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Unequal clustering in wireless sensor network: a review

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Article Info	ABSTRACT
	In recent time, the applications' diversity of wireless sensor network (WSN) attracts many researchers. WSN comprises of many sensor nodes with limited battery power. Therefore, energy consumption should be controlled to the optimum. Clustering is an efficient solution for energy management in WSN, but clustering does not consider the sink node location. It will cause the energy hole problem in multi-hop routing. Energy hole problem was solved by unequal clustering. A review of various unequal clustering mechanisms is presented in this paper. The comparison between the various mechanisms was based on cluster head election process, cluster properties, simulation parameters and energy efficiency to highlight a more efficient and scalable unequal clustering algorithm for WSN.

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1. INTRODUCTION

Recent advances in wireless communication technologies and digital electronics have produced a small device called 'nodes'. These nodes can sense, monitor and gather important information from their surrounding environment. The collected information/data will be processed and sent to the nearest sink node through wireless sensor network (WSN) for real-time decision-making. The WSN is a low-cost wireless network that can be rapidly deployed in hard-to-reach places, such as in an underground and underwater environment. The underground sensor nodes are provided with high transmission power to overcome the noisy channel attenuation. In contrast, the underwater sensor nodes are designed to be waterproof and resistant to moisture and salinity [1-5].

Also, WSN is used in diverse applications, such as health monitoring [6-8], process monitoring [9-11], disaster prevention [12-14], and pipeline corrosion detection [15-17]. WSN is constrained by limited battery power, less bandwidth capacity, limited radio channel, and processing capabilities. Various researchers are working to overcome these constraints, especially on prolong the network lifetime by minimizing energy consumption [18-23].

Clustering is an efficient mechanism for minimizing the sensor nodes energy consumption in WSN, as illustrated in Figure 1 [24-27]. Clustering mechanism prevents every sensor nodes from sending the collected data by assigning a cluster head (CH) for every sensor members to forward the aggregated data to sink node via a single or multi-hop connection. There is two types of traffic between sensor nodes in clustering: the intra-cluster and inter-cluster traffic. The traffic between CH and its cluster members is

intra-cluster traffic while the traffic between CH to other relaying CHs till reach to the sink node is inter-cluster traffic. Clustering mechanism reduced the traffic load and extended the network lifetime. Despite these advantages, the CHs near the sink node dissipates their energy faster. They have to receive the intra-cluster traffic from their cluster members and collect and forward the inter-cluster traffic from other relaying CHs to the sink node causing the energy hole problem. Figure 1 shows the clustering approach in WSN.
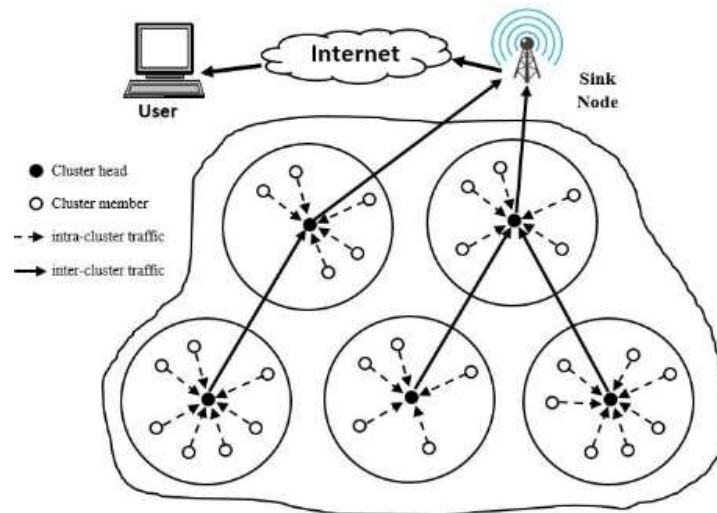

Figure 1. The clustering approach in WSN [28]

A low energy adaptive clustering hierarchy (LEACH) is the most famous clustering protocol in WSN [29]. In this type of routing protocol, a clustering mechanism is utilized to reduce the energy consumption. LEACH protocol consists of several rounds. Each round starts with the setup phase and ends with the steady-state phase. The sensor nodes received the advertisement messages from the CHs that they generated randomly and sent a join request message. Finally, each CH establishes a TDMA schedule and send it to the member nodes [30]. Every CH aggregates the collected data from its member nodes in the steady-state phase and forward it to the sink node based on single-hop communication [30].

