar tasks and are typically grouped into clusters based on specific requirements. This means that creation of clusters and assigning specific task to cluster heads (CHs) can significantly contribute to scalability, lifetime, and energy efficiency. In this paper, authors present an ample survey of various cluster based routing protocols proposed in recent years. The rest of the paper is organized as follows. Section 2, describes the routing protocols in wireless sensor networks. Section 3, describe the cluster based routing protocols. Section 4, compare the different cluster based routing protocols in WSN. Some open issues are discussed in section 5 and section 6 concludes the paper.

## 2. Routing Protocols in Wireless Sensor Networks

Routing is a method to find out a path between the source node and the destination node [5]. Routing in WSN is really challenging due to the intrinsic characteristics that differentiate these networks from other networks. The design of routing protocols in WSNs is affected by several exigent factors. The efficient communication can be achieved in WSNs by overcoming these factors.

### *2.1. Design Challenges of Routing Protocols in WSNs*

Routing protocols [4,7] in WSNs are responsible for discovering and maintaining energy efficient routes in the networks, in order to make communication reliable and efficient. Due to the limitations in the kind of network, the main aim of routing protocol design is extending the network life time by keeping the sensors alive as much as possible. This issue results in keeping the network connected for a long period of time. There are some challenging factors which are important in designing routing protocols. These are given as:

*2.1.1. Node deployment:* Deployment is very application dependent and affects the performance of the routing protocols. It can be manual or randomized [4,6]. In the first strategy, the nodes are manually placed and data is routed through predestined paths. In manual deployment, coverage of area is satisfied with careful choice of node density. Although, this is good choice when nodes are costly and their operations are influenced by their locations, it is not good for harsh environments [8]. On the other hand, in random deployment, the nodes are scattered arbitrarily. If the application is related to event detection, then it is efficient to have a random node deployment to get effective results [9,10].

*2.1.2. Energy consumption:* The main aim of routing protocols is to convey data among sensors and sink in efficient manner. Each sensor node consumes energy in sensing, processing, receiving and transmitting information [2]. Among these data transmission is the most energy consuming task [11]. Since, the sensor nodes have limited energy resources, energy depletion of some nodes results in great topology and network connectivity changes, reorganization of network and finding new routes. So, there is a need to design routing protocols that can accommodate the trade off between energy optimization and accuracy [12,13].

*2.1.3. Nature of node:* In WSN, the nodes that are scattered over the environments can be either homogeneous or heterogeneous. Homogeneous nodes have the same capabilities such as, range of transmission, battery life, and processing capacity while heterogeneous nodes have different capabilities [4]. The majority of the network architecture assumes that the sensor nodes are stationary. However, mobility of base stations as well as of nodes is necessary in several applications [14].

*2.1.4. Coverage:* In WSNs, each node prevails a certain view of the environment. A given sensor's view of the environment is limited both in range and in accuracy. Hence coverage area is essential design issue [11].

*2.1.5. Scalability:* The number of nodes deployed in the field may be variable i.e. few numbers to few thousands. The routing protocol be required to be able to work with massive amount of nodes [4,11]. When the number of nodes is extensive, it is infeasible that each node maintain a global knowledge of network topology.

*2.1.6. Quality of service (QoS):* The routing protocols should be able to provide certain level of QoS that is required by the application. The QoS parameters can be bandwidth, delivery delay, throughput, jitter etc.[15]. For instance, target detection and tracking applications requires low transmission delay for the time sensitive data. While, multimedia networks requires high throughput [16].

*2.1.7. Application:* The routing protocols are very application specific. In other words, different scenario or network environments need different routing protocols. From the application's viewpoint, data can be collected from the environment using various methods such as, time driven, event driven, and query driven methods. In time driven methods, the sensor nodes send their data periodically to BS or Gateways. In event driven methods, sensor nodes report the collected data when the event occurs. Eventually, in query driven methods, the BS request the data from the nodes and send a query [4,16].

