IJARST

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science & Technology (IJARST)

Volume 2, Issue 4, June 2020

Clustering in Wireless Sensor Networks

Ms. Suman Ahlawat[1], Dr. Anoop Sharma[2], Dr. Aman Jain[3]

Research Scholar in Singhania University, Jhunjunu[1]

Dean Department of CS and IT, Singhania University, Jhunjunu[2]

Professor, Maharishi Arvind Institute of Science and Management, Jaipur[3]

suman.ahlawat81@gmail.com

Abstract: *In WSN, sensor nodes are deployed to operate autonomously in remote environments. Depending on the network orientation, WSN can be of two types: flat network and hierarchical or cluster-based network. Various advantages of cluster-based WSN are energy efficiency, better network communication, efficient topology management, minimized delay, and so forth. As a result, clustering has become a key research area in WSN. Various approaches for WSN, using cluster concepts, have been proposed. The objective of this paper is to review and analyze the some of the important cluster-based WSN algorithms using various measurement parameters. In this paper, unique performance metrics are discussed which efficiently evaluate prominent clustering schemes.*

Keywords: WSN, Wireless Sensor Network, Clustering Analysis

I. INTRODUCTION

Wireless sensor networks (WSNs) are highly resource constrained with limited power, bandwidth, processing capabilities, storage, and computational capabilities. Therefore, sensor nodes are mostly inoperable and irreplaceable when failure occurs due to energy exhaustion. Increasing network sustainability and lifetime are the key issues for the contemporary studies in sensor domain. Normally, energy exhaustion is highly dominated by radio transmission. The energy exhaustion of radio communication is directly related to any transmission in the network. Clustering technique reduces the number of radio transmissions and increases sensor network lifetime. Thus, clustering technique can, efficiently, increase lifetime of various sensor applications, such as robot control, environmental control, offices, smart homes, manufacturing environments, body area networks, and underwater sensor networks [5–10].

In traditional flat WSN, node's status and functionality are identical, and node acts as a data generator and router. Flat network is not efficient in energy conserving as compared to cluster-based WSN wherein network size is larger. Transmission happens in traditional flat network in the form of flooding [11]. In flooding, message is sent from the source node to destination where the entire network is used for a single operation. However, such technique causes data redundancy. To overcome the problem of data redundancy in flat network, directed diffusion technique has been suggested in [12, 13]. Direct Diffusion continuously monitors redundant data. However, this technique is not efficient where data input stream is large like environment monitoring. Another technique has been proposed to avoid redundancy in flat network is rumor. However, this technique also gives poor results when the number of events gets larger. Flat sensor network scheme is mainly proactive which yields unsatisfactory performance for highly dense network [15–17]. Large sensor network generates more data that highly affects flat network performance. Communication overhead of flat network routing protocols is (n^2), where n represents the total number of nodes in the network [5]. This result implies that such algorithm increases routing overheads. Therefore, flat network performs efficiently in a situation where network size is small.

To achieve the small sensor network features in a large sensor network, various solutions have been proposed to break a sensor network into smaller groups. Clustering is the one that demonstrates scalable results. The basic idea behind clustering is to group down the network into small networks. Clustering provides logical organization of small units and hence is easy to manage. The structured networks have many advantages as compared to flat network, such as data aggregation, reducing communication overhead, ease of managing, minimizing overall power consumption, energy efficiency, and prolonging sensor network life time. Moreover, clustering results in efficient dynamic routing from sensor to sensor or to specific nodes like sink node [7, 18, 19].

Few challenges of WSN are as follows:

(i) Sensor nodes have low transmission bandwidth and low processing capabilities.
(ii) Overall network performance is affected by the limited power in sensor nodes.
(iii) New deploy nodes execute cluster formation scheme while new redeployed nodes execute cluster maintenance. Such schemes are very critical for large network.
(iv) Network performance degrades when the maximum extent of nodes in a network is undefined.
(v) In multihop networks, every node acts as a data originator and data router. Therefore, node(s) malfunction(s) causes topological manipulation which requires network reorganization and packet rerouting.
(vi) Data transmission difficulties are unpredictable in WSN; thus, a proper fault tolerance or reliability schemes are essential.