The unequal clustering mechanism is a solution for clustering in WSN. It is adopted to reduce the cluster size near to the sink node [31-35]. In contract, the distance far from the sink node produces a large cluster size. This mechanism saved inter-cluster traffic energy by reducing the intra-cluster traffic for CHs near to the sink node. The overhead between intra-cluster and inter-cluster traffic is balanced by unequal clustering mechanism. Figure 2 shows the structure of unequal clustering mechanism.

A few survey researches works have been done for unequal clustering based on the literature, unlike clustering. The authors in [37] presented a survey of unequal clustering algorithms. They compared them based on node deployment in fields, node type, number of nodes in a cluster, energy efficiency, sink node location awareness and heterogeneous level. Another study presented by [38]. It concludes that hybrid unequal clustering with layering protocol (HUCL) perform better than others concerning network lifespan and other metrics. A comparative study between various unequal clustering algorithms is presented by [28]. They explained the clustering features for the unequal clustering technique and clarified the algorithm's nature adopted in the clustering. In [36], the objectives and unequal clustering protocols characteristics are discussed. A comparative study between different unequal clustering algorithms is presented concerning CH properties, clustering process, and cluster properties. The importance of unequal clustering algorithms in solving the energy hole problem caused by clustering in WSN and the few published survey research papers on unequal clustering algorithms motivate us to do this study. This paper compares various unequal clustering techniques based on CH election process, cluster properties, simulation parameters, and energy efficiency. Section 2 presents the mechanism used in various unequal clustering routing algorithms, while section 3 compares them. Finally, section 4 concludes the paper.
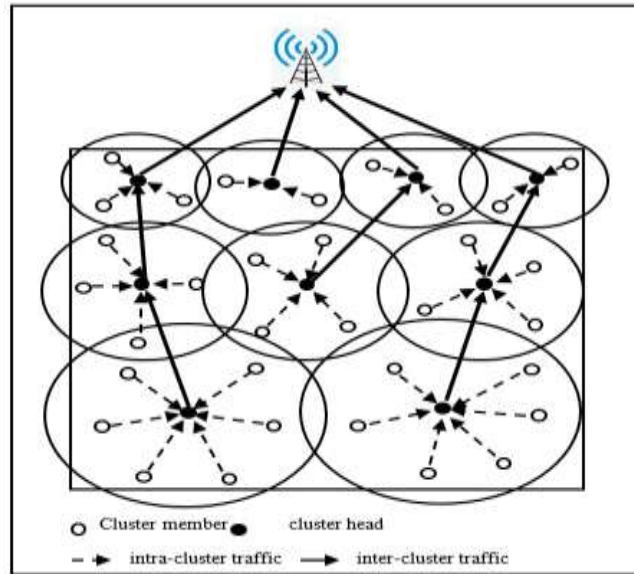
Figure 2. The structure of unequal clustering mechanism [36]

2. UNEQUAL CLUSTERING ALGORITHMS
The mechanism used in various unequal clustering algorithms is discussed in this section.

2.1. Energy efficient unequal clustering (EEUC)
EEUC is used for periodical data gathering in WSN [31]. EEUC partitioned the network into unequal cluster size to solve the energy hole problem by calculating the distance between sensor nodes and sink node based on received signal strength. Unequal cluster size produces a small cluster near to sink node to save energy for inter-cluster traffic. Several temporally CHs are selected in EEUC with higher residual energy based on a probability function. Suppose there is more than one temporally CH in the same competition radius. In that case, the temporally higher residual energy CH becomes the final CH, and the other CH was pushing out from the competition. EEUC adopt multi-hop communication. There is a threshold to decide whether the CH connect directly to the sink node or relaying the packet by another CH. The CH with higher residual energy is eligible to be a relaying node. EEUC outperforms LEACH and HEED in network lifetime and energy consumption but considers only residual energy as a metric to choose CH.

2.2. Improved energy efficient unequal clustering (I-EEUC)
I-EEUC is an improved version of EEUC to solve the energy hole problem of clustering [39]. I-EEUC adopt a flooding method for distance calculation between sensor nodes and sink node based on hops rather than received signal strength that has been adopted in EEUC. The flooding method is more accurate than received signal strength when there are obstructions in the network. The node degree for each node in IEEUC is determined based on hops. The transmission radius is adjusted based on node degree to save energy for inter-cluster communication by reducing the cluster size near to sink node. The selection of CH in I-EEUC is same as EEUC. After the clusters are formed, the hops play an essential role to create a communication link between CH and its node members. I-EEUC performs better than EEUC in energy consumption and uses only the residual energy as a metric to choose CH.