### *2.2. Classification of Routing Protocols in WSNs*

In WSNs, the network layer is used to implement the routing of incoming data. In multi-hop networks, the source

node cannot reach the sink directly. So, intermediate nodes have to relay their packets. The implementation of routing tables gives the solution. WSN routing protocols can be classified into five ways, according to the way of establishing the routing paths, according to the network structure, according to the protocol operation, according to the initiator of communications, and according to how a protocol selects a next hop on route of forwarded message. The taxonomy of routing protocols is shown in figure 2.

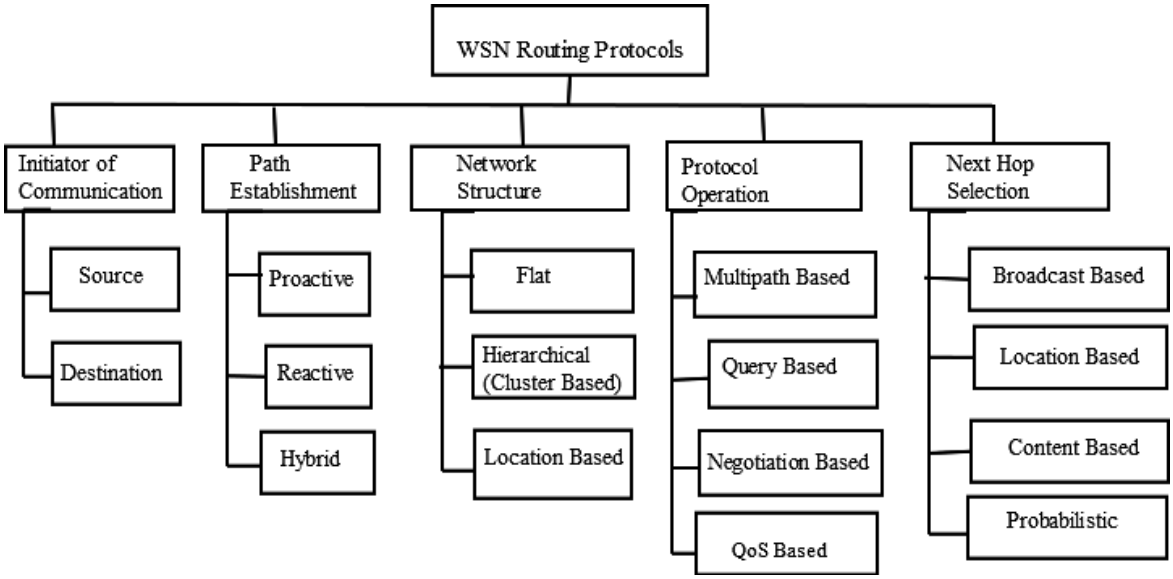


Fig.2. Taxonomy of routing protocols in WSNs

The network structure based routing protocols are categorized as: flat based, hierarchal based (cluster based), and location based routing protocols. In flat based routing, every sensor node plays same role. While, in hierarchal based routing, sensor nodes have different roles. So, when network scalability and efficient communication is needed, hierarchal or cluster based routing is the best choice.

## 3. Cluster Based Routing Protocols in Wireless Sensor Networks

The cluster based routing [17,18,19] is energy efficient method in which nodes those having high energies are arbitrarily selected for processing and sending data while nodes those having low energies are used for sensing and sending information to the cluster heads (CHs). This property of cluster based routing contributes to the scalability, lifetime maximization, and energy minimization. The cluster based routing protocols plays a pivotal role in achieving application specific goals [20,21,22]. The cluster based routing protocols are classified into three broad categories: block cluster based, grid cluster based, and chain cluster based routing protocols. The taxonomy of cluster based routing protocols is shown in figure 3.