II. Earlier Review of Articles in Cluster-Based WSNs

Cluster-based WSNs are a highly dynamic research area. The published articles in this domain are extremely diverse in terms of their approaches and implementations. However, there exist a few published survey papers, such as [20, 21], which provide a diverse comparison approach. A brief survey on cluster-based algorithms is presented in [21], where different taxonomy for measuring cluster-based architectures is presented with their advantages and disadvantages. However, article [21] explores the limited performance metrics. It overlooks some imperative performance metrics in exploring clustered protocols, such as communication cost. Moreover, quantitative analysis is not presented in [21].

An extensive review on clustering protocols for WSN is presented in [22]. This article mentions taxonomy of cluster structures and then shortens several cluster procedures on convergence time based protocols. It compares these clustering methods based on cluster overlapping, location awareness, cluster stability, and convergence rate.

A review paper presented in [23] discusses clustering protocols in WSN, which are categorized based on cluster formation and cluster-head (CH) selection. The authors discuss various significant design issues, and present various performance problems linked with the clustering algorithms. Another study, conducted in [24] on CH election policies, presents various types of taxonomy, such as deterministic, adaptive and joint metric schemes. The CH election cost is compared with cluster development and CHs distribution. Moreover, necessity of scalable, energy efficient and stable clustering schemes is placed forward for WSN.

Here, in [25], the authors state the overall cluster formation techniques in WSN. They review a simple organization of the only three considerations during cluster formation, namely, centralized or distributed CH formation, single-hop or multihop intra- and inter clusters communication. They also highlight some issues in WSN and introduce few routing methods.

Review paper in [26] discusses three noticeable benefits of clustering approaches, such as high scalability, less outflows, and easy preservation. The authors present an organization of WSN cluster structures and eight cluster characteristics. They have studied some energy efficient cluster-based WSN protocols, namely, HCC, LEACH, PEGASIS, HEED, TEEN, APTEEN, ACE, EECS, EEUC, PEACH, FLOC, LID, DCA, 3HBA, and CDS. In [26], each algorithm is measured based on clustering head election characteristic and clustering characteristics. A survey on cluster-based WSN protocols discusses the important issues of five famous cluster-based WSN algorithms, namely, TL-LEACH, EECS, EEUC, HEED, and LEACH in [27]. The authors compare all these cluster based protocols based on various metrics, such as uniformity of CH distribution, residual energy, distance of hop, cluster size, and delay and cluster formation techniques. Another study is conducted in [28] which compares various cluster based algorithms. They present some basic ideas associated with the clustering procedure. They examine LEACH-based protocols with active and reactive protocols in WSN and compare the major performance metrics of these algorithms.

Design issues and comparative study of cluster-based WSN algorithms to improve the network lifetime are studied in [29]. Authors in [22] highlight various challenging elements that affect the design of clustering protocols. Moreover, several effective classical cluster-based schemes in WSNs with comparative study are conversed in the article.

ISSN (Online) 2581-9429
IJARST
International Journal of Advanced Research in Science & Technology (IJARST)
Volume 2, Issue 4, June 2020

III. Overview of Cluster-Based WSN

3.1. What Is Cluster-Based Network?

The performance of the flat network may degrade once the size of the network increases. This is because of the fact that increasing the network size and control overhead in wireless sensor network also leads to the relevant increases. Clustering is one of the widely investigated solutions to scale down the large flat sensor network and to make the network operations more efficient.

In clustering, the network is organized into logical groups which depend on network characteristics and applications' requirements. Cluster-based WSN has various advantages as compared to flat WSN, such as energy efficiency and prolonging network lifetime [19]. Cluster-based WSNs are defined as a hierarchal organization of sensor network. Numerous researches emphasize the operative and proficient clustering structures for WSN. Typically, in a cluster-based architecture, network is divided into virtual groups as shown in Figure 1.

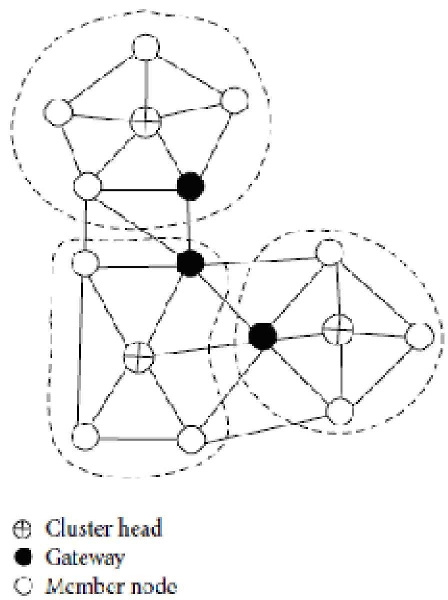

Figure 1: Cluster-based network.