2.3. Energy-aware unequal clustering with fuzzy (EAUCF)
EAUCF is a distributed, competitive unequal clustering algorithm to address the hot spot problem in WSN [40]. In EAUCF, a random number is generated randomly by every sensor node in each round to compare it with the predefined threshold value. The threshold value is the desired CHs percentage temporally. The node becomes a temporally CH when its random number less than a predefined threshold. Unlike EEUC, EAUCF calculates the competition radius for each temporally CH based on the distance to the sink node and residual energy. The competition radius is the range in which the temporally CH advertising message can reach the nearby nodes-the fuzzy logic approach utilized by EAUCF to calculate the competition radius. The distance to the sink node and residual energy are two fuzzy input variables. Based on the two fuzzy variables, the temporally CH node decreases its competition radius dynamically when its energy becomes low and near the sink node to avoid the dead node. After every temporally CH node

calculates the competition radius, the temporally CH nodes start the CH competitive phase by sending the candidate CH message. The higher residual energy node wins the competition and becomes the final CH. The final CH node sends the join request message to the nodes within its competition radius to form a cluster. EAUCF balances the energy load between sensor nodes better than LEACH and EEUC but does not consider the node degree in the CH selection process.

2.4. Distributed load balancing unequal clustering using fuzzy logic (DUCF)

DUCF is a distributed scheme for uniform distribution of energy between CHs to solve the clustering problem [41]. There are two phases in DUCF cluster formation and data aggregation. In the cluster formation phase, node degree, residual energy and distance to sink node are three input variables for the fussy inference system (FIS). The output of FIS is chance and size. Chance is used to choosing the CH while size partition the network into a cluster of unequal size to ensure small cluster size near the sink node. DUCF adopts a multi-hop connection between CHs to deliver data packets to sink node and preserve energy for inter-cluster traffic in data aggregation phase. Based on the simulation results, DUCF performs better than LEACH, CHEF and EAUCF.

2.5. Unequal-clustering routing algorithm (UCRA)

The unequal clustering algorithm (UCA) is combined with multi-hop routing to form a UCRA [42]. The UCA start in the deployment stage in which the sink node computes its distance to each node. After that, the sink node location and maximum and minimum distance are broadcasted by sink node-this information helps produce unequal cluster size. In the next stage, each sensor node computes its competition radius. The competition radius decreases when the distance to the sink node decrease. Therefore, more clusters are produced near to the sink node to preserve more energy for inter-cluster traffic. Finally, the CHs with minimum node degree and higher residual energy are selected to form the clusters [43]. After the clusters are formed, the CHs start to aggregate the collected information from their member nodes.

The source CH calculates the optimal one-hop distance and its distance to the sink node in the multi-hop routing algorithm. Based on the location information, the source CH calculates the optimal next hop cluster member. After that, the source CH broadcasts the query message to nearby CHs. The CH receiver this message calculates their distance to the sink node. If their distance is less than source CH distance, the nearby CHs reply to the source CH. Then, the source CH calculates the distance between the nearby CHs and its optimal next-hop member node to find the nearby CH closest to the optimal next-hop member node. Finally, the packet is routed from the source CH to the nearby CH, and the procedure is repeated to reach the sink node. The optimal next-hop member node serves as an alternative relay node when there is no relay CH node. UCRA outperforms HEED and EEUC by minimizing the speed of the first node dies but ignores the sink node location in the CH election process.

2.6. Fuzzy logic based unequal clustering (FBUC)

FBUC is an improvement version of EAUCF [44]. At the first round of FBUC, a random number generates for each node. Unlike EAUCF, FBUC uses probabilistic threshold value. The node becomes a candidate CH when its random number less than a predefined threshold value. After that, the fuzzy logic with three variables is used to calculate the candidate CHs competition radius. The node degree, residual energy, and distance to the sink node are the three variables. The node degree variable ensures that competition radius for the candidate CH near to the sink node has a small size. Each candidate CH calculates its competition radius and send CH message to its neighbours, including its ID, residual energy and competition radius. The candidate CH becomes a final CH when its residual energy greater than the neighbour nodes. The member nodes use two fuzzy variables: distance to the sink node and node degree to join the appropriate CH. The member node chooses the CH that has a minimum distance to it and less node degree. FBUC outperforms LEACH and EAUCF in the energy consumption and network lifetime but uses only three fuzzy variables: close, medium and far for the distance to the sink node. Therefore, these three variables are not appropriate for a large scale network.