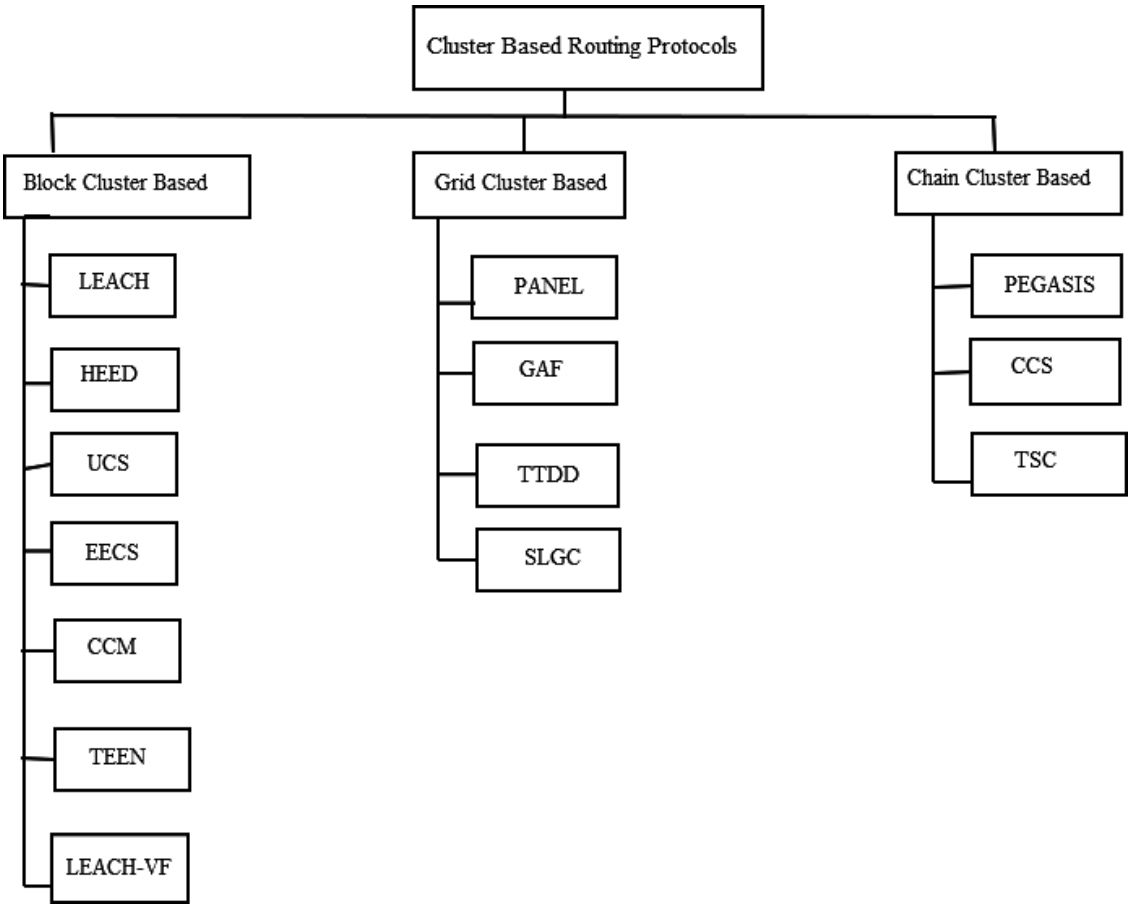


Fig.3. Taxonomy of cluster based routing protocols in WSNs

The popular block cluster based routing protocols are: LEACH, HEED, UCS, EECS, CCM, TEEN, LEACH-VF etc as shown in figure 3. The merits and limitations of block cluster based routing protocols are given in table 1. The popular grid cluster based routing protocols are: PANEL, GAF, TTDD, SLGC etc as shown in figure3. The merits and limitations of grid cluster based routing protocols are given in table 2. The popular chain cluster based routing protocols are: PEGASIS, CCS, TSC etc as shown in figure 3. The merits and limitations of these protocols are given in table 3.