Figure 1 describes cluster-based network where the network is logically divided into clusters represented by dotted lines. There may exist three types of nodes in the network, namely, cluster head (CH), gateway (GW), and member node (MN). In a cluster, cluster-head is the local coordinator that aggregates and forwards data to base station. Meanwhile, member nodes (MNs) are the leaf nodes that send data to cluster-head. Nodes, which lay between two clusters, are known as gateway nodes, where the gateways connect two or more cluster heads. The advantage of the gateway node is to form a predefined multihop inter cluster communication route, known as backbone of the network. Each CH retains neighboring GWs' information in its routing table where the routing table helps the CHs to make routing decision promptly. Backbone makes the data communication more efficient. The various features of cluster-based WSN are summarized as follows.

3.1.1. Features of Cluster-Based WSN

Data Fusion: During data fusion, CHs gather data from different nodes and send them to the base station (BS). Data fusion also eliminates redundant data on CH level, which eliminates extra burden on sensor nodes during communication. Hence, data fusion enhances the overall network lifetime [30] and reserves the entire network energy [31].

Data Load Management: Cluster provides efficient data load management and uniform network lifetime. CHs, closer to the BS, experience extra data loads in order to relay data from upper layers. To overcome this problem, CHs, which are closer to the BS, keep lesser member nodes to diminish load. Thus, the entire nodes have equal energy exhaustion, and network lifetime becomes uniform [32].

Efficient Energy Saving: In flat networks, data is transmitted through flooding, whereas in cluster-based network data is aggregated on CH level and sends it to the BS via multihop routing. Multihop routing in cluster-based network helps in decreasing the number of transmission paths, which saves energy exponentially [33].

Relay Node: Network is partitioned or disconnected when nodes fail to communicate. The relay node is used to re-establish the path and join the partitions. Relay node can be static or mobile. However, initial task of a static node is to find out the disjoint portion and then to deploy relay node there. However, mobile relay node is a special type of node which places itself in disjoint portion [34].

Robustness: Once the cluster-based WSN is formed, the second important step is cluster maintenance. Cluster maintenance is useful to maintain the network integrity. It handles different scenarios, such as changing network size, movements in nodes, and unexpected operational flaw. Clustering algorithms merely require managing these variations within each cluster. Therefore, cluster maintenance makes the network highly robust and more convenient in topological manipulations.

Collision Avoidance: In sensor network, when single channel is considered it is shared among sensor nodes. Thus, the performance of the network decreases when many nodes send data concurrently which causes collision. This can be efficiently solved in cluster-based WSN, where CH assigns unique time slot to every member node via scheduling [35].

Latency Reduction: Latency refers to the total time that a message requires to travel from source to destination node. Cluster-based WSN enhances the delivery performance of the packet by maintaining routing table at the CH level to make efficient routing decision. Moreover, cluster-based networks grounded on connected dominating set (CDS) form a predefined communication pathway called backbone tree, which enables quick and efficient multihop routing [32].

Secure Data Communication: As data aggregation is performed by CH, malicious nodes may attack to alter or hack data. In cluster-based WSN, strong authentication schemes are developed to avoid malicious nodes joining the network. These schemes improve data integrity and confidentiality [30].

Fault Tolerance: Sensor nodes may be affected by hardware failure, delay, interference, energy exhaustion, and so forth. Due to such constraints, where the nodes are not replaceable in harsh atmosphere, cluster-based protocols are suitable. Therefore, WSNs must have the ability to reconfigure themselves without human intervention, particularly in harsh environments and inaccessible locations. In order to secure aggregated data, fault tolerance technique needs to be considered during protocol design stage. Cluster maintenance and CH backup are more feasible techniques to secure the entire network reconstruction when CH is malfunctioning [36, 37].