2.7. Unequal clustering based on network partition and distance (UCNPD)

UCNPD is proposed by [45] to consider energy balancing based on network partition and distance. In the initial stage, UCNPD calculates the distance between the sink node and sensor nodes based on the received signal strength indicator (RSSI). The network in UCNPD is partitioned to near area nodes and non-near area nodes. The near area nodes are responsible for forwarding the inter-cluster packets directly to the sink node via single-hop communication. These nodes do not participate in the cluster reconstruction to maintain their energy for relaying packets to the sink node. In the clustering stage, the non-near area nodes calculate the competition radius. Once the competition radius information is transmitted, they count the node

degree. After that, a timing time is calculated by each node to choose a CH. During this time, the nodes that will receive a broadcast message leave the competition and wait for the state while the node that does not receive any message becomes a CH and broadcasts a CH message. Then, the waiting nodes form the cluster with the appropriate CH. The nodes with higher residual energy, larger competition radius and higher node degree are more eligible to become a CH. After the clusters are formed, the CHs collect and aggregate information from their cluster members. The CH forward the information to the sink node via intermediate CH and choose the next hop according to the selected function. The higher residual energy and lower degree node become the next hop CH node. The near area nodes construct a CH with zero member nodes and forward the received information directly to the sink node. UCNPD balance the energy consumption between sensor nodes better than LEACH, EEUC and I-EEUC but not pay attention to the residual energy in the competition radius calculation.

2.8. Unequal cluster-radius based on node density (URBD)

URBD is a distributed clustering algorithm to solve the energy hole problem in WSN [46]. It starts with the CH selection phase in which the cluster's maximum arbitrary radius (R_T) is assigned to each sensor node. The R_T is updated when the distance to the sink node by every sensor node is specified. It generates unequal cluster size with a decreasing radius as it approaches the sink node. The nodes that do not receive a control message can calculate their distance to the sink node based on another node's information. Hence, network scalability will increase. After every node calculated their size, they start to send a query message within their R_T to find their neighbours. Finally, a random number is generated for each node to become a CH and calculates the probability value and send it to its neighbours. The nodes compare the received probability values from other nodes and leave the competition if they value less than the received value. The advantage of URBD is that the competition does not repeat in every round. This mechanism mitigates the control overhead in the network. Since the current CH know its member nodes distance and residual energy, the node with minimum distance and higher residual energy become the new CH.
The nodes that leave the competition in the first round calculate the scoring function and decide which CH to join. The nodes join a CH that is closest to them and less node density.

In the communication phase, CHs collect and aggregate the data from their members via intra-cluster single-hop connection and forward it to the sink node via the inter-cluster multi-hop link. URBD reduces the control overhead in the whole network and extends the network lifetime. The simulation result shows that URBD outperforms other protocols in scalability.

2.9.   Fuzzy and ant colony optimization based combined MAC, routing and unequal clustering cross-layer protocol (FAMACROW)

FAMACROW is a cross-layer protocol designed based on the combination of hierarchical clustering with MAC [47]. There are three phases in FAMACROW: network setup, neighbour finding and steady-state phase. The sensor nodes are divided into several layers in the network setup phase. Each node uses a non-persistent CSMA MAC protocol to broadcast its information to neighbouring nodes in its layer during the neighbour finding phase. The steady-state phase consists of clustering, CH selection and data delivery to the sink node. Residual energy, communication link and node degree are the three fuzzy variables used to select CH. In the clustering process, nodes in the first layer pushing out from the competition to be a CH and forward the received packets directly to the sink node. FAMACROW divided the network into unequal cluster size to mitigate the hot spot problem. FAMACROW also delivers the inter-cluster traffic to the sink node using the ant colony optimization algorithm (ACO). The residual energy, queue length, distance to sink node, and delivery likelihood are four parameters used by ACO to choose the relaying CH. FAMACROW outperforms UCR, ULCA, EAUCF, and IFUC in energy consumption, network lifetime and throughput.