Table 1. Summary of merits and limitations of block cluster based routing protocols

| Algorithm | Merits | Limitations |
|---|---|---|
| LEACH [23] | • Each node has equal chance to become cluster head but cannot be selected as cluster head in subsequent round so load is shared between nodes<br>• LEACH uses TDMA so it keeps CHs from unnecessary collisions | • LEACH use single hop communication so it can not used in large scale networks<br>• CHs are elected on the basis of probability so uniform distribution cannot be ensured and it cannot provide load balancing |
| HEED [24] | • Fully distributed routing scheme | • Unbalanced Energy consumption due to more CH |

| | | |
|---|---|---|
| | • HEED achieves load balancing and uniform CH distribution | generation |
| | • HEED achieve high energy efficiency and scalability by communicating in multi-hop way | • Massive overhead due to multiple rounds<br>• Additional overhead due to several epochs |
| UCS [25] | • Nodes in cluster can be variable<br>• UCS is bi-layered model and two-hop inter cluster communication | • It is limited by assumptions that CHs are predetermined as well as network is not homogeneous.<br>• Residual energy of node is not considered and not sufficient for large range networks |
| EECS [26] | • EECS constructs more balanced network in term of energy consumption and communication load<br>• Use dynamic sizing of clusters | • Lot of overhead due to global information for communication<br>• Single hop communication consume lot of energy |
| CCM [27] | • Less energy consumption compared with LEACH | • Chain head selection criterion |
| LEACH-VF [28] | • Solve the problem of area with overlapped sensing coverage and sensing hole<br>• In LEACH-VF some nodes can be moved to coverage inside the cluster are | • Poor energy efficiency<br>• Load balancing is not up to the mark |
| TEEN [29] | • Data transmission can be controlled by varying two thresholds<br>• Well suited for time critical applications | • Whenever thresholds are not meet ,the node will not communicate<br>• Data may be lost if CHs are not able to communicate with each other |

Table 2. Summary of merits and limitations of grid cluster based routing protocols

| Algorithm | Merits | Limitations |
|---|---|---|
| PANEL [30] | • PANEL is energy efficient that ensure load balancing and long network life time<br>• Supports asynchronous applications | • Clusters are predetermined<br>• To determine geographic position information, special conditions are needed, which is not always available |
| GAF [31] | • GAF increase the network lifetime by saving energy<br>• Routing fidelity is maintained | • Large traffic injection and delay is not predictable |
| TTDD [32] | • Resolve the numerous mobile sinks and moving problem of sink in large scale WSNs<br>• Suitable to event detecting WSNs among irregular data traffic | • Large latency<br>• Low energy efficiency<br>• TTDD require sensor nodes to be stationary and location aware |
| SLGC [33] | • Lower energy consumption in SLGC compared to LEACH | • Large overhead due to complex data communication |

Table 3. Summary of merits and limitations of chain cluster based routing protocols

| Algorithm | Merits | Limitations |
|---|---|---|
| PEGASIS [34] | • Energy load is distributed uniformly | • Long delays cause a node to become bottleneck |
| | • Reduce overhead due to dynamic cluster formation | • Network is not very scalable |
| | • Decrease number of data transmission | • Not suitable for time varying topologies |
| CCS [35] | • Energy consumption is reduced | • Unbalanced energy consumption |
| | • Reduced data flow from BS in CCS | • Large delay due to long chain |
| TSC [36] | • TSC reduces redundant data transmission in network by breaking long chains into smaller chains | • Node distribution in unbalanced |

## 4. Comparison

Table 4 summarizes the comparison between popular cluster based routing protocols on the basis of energy efficiency, delivery delay, cluster stability, load balancing, and algorithmic complexity.