Data Communication Assurance: CH sends the aggregated data to the base station through single-hop or multihop routing. In mobile network, the probability of data loss takes keen interest in recent researches because of its high chance of occurrence. To handle such problems in mobile node, the node sends a joint request to its CH before the actual data communication takes place. If the sender receives the acknowledgement message, then it initiates data transmission; otherwise the sender node considers that it is no more a part of the network and that it needs to rejoin the network. When the node is rejoined, the network then initiates data sending to parent node. Thus, connectivity assurance between member nodes and their CH is a crucial task for successful data delivery [38].

Deadlock Prevention: In multihop communication, data is transmitted to the base station using intermediate nodes. In this criterion, different nodes relay the data to the base station. Thus, the node closer to the sink node is overburdened with more information as compared to far nodes. Therefore, nodes, closer to the BS, deplete energy quicker, and deadlock occurs near the BS. This may cause the partition of the entire network into groups. Consequently, the far nodes may not be able to approach BS because of the limited range. Meanwhile, other nodes still have energy. To handle such problems, load balanced clusters were investigated, where a cluster, nearer to base station, retains smaller number of MNs than a cluster far from the base station. Therefore, nearer CH maintains enough energy for inter cluster communication. Consequently, deadlock prevention can be efficiently handled by using unequal size cluster [39, 40].

Network Lifetime: Increasing of network lifetime is an important consideration as nodes retain limited power, bandwidth, and processing capabilities. Typically, it is a highly crucial task to optimize a few problems in WSNs, such as intra cluster communication cost, redundant data gathering, and uniform cluster loads. Such factors are taken into consideration during CH election, which extends the lifetime of the network. Moreover, higher energy route is prioritized for data transmission, where such criterion adopts uniformed energy depletion in the network and enhances network lifetime [41, 42].

Efficient Quality of Services: The functionalities and network applications of WSN prompt the prerequisite of quality of service (QoS). Typically, effective QoS parameters are end-to-end delay, reliability, throughput, jitter, and bandwidth. It is difficult to satisfy all the necessities of QoS parameters in cluster-based protocols. Trade-off is required to consider one or more QoS parameters based on application requirements. The state-of-the-art cluster-based protocols emphasize the energy efficiency, rather than QoS. QoS issues are considered for real time application domain, such as healthcare application, battlefield applications, and event observing [43, 44].

IV. PERFORMANCE METRICS OF CLUSTER-BASED WSN

In this section, a set of performance metrics are enumerated which can be used to categorize and differentiate cluster based WSN algorithms. One of the benefits of clustering is to make network scalable in situation when sensor nodes' number is huge. Nevertheless, there are downsides of using a cluster-based network, such as higher cost overhead during network construction as compared to flat sensor network. Cost of clustering is an important parameter to authenticate the effectiveness of the scheme. Moreover, it also refers to the improvement of network structure in terms of network scalability. Based on these parameters, the cost of clustering is evaluated more efficiently.

Cluster Formation: Cluster formation is the setup phase of building cluster-based architecture from flat sensor network. Cluster formation is divided into two categories, namely, network model and cluster-head election.

(i) Network Model. Network model represents the characteristics of a network. Two basic components of network model are described below.

- **(a) Node Type.** A node can be of two types, either mobile node or stationary node. In the former way, CHs, MNs, or GWs or all three can be mobile. Therefore, mobile node (CH or MN) changes its position dynamically in terms of other nodes. A challenging problem in such scenario is to retain cluster for long time and to overcome problems associated with packet loss. On the other hand, in stationary nodes, CHs, MNs, and GWs are the static nodes that do not change their positions in terms of other nodes [22].
- **(b) Network Type**. In WSN, cluster formation is either distributed or centralized. In centralized technique, a base station or CH needs universal information about the sensor network. In the distributed technique, a node becomes either CH or member node without the entire network information.

(ii) *Cluster-Head Election*. CH election can be of different types: ID-based heuristic [45], degree-based heuristic [46], coverage based heuristic [47], and greater weight based heuristic. In ID-based heuristic, node ID is taken into consideration for CH election, like a smallest ID node becomes CH. In degree-based heuristic, quantity of neighbors is considered for CH election, while collaborative cover based heuristic considers average hop distance between two communicating nodes. It is indicated in [48] that the degree based heuristic is better than ID-based heuristic in recognizing smaller size CDSs. However, collaborative cover heuristic [47] is better than degree-based heuristic in recognizing smaller size CDSs. Moreover, in weight based clustering, various parameters are considered to elect CH, such as remaining energy, communication cost, and distance. In weight based criterion, a node is elected as a CH based on energy cost.