2.10. Comparison between various unequal clustering routing protocols

A comparison between various unequal clustering routing protocols is illustrated in Table 1. The table started by comparing different unequal clustering algorithms based on the CH selection process parameters consisting of residual energy, node density (no. of nodes) and sink node location. Next, the comparison between various algorithms is based on clustering properties (single-hop intra-cluster and multi-hop inter-cluster). The comparison between various algorithms are subsequently based on simulation parameters used (node type, node deployment in field and sink node location). Finally, the comparison between various algorithms is based on the most critical factor in WSN routing protocol: energy efficiency. Some routing algorithms use only residual energy as a metric for CH selection while others used two or three metrics. The routing algorithms that adopt residual energy, node density and sink node location are more energy-efficient and reliable.

Table 1. A summary of various unequal clustering algorithms

| Algorithm | Parameters for CH selection | | | Cluster Properties | | Simulation parameters | | | Energy efficiency |
	RE	SN	NN	Single hop intra cluster	Multi hop inter cluster	Node type	Node deployment in fields	Sink node location	
EEUC	√	×	×	√	√	homogenous	Square field	outside	Better than LEACH & HEED
I-EEUC	√	×	×	√	√	homogenous	Square field	outside	Better than LEACH & EEUC
EAUCF	√	√	×	√	√	homogenous	Square field	outside	Better than LEACH, CHEF and EEUC
DUCF	√	√	√	√	√	homogenous	Square field	outside	Better than LEACH, CHEF and EAUCF
UCRA	√	×	√	√	√	homogenous	Square field	outside	Better than HEED & EEUC
FBUC	√	√	√	√	√	homogenous	Square field	outside	Better than LEACH & EAUCF
UCNPD	√	√	√	√	√	homogenous	Square field	outside	Better than LEACH, EEUC and I-EEUC
URBD	√	√	√	√	√	homogenous	Square field	inside	Better than LEACH, EEUC, & EAUCF
FAMACROW	√	×	√	√	√	homogenous	Square field	inside	Better than UCR, ULCA, EAUCF, and IFUC

Note: CHEF: cluster head election using fuzzy logic; HEED: hybrid energy-efficient distributed; RE: residual energy; SN: sink node; NN: number of nodes;
ULCA: unequal layered clustering approach; IFUC: improved fuzzy unequal clustering

3.   CONCLUSION

Unequal clustering eliminates the energy hole problem caused by clustering by distributing the energy load between sensor nodes and extending the network lifetime. We reviewed various unequal clustering proposed algorithms in this paper. We compared them based on CH selection parameters, cluster properties, simulation parameters and energy-efficient. EEUC and I-EEUC choose a CH with higher residual energy. UCRA ignores the sink node location while EAUCF does not consider the node density. DUCF, FBUC, UCNPD, URBD and FAMACROW use distance to the sink node, node density, and residual energy as a metrics for CH selection perform better in reducing the energy consumption between sensor nodes. Despite DUCF, FBUC and UCNPD use triple metrics to choose CH like URBD and FAMACROW, but URBD adopts a dynamic competition radius. Also, nodes that have not received a control message from the sink node calculate their distance via another nodes knowledge to increase the scalability. FAMACROW use delivery likelihood in inter-cluster communication and LQI in cluster head selection process to improve reliability. We conclude that URBD is more suitable for large networks, and FAMACROW is ideal for reliable applications.