Table 4. Comparison between popular clusters based routing protocols

| Scheme Name | Energy Efficiency | Delivery Delay | Cluster Stability | Scalability | Load Balancing | Algorithm Complexity |
|---|---|---|---|---|---|---|
| LEACH | Very low | Very small | Medium | Very low | Medium | Low |
| HEED | Medium | Medium | High | Medium | Medium | Medium |
| UCS | Very low | Small | High | Low | Bad | Medium |
| EECS | Medium | Small | High | Low | Medium | Very high |
| CCM | Very low | Small | High | Very low | Medium | Medium |
| LECH-VF | Medium | Small | High | Very low | Medium | Medium |
| TEEN | Very high | Small | High | Low | Good | High |
| GAF | Medium | Very small | Medium | High | Medium | Medium |
| PANEL | Medium | Medium | Low | Low | Good | High |
| TTDD | Very low | Very large | Very high | Low | Good | Low |
| SLGC | Medium | Very small | Medium | Very low | Medium | Medium |
| PEGASIS | Low | Very large | Low | Very low | Medium | High |
| CCS | Low | Large | Low | Low | Very bad | Medium |
| TSC | Medium | Medium | Medium | Medium | Bad | Medium |

## 5. Issues in Cluster Based Routing Protocols

The much research work has been done to query the drawbacks of clustering techniques and to improve the individuality of cluster based routing methods but there are still several issues to be addressed for the efficient use of cluster based routing techniques [37,38,39,40] . The some open issues need to be addressed are:

- *Calculation and selection of cluster heads (CHs):* CH is utility of computation and communication energy model for the clustering schemes. If the multi hop scheme is used then CHs count supposed to be revised. The performance and availability of adjacent CHs is an important factor for relaying the data of clusters. Consequently, CH role in rotation of adjacent clusters must be considered as dominant factor in selection process of CH.

- *Scalability:* In a few large scale deployments, it is usually desirable to enlarge the monitoring area amid new nodes. So, careful observations are required to check the adaptability and scalability of clustering techniques.

- *Topology of network:* Topology changes owed to territorial circumstances in realization of WSNs. So, it is important to focus on the strength of clustering methods.

- *Fault tolerance:* Transient fault management owed to temporal link failures desires much more attention.

- *Redundancy management:* Minimizing the use of massively redundant nodes for building trustworthy and proficient relay backbone. The combined data of CHs relayed to BS must be investigated further.

## 6. Conclusion

Wireless sensor networks have fascinated much concern for both civil and military applications. Examples consist of environmental monitoring, border protection, battle-field, and security surveillance. In these applications a huge number of sensors are needed, requiring careful architecture and network management. To support scalability, grouping nodes into clusters has been popular method in WSNs. In this work, we surveyed the status of research and classified the different clustering methods. This paper classifies the taxonomy of cluster based routing protocols. In this work, we focus on the merits and limitations of different cluster based routing protocols and represent them in tabular form. On the basis of comparison between different schemes, it is clear that cluster based routing protocols are useful in performance improvement of wireless sensor networks. This paper will be very useful for the research group those are interested in the development, modification or optimization of routing algorithms for WSNs.

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## References

1. Akyildiz, I.F., Su, W., Sankarasubramaniam, Y., Cyirci, E., "Wireless Sensor Networks: A Survey", *Computer Networks*, Vol. 38, no.4: pp. 393-422, 2002.
2. Romer, Kay, Friedemann Mattern, "The Design Space of Wireless Sensor Networks", *IEEE Wireless Communications* 11 (6): 54-61, 2004.
3. F. Hu, W. Siddiqui, and X. Cao, "SPECTRA: Secure Power-Efficient Clustered- Topology Routing Algorithm in Large-scale Wireless micro-Sensor Networks", *International Journal of Information Technology*, vol. 11, no. 2, pp. 95–118, 2005.
4. Al-Karaki, J.N., and A.E. Kamal, "Routing Techniques in wireless sensor networks: a survey", IEEE Wireless Communication 11:6-28, 2004.
5. Kazem Sohraby, Daniel Minoli, Taieb Znati, "Wireless Sensor Networks: Technology: Protocols and Applications", John Wiley & Sons, 2007.
6. Yick, J., Biswanath, M., Ghosal, D., "Wireless Sensor Network Survey", *Computer Networks*, vol.52 (12):2292-2330, 2008.
7. B. Krishnamachari, D. Estrin, S. Wicker, "Modelling data centric routing in wireless sensor networks", in *Proceedings of IEEE INFOCOM*, New York, NY, June 2002.