Cluster Complexity: Cluster complexity defines the transmission complexity of the network. There are two types of cluster complexity, namely, computational complexity and communication complexity.

(i) **Computational Round/Time Complexity.** Computational round specifies the total number of rounds in which cluster formation is accomplished. Computational round is a significant metric in cluster formation for static and mobile sensor network. It indicates an unbound time complexity in mobile sensor nodes. Hence, the more round results more data communication which decreases the efficiency of clustering algorithms [49].

(ii) **Communication Complexity/ Message Complexity**. Message complexity is categorized into three types that are data aggregation, broadcasting, and multicasting. Converge-casting is an example of data aggregation that is performed at CH level and initiated from bottom to top manner towards the base station (BS). In broadcasting, messages are disseminated from top (base station) and go down in the entire network [50], while in multicasting, messages are disseminated from one node to set of nodes. Moreover, communication complexity is also dependent on the number of edges.

(iii) **Control Message.** During network formation and maintenance, nodes exchange control information, which is unlike data message. Control message is directly proportional to energy depletion of a node. Moreover, the control information results in more energy depletion and vice versa. All the studied algorithms in this paper are evaluated via three scales: low, medium, and high [51, 52].

Cluster Communication: Cluster communication is a data sending mechanism from MNs to CH and from CH to base station. There are two types of data communication mechanism and those are intra-cluster and inter-cluster.

(i) **Intra-cluster Communication**. In cluster-based WSN, intra-cluster communication is diversified into two approaches, such as single-hop intra-cluster communication manner and multiple-hop intra-cluster communication manner. In the case of single-hop intra-cluster, all MNs in the cluster send data to the corresponding CH straightly, while in multihop intra-cluster data moves through intermediate MNs in order to convey the message to the corresponding CH. Single-hop intra-cluster performs efficiently comparatively multihop intra-cluster communication in terms of energy conservation [53, 54].

(ii) **Inter-cluster Communication**. In cluster-based WSN, inter-cluster communication is also diversified into two classes which are single-hop inter-cluster communication manner and multiple-hop inter-cluster communication manner. In the case of inter-cluster singlehop, all CHs communicate with the BS directly. In contrast, data is relayed through intermediate nodes towards base station in inter-cluster multiple-hop. To increase scalability of sensor network, multihop inter-cluster communication performs efficiently as compared to single-hop inter-cluster routing.

Cluster Management: Cluster management deals with the topological manipulation in the cluster-based WSN. It is categorized into two types: cluster maintenance and domino effects.

(i) **Cluster Maintenance**. Cluster-based network formation deals with the clusters formation, where cluster maintenance handles the topological changes when clusters are formed. Cluster topology manipulates new neighboring node discovery or the existing node leaving the cluster-based network. Thus, cluster maintenance deals with updating the cluster structure according to the change network topology. If clustering scheme is not scalable enough to facilitate cluster maintenance, then it results in domino effects. Thus, the whole network needs to be rebuilt from scratch.

(ii) **Domino Effects**. There are some situations where cluster-based network is rebuilt from scratch due to damage or movement of sensor node. Such situation occurs when cluster has no maintenance mechanism. In other words, domino effect results in reclustering the entire network when the existing nodes want to leave or new nodes want to join the network while maintenance mechanism is absent in the network.

References

[1]. E. M. Belding-Royer, "Hierarchical routing in ad hoc mobile networks," *Wireless Communications and Mobile Computing*, vol. 2, no. 5, pp. 515–532, 2002.

[2]. J. I. Bangash, A. H. Abdullah, M. H. Anisi, and A.W. Khan, "A survey of routing protocols in wireless body sensor networks," *Sensors*, vol. 14, no. 1, pp. 1322–1357, 2014.

[3]. D. Karaboga, S. Okdem, and C. Ozturk, "Cluster based wireless sensor network routing using artificial bee colony algorithm," *Wireless Networks*, vol. 18, no. 7, pp. 847–860, 2012.

[4]. P. Jiang, Y. Xu, and F. Wu, "Node self-deployment algorithm based on an uneven cluster with radius adjusting for underwater sensor networks," *Sensors*, vol. 16, no. 1, p. 98, 2016.