REFERENCES

[1]   H. Ouldzira, H. Lagraini, A. Mouhsen, M. Chhiba, and A. Tabyaoui, "MG-leach: an enhanced leach protocol for wireless sensor network.," *Int. J. Electr. Comput. Eng.*, vol. 9, no. 4, pp. 3139-3145, 2019.
[2]   Q. A. Gian, D. T. Tran, D. C. Nguyen, and T. D. Bui, "Flexible Configuration of Wireless Sensor Network for Monitoring of Rainfall-Induced Landslide," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 12, no. 3, pp. 1030-1036, 2018.
[3]   K. W. Al-Ani, A. S. Abdalkafor, and A. M. Nassar, "An overview of wireless sensor network and its applications," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 17, no. 3, pp. 1480-1486, 2019, doi: 10.11591/ijeecs.v17.i3.pp1480-1486.
[4]   S. Fattah, A. Gani, I. Ahmedy, M. Y. I. Idris, and I. A. T. Hashem, "A survey on underwater wireless sensor networks: Requirements, taxonomy, recent advances, and open research challenges," *Sensors (Switzerland)*, vol. 20, no. 18, pp. 1-30, 2020, doi: 10.3390/s20185393.
[5]   M. A. Akkaş and R. Sokullu, "Wireless underground sensor networks: Channel modeling and operation analysis in the terahertz band," *Int. J. Antennas Propag.*, 2015, doi: 10.1155/2015/780235.
[6]   U. Gogate and J. Bakal, "Healthcare monitoring system based on wireless sensor network for cardiac patients," *Biomed. Pharmacol. J.*, vol. 11, no. 3, pp. 1681-1688, 2018, doi: 10.13005/bpj/1537.
[7]   M. Abdulkarem, K. Samsudin, F. Z. Rokhani, and M. F. A Rasid, "Wireless sensor network for structural health monitoring: A contemporary review of technologies, challenges, and future direction," *Struct. Heal. Monit.*, vol. 19, no. 3, pp. 693-735, 2020, doi: 10.1177/1475921719854528.

[8]   M. Aminian, "A Hospital Healthcare Monitoring System Using Wireless Sensor Networks," *J. Heal. Med. Informatics*, vol. 04, no. 02, pp. 4-9, 2013, doi: 10.4172/2157-7420.1000121.

[9]   J. Aponte-Luis, J. A. Gómez-Galán, F. Gómez-Bravo, M. Sánchez-Raya, J. Alcina-Espigado, and P. M. Teixido-Rovira, "An efficient wireless sensor network for industrial monitoring and control," *Sensors (Switzerland)*, vol. 18, no. 1, 2018, doi: 10.3390/s18010182.

[10]   G. Zhao, "Wireless Sensor Networks for Industrial Process Monitoring and Control: A Survey," *Netw. Protoc. Algorithms*, vol. 3, no. 1, pp. 46-63, 2011, doi: 10.5296/npa.v3i1.580.

[11]   M. Erdelj *et al.*, "Applications of Industrial Wireless Sensor Networks," *CRC Press*, 2013, https://hal.inria.fr/hal-00788629.

[12]   Di. Pant, S. Verma, and P. Dhuliya, "A study on disaster detection and management using WSN in Himalayan region of Uttarakhand," *Proc. - 2017 3rd Int. Conf. Adv. Comput. Commun. Autom. (Fall), ICACCA 2017*, vol. 2018-Janua, 2018, pp. 1-6, doi: 10.1109/ICACCAF.2017.8344703.

[13]   R. K. Jha, A. Singh, A. Tewari, and P. Shrivastava, "Performance analysis of disaster management using WSN technology," *Procedia Comput. Sci.*, vol. 49, no. 1, pp. 162-169, 2015, doi: 10.1016/j.procs.2015.04.240.

[14]   M. Sheik Dawood, J. Suganya, R. Karthika Devi, and G. Athisha, "A Review on Wireless Sensor Network Protocol for Disaster Management," *Int. J. Comput. Appl. Technol. Res.*, vol. 2, no. 2, pp. 141-146, 2013

[15]   M. Golshan, A. Ghavamian, A. Mohammed, and A. Abdulshaheed, "Pipeline Monitoring System by Using Wireless Sensor Network," *IOSR J. Mech. Civ. Eng.*, vol. 13, no. 3, pp. 43-53, 2016, doi: 10.9790/1684-1303054353.

[16]   M. S. A. Rahman and H. Hasbullah, "Early detection method of corrosion on buried pipeline," *Proc. 2010 Int. Symp. Inf. Technol. - Eng. Technol. ITSim'10*, vol. 2, pp. 760-764, 2010, doi: 10.1109/ITSIM.2010.5561547.

[17]   M. Y. Aalsalem, W. Z. Khan, W. Gharibi, M. K. Khan, and Q. Arshad, "Wireless Sensor Networks in oil and gas industry: Recent advances, taxonomy, requirements, and open challenges," *J. Netw. Comput. Appl.*, vol. 113, pp. 87-97, 2018, doi: 10.1016/j.jnca.2018.04.004.