8. W.B. Heinzelman, A.P. Chandrakasan, H. Balakrishnan, "Application specific protocol architecture for wireless micro sensor networks", *IEEE Transactions on Wireless Networking*, 2002.
9. Mauri, K., Hannikainen, M., Hamalainen, T., "A survey of application distribution in wireless sensor networks", *EURASIP Journal on Wireless Communications and Networking*, vol. 2005: pp. 774-788, 2005.
10. P. Kumar, M. P. Singh, and U. S. Triar, "A Review of Routing Protocols in Wireless Sensor Network", *International Journal of Engineering Research & Technology(IJERT)*, vol. 1, no. 4, pp. 1–14, 2012.
11. Haneef, M., D. Zhongliang, "Design challenges and comparative analysis of cluster based routing protocols used in wireless sensor networks for improving network life time", Adv. Inform. Service Sci. 4:450-459, 2012.
12. Akyildiz, I.F., Varun, M.C., "Wireless Sensor Networks", John Wiley & Sons, 2010.
13. Cordiero, C.M., Agarwal, D.P., "Ad Hoc and Sensor Networks: Theory and Applications", World Scientific, Singapore, 2011.
14. Ye, F., Luo, H., Cheng, J., Lu, S., Zhang, L., "A Two tier data dissemination model for large scale wireless sensor networks", in Proceedings of ACM/IEEE Mobicom, 2002.
15. Murthy, C.S.R., Manoj, B.S., "Ad Hoc Wireless Networks: Architecture and Protocols", Printice-Hall, New Jersey, USA, 2004.
16. Dargie, W., Poellabauer, C., "Fundamental of Wireless Sensor Networks: Theory and Practice", John Wiley & Sons, New York, USA, 2010.
17. Ameer Ahmad Abbasi, Mohamed Younis, "A survey on clustering algorithms for wireless sensor networks", *computer Communication* 30(2007) 2826-2841.
18. X. Liu, "A Survey on Clustering Routing Protocols in Wireless Sensor Networks", *Sensors*, vol. 12, pp. 11113–11153, 2012.
19. S. Naeimi, H. Ghafghazi, C.O. Chow, and H. Ishi, "A survey on the taxonomy of cluster- based routing protocols for homogeneous wireless sensor networks", Sensors, vol. 12, no. 6, pp. 7350–7409, 2012.
20. S. Bandyopadhyay and E. J. Coyle, "An Energy Efficient Hierarchical Clustering Algorithm for Wireless Sensor Networks," IEEE INFOCOM, April 2003.
21. U. Han, S. Park, S. Kim, and Y. Chung, "An Enhanced Cluster Based Routing Algorithm for Wireless Sensor Networks," in Proc. of PDPTA, pp. 758–763, 2006.
22. G. Gupta, M. Younis, "Load-balanced clustering in wireless sensor networks", in Proceedings of the International Conference on Communication (ICC 2003), Anchorage, Alaska, May 2003.
23. Heinzelman, W.R., Chandrakasan, A., Balakrishnan, H., "Energy efficient communication protocol for wireless micro sensor networks", in Proceedings of the Hawaii International Conference on System Sciences, 2000.
24. O. Younis, S. Fahmy, "HEED: A Hybrid, Energy-Efficient, Distributed clustering approach for Ad Hoc sensor networks", *IEEE Transactions on Mobile Computing* 3 (4) (2004) 366–379.
25. S. Soro, W. B. Heinzelman, "Prolonging the Lifetime of Wireless Sensor Networks via Unequal Clustering," in Proceedings of *19th IEEE International Parallel and Distributed Processing Symposium*, 2005.