[5]. P. Jiang, J. Liu, B. Ruan, L. Jiang, and F. Wu, "A new node deployment and location dispatch algorithm for underwater sensor networks," *Sensors*, vol. 16, no. 1, p. 82, 2016.

[6]. E. Valero, A. Sivanathan, F. Bosch´e, and M. Abdel-Wahab, "Musculoskeletal disorders in construction: a review and a novel system for activity tracking with body area network," *Applied Ergonomics*, vol. 54, pp. 120–130, 2016.

[7]. J. Zymunt and J. Y. H. Haas, "Gossip-based ad hoc routing," in *Proceedings of the 21st Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM '02)*, vol. 3, pp. 1707–1716, IEEE, 2002.

[8]. C. Intanagonwiwat, R. Govindan, D. Estrin, J. Heidemann, and F. Silva, "Directed diffusion for wireless sensor networking," *IEEE/ACM Transactions on Networking*, vol. 11, no. 1, pp. 2–16, 2003.

[9]. Y. Pang, Y. Guo, X. Xue, and C. F. Martin, "A POMDP based routing model to enhance directed diffusion in wireless sensor networks," in *Proceedings of the International Conference on Control Engineering and Communication Technology (ICCECT '13)*, pp. 180–183, IEEE Computer Society, 2013.

[10]. D. Braginsky and D. Estrin, "Rumor routing algorithm for sensor networks," in *Proceedings of the 1st ACM International Workshop on Wireless Sensor Networks and Applications (WSNA '02)*, pp. 22–31,ACM,Atlanta,Ga, USA, September 2002.

[11]. P. Gupta and P. R. Kumar, "The capacity of wireless networks," *IEEE Transactions on Information Theory*, vol. 46,no. 2, pp. 388–404, 2000.

[12]. K.Xu, X. Hong, and M. Gerla, "An ad hoc network with mobile backbones," in *Proceedings of the International Conference on Communications (ICC '02)*, pp. 3138–3143, May 2002.

[13]. A. Sinha and D. K. Lobiyal, "Performance evaluation of data aggregation for cluster-based wireless sensor network," *Human-Centric Computing and Information Sciences*, vol. 3, article 13, pp. 1–17, 2013.

[14]. C. E. Perkins, E. M. Royer, S. R. Das, and M. K. Marina, "Performance comparison of two on-demand routing protocols for ad hoc networks," *IEEE Personal Communications*, vol. 8, no. 1, pp. 16–28, 2001.

[15]. N. Vlajic and D. Xia, "Wireless sensor networks: to cluster or not to cluster?" in *Proceedings of the International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM '06)*, pp. 258–266, IEEE Computer Society, Buffalo-Niagara Falls, NY, USA, June 2006.

[16]. J. Y. Yu and P. H. J. Chong, "A survey of clustering schemes for mobile ad hoc networks," *IEEE Communications Surveys & Tutorials*, vol. 7, no. 1, pp. 32–48, 2005.

[17]. X. Liu, "A survey on clustering routing protocols in wireless sensor networks," *Sensors*, vol. 12, no. 8, pp. 11113–11153, 2012.

[18]. A. A. Abbasi and M. Younis, "A survey on clustering algorithms for wireless sensor networks," *Computer Communications*, vol. 30, no. 14-15, pp. 2826–2841, 2007.

[19]. P. Kumarawadu, D. J. Dechene, M. Luccini, and A. Sauer, "Algorithms for node clustering in wireless sensor networks: a survey," in *Proceedings of the 4th International Conference on Information and Automation for Sustainability (ICIAFS '08)*, pp. 295–300, December 2008.

[20]. B. P. Deosarkar, N. S. Yadav, and R. P. Yadav, "Cluster head selection in clustering algorithms for wireless sensor networks: a survey," in *Proceedings of the International Conference on Computing, Communication and Networking (ICCCN '08)*, pp. 1–8, IEEE, St. Thomas, Virgin Islands, USA, December 2008.

[21]. C.Wei, J. Yang, Y. Gao, and Z. Zhang, "Cluster-based routing protocols in wireless sensor networks: a survey," in *Proceedings of the International Conference on Computer Science and Network Technology (ICCSNT '11)*, pp. 1659–1663, IEEE, Harbin, China, December 2011.

[22]. C. Jiang, D. Yuan, and Y. Zhao, "Towards clustering algorithms in wireless sensor networks-a survey," in *Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC '09)*, Budapest, Hungary, April 2009.