[18]   H. Gou and Y. Yoo, "An Energy Balancing LEACH Algorithm for Wireless Sensor Networks," *2010 Seventh Int. Conf. Inf. Technol.*, 2010, pp. 822-827, doi: 10.1109/ITNG.2010.12.

[19]   J. Shan, L. Dong, X. Liao, L. Shao, Z. Gao, and Y. Gao, "Research on Improved LEACH Protocol of Wireless Sensor Networks," *PRZEGLĄD ELEKTROTECHNICZNY*, no. 1, pp. 75-77, 2013.

[20]   W. Lee, K. D. Jung, and J. Y. Lee, "Improvement of cluster head selection of leach protocol," *Int. J. Appl. Eng. Res.*, vol. 12, no. 20, pp. 10002-10006, 2017.

[21]   G. N. Basavaraj and C. D. Jaidhar, "Low latency and energy efficient cluster based routing design for wireless sensor network," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 13, no. 2, pp. 615-625, 2019.

[22]   A. O. Abu Salem and N. Shudifat, "Enhanced LEACH protocol for increasing a lifetime of WSNs," *Pers. Ubiquitous Comput.*, vol. 23, pp. 901-907, 2019, doi: 10.1007/s00779-019-01205-4.

[23]   H. Liang, S. Yang, L. Li, and J. Gao, "Research on routing optimization of WSNs based on improved LEACH protocol," *EURASIP J. Wirel. Commun. Netw.*, vol. 2019, no. 1, 2019, doi: 10.1186/s13638-019-1509-y.

[24]   W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, "An application-specific protocol architecture for wireless microsensor networks," *IEEE Trans. Wirel. Commun.*, vol. 1, no. 4, pp. 660-670, 2002.

[25]   O. Boyinbode, H. Le, A. Mbogho, M. Takizawa, and R. Poliah, "A survey on clustering algorithms for wireless sensor networks," *Proc. - 13th Int. Conf. Network-Based Inf. Syst. NBiS 2010*, 2010, pp. 358-364, doi: 10.1109/NBiS.2010.59.

[26]   V. Geetha, P. V. Kallapur, and S. Tellajeera, "Clustering in Wireless Sensor Networks: Performance Comparison of LEACH & LEACH-C Protocols Using NS2," *Procedia Technol.*, vol. 4, pp. 163-170, 2012, doi: 10.1016/j.protcy.2012.05.024.

[27]   H. Ennajari, Y. Ben Maissa, and S. Mouline, "Energy efficient in-network aggregation algorithms in wireless sensor networks: A survey," *Lect. Notes Electr. Eng.*, vol. 397, pp. 135-148, 2017, doi: 10.1007/978-981-10-1627-1_11.

[28]   S. Arjunan and S. Pothula, "A survey on unequal clustering protocols in Wireless Sensor Networks," *J. King Saud Univ. - Comput. Inf. Sci.*, vol. 31, no. 3, pp. 304-317, 2019, doi: 10.1016/j.jksuci.2017.03.006.

[29]   H. Heinzelman, W., Chandrakasan, A., and Balakrishnan, "Energy-Efficient Communication Protocols for Wireless Microsensor Networks, " *Proceedings of the 33rd Hawaaian International Conference on Systems Science (HICSS)*, January 2000, pp. 1-10.

[30]   A. Al-Shaikh, H. Khattab, and S. Al-Sharaeh, "Performance comparison of LEACH and LEACH-C protocols in wireless sensor networks," *J. ICT Res. Appl.*, vol. 12, no. 3, pp. 219-236, 2018, doi: 10.5614/itbj.ict.res.appl.2018.12.3.2.

[31]   C. Li, M. Ye, G. Chen, and J. Wu, "An energy-efficient unequal clustering mechanism for wireless sensor networks," in *IEEE International Conference on Mobile Adhoc and Sensor Systems Conference,* 2005.

[32]   X. Chen, Z. Yang, and H. Cheng, "Unequal clustering mechanism of LEACH protocol for wireless sensor networks," *2009 WRI World Congr. Comput. Sci. Inf. Eng. CSIE 2009*, vol. 1, pp. 258-262, 2009, doi: 10.1109/CSIE.2009.522.

[33]   P. Ren, J. Qian, L. Li, Z. Zhao, and X. Li, "Unequal clustering scheme based LEACH for wireless sensor networks," *Proc. - 4th Int. Conf. Genet. Evol. Comput. ICGEC 2010*, 2010, pp. 90-93, doi: 10.1109/ICGEC.2010.30.