26. M. Ye, C. Li, G. Chen, and J. Wu, "EECS: an energy efficient clustering scheme in wireless sensor networks," in *Proceedings of 24th IEEE International Performance, Computing, and Communications Conference*, pp. 535–540, 2005.
27. F. Tang, I. You, S. Guo, M. Guo, and Y. Ma, "A chain-cluster based routing algorithm for wireless sensor networks", *Journal of Intelligent Manufacturing*, vol. 23, no. 4, pp. 1305–1313, 2010.
28. M. B. Yassein, A. Al-Zou, Y. Khamayseh, and W. Mardini, "Improvement on LEACH Protocol of Wireless Sensor Network (VLEACH)", *International Journal of Digital Content: Technology and its Applications*, vol. 3, no. 2, pp. 132–136, 2009.
29. A. Manjeshwar and D. P. Agrawal, "TEEN: A Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks" in *Proceedings of 15th International Parallel and Distributed Processing Symposium*, pp. 2009–2015.
30. L. Buttyan and P. Schaffer, "PANEL: Position-based Aggregator Node Election in Wireless Sensor Networks", in *Proceedings of IEEE International Conference on Mobile Adhoc and Sensor Systems*, pp. 1–9, 2007.
31. Y. Xu, J. Heidemann, and D. Estrin, "Geography-informed Energy Conservation for Ad Hoc Routing", in *Proc. of the 7th annual international conference on Mobile computing and networking*, 2001, pp. 70–84.
32. H. Luo, F. Ye, J. Cheng, S. Lu, and L. Zhang, "TTDD: Two-Tier Data Dissemination in Large-Scale Wireless Sensor Networks", *Wireless Networks*, vol. 11, no. 1–2, pp. 161–175, 2005.
33. A. G. Delavar, S. Shamsi, N. Mirkazemi, and J. Artin, "SLGC: A New Cluster Routing Algorithm in Wireless Sensor Network for Decrease Energy Consumption", *International Journal of Computer Science, Engineering and Application*, vol. 2, no. 3, pp. 39–51, 2012.
34. S. Lindsey, C. Raghavendra, and K. M. Sivalingam, "Data Gathering Algorithms in Sensor Networks Using Energy Metrics", *IEEE Transactions on Parallel and Distributed Systems*, vol. 13, no. 9, pp. 924–935, 2002.
35. S. Jung, Y. Han, and T. Chung, "The Concentric Clustering Scheme for Efficient Energy Consumption in the PEGASIS", in *Proc. of 9th International conference on Advanced Communication Technology*, pp. 260–265, 2007.
36. N. Gautam, W. Il Lee, and J. Y. Pyun, "Track-Sector Clustering for Energy Efficient Routing in Wireless Sensor Networks", in *Proc. of 9th IEEE International Conference on Computer and Information Technology*, pp. 116–121, 2009.
37. X. liu and J. Shi, "Clustering Routing Algorithms in Wireless Sensor networks: an overview",*KSII Transactions on Internet and Information Systems*, Vol 6, No.7, 2012 :pp.1735-1755.
38. G. Sikander, M.H.Zafar, A. Raza, M.I. Babar, S.A. Mahmud, and G.M. Khan, "A survey of cluster based routing schemes for wireless sensor network", *Smart Computing Review*, Vol 3, No 4, August 2013.
39. Duc Ching Hoang, Rajesh Kumar, Sanjib Kumar Panda, "Realisation of cluster based protocols using fuzzy C-mean algorithms for wireless sensor networks", *IET Wireless Sensor System*, Vol 3,Issue 3, 2013: pp.163-171.
40. Dilip Kumar, "Performance analysis of energy efficient clustering protocol for maximizing lifetime of wireless sensor networks", *IET Wireless Sensor System*, Vol 4, Issue 1:pp.9-16, 2014.