[23]. O. Boyinbode, H. Le, and M. Takizawa, "A survey on clustering algorithms for wireless sensor networks," *International Journal of Space-Based and Situated Computing*, vol. 1, no. 2/3, pp. 130–136, 2011.

[24]. L. M. Arboleda C and N. Nasser, "Comparison of clustering algorithms and protocols for wireless sensor networks," in *Proceedings of the Canadian Conference on Electrical and Computer Engineering (CCECE '06)*, pp. 1787–1792, Ottawa, Canada, May 2006.

[25]. M.Haneef and D. Zhongliang, "Design challenges and comparative analysis of cluster based routing protocols used in wireless sensor networks for improving network life time," *Advances in Information Sciences and Service Sciences*, vol. 4, no. 1, pp. 450–459, 2012.

[26]. S. Ozdemir and Y. Xiao, "Secure data aggregation in wireless sensor networks: a comprehensive overview," *Computer Networks*, vol. 53, no. 12, pp. 2022–2037, 2009.

[27]. R. Rajagopalan and P. K. Varshney, "Data aggregation techniques in sensor networks: a survey," *IEEE Communications Surveys and Tutorials*, vol. 8, no. 4, pp. 48–63, 2006.

[28]. J. He, S. Ji, Y. Pan, and Y. Li, "Greedy construction of load balanced virtual backbones in wireless sensor networks," *Wireless Communications and Mobile Computing*, vol. 14, no. 7, pp. 673–688, 2014.

[29]. K. Maraiya, K. Kant, and N. Gupta, "Wireless sensor network: a review on data aggregation," *International Journal of Scientific & Engineering Research*, vol. 2, no. 4, pp. 1–7, 2011.

[30]. S. Lee, M. Younis, and M. Lee, "Connectivity restoration in a partitioned wireless sensor network with assured fault tolerance," *Ad Hoc Networks*, vol. 24, pp. 1–19, 2015.

[31]. S. H. Lee, S. Lee, H. Song, and H. S. Lee, "Gradual cluster head election for high network connectivity in large-scale sensor networks," in *Proceedings of the 13th International Conference on Advanced Communication Technology: Smart Service Innovation through Mobile Interactivity (ICACT '11)*, pp. 168–172, February 2011.

[32]. M. Yu,H. Mokhtar, and M. Merabti, "A survey of network management architecture in wireless sensor network," in *Proceedings of the 6th Annual Post Graduate Symposium on The Convergence of Telecommunications, Networking and Broadcasting*, 2006.

[33]. [33] M. Younis, I. F. Senturk, K. Akkaya, S. Lee, and F. Senel, "Topology management techniques for tolerating node failures in wireless sensor networks: a survey," *Computer Networks*, vol. 58, no. 1, pp. 254–283, 2014.

[34]. N. M. Freris, H. Kowshik, and P. R. Kumar, "Fundamentals of large sensor networks: connectivity, capacity, clocks, and computation," *Proceedings of the IEEE*, vol. 98, no. 11, pp. 1828–1846, 2010.

[35]. A.-F. Liu, P.-H. Zhang, and Z.-G. Chen, "Theoretical analysis of the lifetime and energy hole in cluster based wireless sensor networks," *Journal of Parallel and Distributed Computing*, vol. 71, no. 10, pp. 1327–1355, 2011.

[36]. G. Chen, C. Li, M. Ye, and J. Wu, "An unequal cluster based routing protocol in wireless sensor networks," *Wireless Networks*, vol. 15, no. 2, pp. 193–207, 2009.

[37]. A. A. Aziz,Y. A. Sekercioglu, P. Fitzpatrick, and M. Ivanovich, "A survey on distributed topology control techniques for extending the lifetime of battery powered wireless sensor networks," *IEEE Communications Surveys & Tutorials*, vol. 15, no. 1, pp. 121–144, 2013.

[38]. Y. Liao, H. Qi, and W. Li, "Load-balanced clustering algorithm with distributed self-organization for wireless sensor networks," *IEEE Sensors Journal*, vol. 13, no. 5, pp. 1498–1506, 2013.