[34]   B. Baranidharan, S. Srividhya, and B. Santhi, "Energy Efficient Hierarchical Unequal Clustering in Wireless Sensor Networks," vol. 7, no. March, pp. 301-305, 2014.

[35]   S. Talbi, L. Zaouche, E. Unequal, C. Algorithm, and S. Networks, "Enhanced Unequal Clustering Algorithm for

Wireless Sensor Networks," *12th ACS/IEEE International Conference on Computer Systems and Applications (AICCSA 2015),* Nov 2015, Marrakech, Morocco, 2016.

[36] A. A. H. Hassan, W. M. Shah, M. F. Iskandar, M. N. Al-Mhiqani, and Z. K. Naseer, "Unequal clustering routing algorithms in wireless sensor networks: A comparative study," *J. Adv. Res. Dyn. Control Syst.*, vol. 10, no. 2 Special Issue, pp. 2142-2156, 2018.

[37] G. VenniraSelvi and R. Manoharan, "A survey of Energy Efficient Unequal Clustering Algorithms for Wireless Sensor Networks," *Int. J. Comput. Appl.*, vol. 79, no. 1, pp. 1-4, 2013, doi: 10.5120/13702-1445.

[38] G. Kaur, "A Review on hierarchical unequal clustering based protocols in Wireless Sensor Network," no. September, pp. 96-99, 2016.

[39] P. Liu, T. L. Huang, X. Y. Zhou, and G. X. Wu, "An improved energy efficient unequal clustering algorithm of wireless sensor network," *Proc. - 2010 Int. Conf. Intell. Comput. Integr. Syst. ICISS2010*, no. 1, 2010, pp. 930-933doi: 10.1109/ICISS.2010.5657032.

[40] H. Bagci and A. Yazici, "An energy aware fuzzy unequal clustering algorithm for wireless sensor networks," *2010 IEEE World Congr. Comput. Intell. WCCI 2010*, 2010, doi: 10.1109/FUZZY.2010.5584580.

[41] B. Baranidharan and B. Santhi, "DUCF: Distributed load balancing Unequal Clustering in wireless sensor networks using Fuzzy approach," *Appl. Soft Comput. J.*, vol. 40, pp. 495-506, 2016, doi: 10.1016/j.asoc.2015.11.044.

[42] R. Zhang, L. Ju, Z. Jia, and X. Li, "Energy efficient routing algorithm for WSNs via unequal clustering," *Proc. 14th IEEE Int. Conf. High Perform. Comput. Commun. HPCC-2012 - 9th IEEE Int. Conf. Embed. Softw. Syst. ICESS-2012*, pp. 1226-1231, 2012, doi: 10.1109/HPCC.2012.180.

[43] R. Zhang, Z. Jia, and L. Wang, "A maximum-Votes and Load-balance clustering algorithm for wireless sensor networks," *2008 Int. Conf. Wirel. Commun. Netw. Mob. Comput. WiCOM 2008*, no. 1, 2008, pp. 1-4, doi: 10.1109/WiCom.2008.943.

[44] R. Logambigai and A. Kannan, "Fuzzy logic based unequal clustering for wireless sensor networks," *Wirel. Networks*, vol. 22, no. 3, pp. 945-957, 2016, doi: 10.1007/s11276-015-1013-1.

[45] D. gan Zhang, S. Liu, T. Zhang, and Z. Liang, "Novel unequal clustering routing protocol considering energy balancing based on network partition & distance for mobile education," *J. Netw. Comput. Appl.*, vol. 88, pp. 1-9, 2017, doi: 10.1016/j.jnca.2017.03.025.

[46] J. Hamidzadeh and M. H. Ghomanjani, "An Unequal Cluster-Radius Approach Based on Node Density in Clustering for Wireless Sensor Networks," *Wirel. Pers. Commun.*, vol. 101, no. 3, pp. 1619-1637, 2018, doi: 10.1007/s11277-018-5779-1.

[47] S. Gajjar, M. Sarkar, and K. Dasgupta, "FAMACROW: Fuzzy and ant colony optimization based combined mac, routing, and unequal clustering cross-layer protocol for wireless sensor networks, " *Applied Soft Computing*, vol. 43, pp. 235-247, 2016.