[39]. D. Sahin, V. C. Gungor, T. Kocak, and G. Tuna, "Quality-of service differentiation in single-path and multi-path routing for wireless sensor network-based smart grid applications," *Ad Hoc Networks*, vol. 22, pp. 43–60, 2014.

[40]. D. I. Tapia, R. S. Alonso, ´ O. Garc´ıa, F. de la Prieta, and B. P´erez-Lancho, "Cloud-IO: cloud computing platform for the fast deployment of services over wireless sensor networks," in *7th International Conference on Knowledge Management in Organizations: Service and Cloud Computing*, vol. 172 of *Advances in Intelligent Systems and Computing*, pp. 493–504, Springer, Berlin, Germany, 2013.

[41]. J. Wu and H. Li, "On calculating connected dominating set for efficient routing in ad hoc wireless networks," in *Proceedings of the 3rd International Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications*, pp. 7–14, ACM, Seattle, Wash, USA, August 1999.

[42]. P.-J.Wan, K.M. Alzoubi, and O. Frieder, "Distributed construction of connected dominating set in wireless ad hoc networks," in *Proceedings of the 35th Annual Hawaii International Conference on System Sciences (HICSS '02)*, pp. 1597–1604, June 2002.

[43]. R. Misra and C. Mandal, "Minimum connected dominating set using a collaborative cover heuristic for ad hoc sensor networks," *IEEE Transactions on Parallel and Distributed Systems*, vol. 21, no. 3, pp. 292–302, 2010.

[44]. M. Cardei, X. Cheng, X. Cheng, and D.-Z. Du, "Connected domination in multihop ad hoc wireless networks," in *Proceedings of the 6th Joint Conference on Information Sciences (JCIS '02)*, pp. 251–255, March 2002.

[45]. B. Zhang, R. Simon, and H. Aydin, "Harvesting-aware energy management for time-critical wireless sensor networks with joint voltage and modulation scaling," *IEEE Transactions on Industrial Informatics*, vol. 9, no. 1, pp. 514–526, 2013.

[46]. X.-Y. Li, Y.Wang, and Y.Wang, "Complexity of data collection, aggregation, and selection for wireless sensor networks," *IEEE Transactions on Computers*, vol. 60, no. 3, pp. 386–399, 2011.

[47]. P. Huang, L. Xiao, S. Soltani, M. W. Mutka, and N. Xi, "The evolution of MAC protocols in wireless sensor networks: a survey," *IEEE Communications Surveys & Tutorials*, vol. 15, no. 1, pp. 101–120, 2013.

[48]. L. A. Villas, A. Boukerche, H. A. B. F. De Oliveira, R. B. De Araujo, and A. A. F. Loureiro, "A spatial correlation aware algorithm to perform efficient data collection in wireless sensor networks," *Ad Hoc Networks*, vol. 12, no. 1, pp. 69–85, 2014.

[49]. L. Wang, J. Yang, Y. Lin, and W. Lin, "Keeping desired QoS by a Partial coverage algorithm for cluster-based wireless sensor networks," *Journal of Networks*, vol. 9, no. 12, pp. 3221–3229, 2014.

[50]. P. T. A. Quang and D.-S. Kim, "Throughput-aware routing for industrial sensor networks: application to ISA100.11a," *IEEE Transactions on Industrial Informatics*, vol. 10,no. 1, pp. 351–363, 2014.

[51]. S. K. Gupta, N. Jain, and P. Sinha, "Energy efficient clustering protocol for minimizing cluster size and inter cluster communication in heterogeneous wireless sensor network," *International Journal of Advanced Research in Computer and Communication Engineering*, vol. 2, no. 8, 2013.

[52]. S. Sharma and S. K. Jena, "Cluster basedmultipath routing protocol for wireless sensor networks," *ACMSIGCOMM Computer Communication Review*, vol. 45, no. 2, pp. 14–20, 2015.

[53]. R.C.Carrano,D. Passos, L. C. S. Magalhaes, and C.V.N. Albuquerque, "Survey and taxonomy of duty cycling mechanisms in wireless sensor networks," *IEEE Communications Surveys and Tutorials*, vol. 16, no. 1, pp. 181–194, 2014.

[54]. C.-C. Chiang, H.-K. Wu, W. Liu, and M. Gerla, "Routing in clustered multihop, mobile wireless networks with fading channel," in *Proceedings of the IEEE Singapore International Conference on Networks (SICON '97)*, 1997.