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A Dynamic Cluster Head Election Protocol for Mobile Wireless Sensor Networks

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Abstract—**A dynamic cluster head election protocol (DCHEP) is proposed in this work to improve network availability and energy efficiency for mobile wireless sensor networks (WSNs) under the beacon-enabled IEEE 802.15.4 standard. The proposed protocol (DCHEP) is developed and simulated using CASTALIA/OMNET++ with a realistic radio model and node behaviour. DCHEP improves the network availability and lifetime and maintains clusters hierarchy in a proactive manner even in a mobile WSN where all the nodes including cluster heads (CHs) are mobile, this is done by dynamically switching CHs allowing nodes to act as multiple backup cluster heads (BCHs) with different priorities based on their residual energy and connectivity to other clusters. DCHEP is a flexible and scalable solution targeted for dense WSNs with random mobility.**

The proposed protocol achieves an average of 33% and 26% improvement to the availability and energy efficiency respectively compared with the original standard.

I. Introduction

WSNs consist of a number of smart devices with limited capabilities in terms of energy, transmission power, processing and memory [1]. In order to design and evaluate routing algorithms for WSNs many aspects have to be taken into consideration including energy efficiency, reliability, addressing scheme, flexibility and scalability. These requirements are even harder to accommodate in a mobile environment where some or all the nodes keep moving and losing connectivity. In a hierarchical WSN with multi-hop communication, if a CH moves away from its parent node or gateway, all of its sub clusters will lose connectivity causing a major deterioration in network reliability and efficiency.

There are many efforts to improve routing in cluster-based mobile WSNs using different approaches for rotating CHs. However, the existing protocols make a number of assumptions that either limit their applications or cause high overhead making them less flexible and less sustainable [2].

A Dynamic Cluster Head Election Protocol (DCHEP) is proposed to improve the availability and lifetime of mobile WSN using dynamic election of CHs and BCHs. The proposed protocol uses the beacon-enabled IEEE 802.15.4 standard and hierarchically elects CHs based on the beacon information and residual energy of the node. DCHEP doesn't use any extra control messages and don't have any extra overhead, it's rather triggered by the presence or absence of the periodic beacons and it lets every node decide whether it's a candidate for becoming a CH or not, each node has a different probability of becoming a CH that corresponds to the residual energy of the node.

DCHEP is different from other protocols because it uses a proactive approach in rotating CHs where nodes do not need a decision from a parent node but rather use their calculated probability and are triggered by the presence or absence of beacons to start the election process.

II. Related Work

There is a large number of WSN routing protocols with different approaches and different requirements including location-based protocols, data-centric protocols, hierarchical protocols, multipath-based protocols, and QoS-based protocols [3][4]. All of these approaches have their advantages and limitations and they are all related to this work. However, the main focus is directed to hierarchical-based routing through clustering because it is energy efficient and it inherits the architectural nature of the Internet making it a flexible and scalable solution [5][6].

Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol is a clustering protocol that was developed in [7] to minimize energy consumption in WSNs by introducing local control in clusters and randomly rotating cluster heads. The LEACH protocol outperforms the direct routing approach in terms of energy consumption and extends the life time of the network. However, it is not efficient in larger networks because it performs single-hop transmission from cluster heads to the base station and it doesn't ensure real load balancing [8].

Some routing protocols propose a backup cluster head to improve reliability and energy efficiency like the Energy Efficient Hierarchical Clustering Algorithm (EEHCA) [9], the backup cluster head is prepared to act as a primary cluster head if the first one fails. EEHCA improves the life time of the network by introducing the backup cluster head but it also assumes that all the nodes are stationary. This protocol was improved by [10] to use multiple backup cluster heads instead of just one to further extend the lifetime and availability of a WSN also with only static nodes.

Various improvements were made to the LEACH protocol and a number of extended-LEACH protocols were introduced to overcome the limitations of LEACH including Multi-Hop LEACH and M-LEACH [11]. M-LEACH supports mobility

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of nodes and CHs but it limits the communication to only two levels making it less scalable, it also assumes that all nodes are equipped with GPS and are location aware but this assumption is not always ideal since it consumes a lot of energy [12]. In addition to that, it requires the base station (BS) to make an informed decision and select CHs based on nodes information. This approach requires the use of extra control signals and data overhead making it less efficient in terms of energy consumption and is prone to transmission errors [13].

The Backup Cluster Head Protocol (BCHP) introduced by [14] proposes a BCH for each cluster in a hierarchical structure to maintain connectivity and take responsibility of the cluster in a reactive manner when a CH fails or leaves the cluster. BCHP is targeted for mobile networks in general and not specifically WSNs and it uses routing tables to determine a path to the destination making it less applicable for WSNs with limited resources, it also assumes that nodes are location-aware.

III. Dynamic Cluster Head Election Protocol

A. Network Setup

In order to build the hierarchy of the network, the sink node starts sending beacons to advertise its presence, neighbouring nodes receive the beacon and send an association request to the sender setting it as their parent node. In the setup phase, connected nodes will decide whether or not to become a CH based on a Pseudo-random value that corresponds to the available residual energy. Connected CHs start to advertise their presence in the same way forming a connected tree as shown in Fig 1.

As shown in (1), the priority of each node is calculated locally using the available residual energy and the initial energy, the connectivity takes the value of 1 or 0 and makes sure that nodes without an available path to the sink do not become CHs. The probability of becoming a CH is calculated in (2), this is triggered if a node receives a beacon for the first time or if it misses a maximum number of beacons after being connected. The preferred number of CHs is one of the most important parameters because it affects network coverage and inter-cluster interference. Selection of the optimum number of CHs for a mobile hierarchical tree WSN depends mainly on the application requirements and the speed of mobile nodes, optimization of this value for different applications is a future plan, it is given in the configuration file of each node in this simulation as 20% of the total number of nodes. Each node generate a pseudo-random number depending on the P(CH) and uses it to determine whether or not to become a CH.

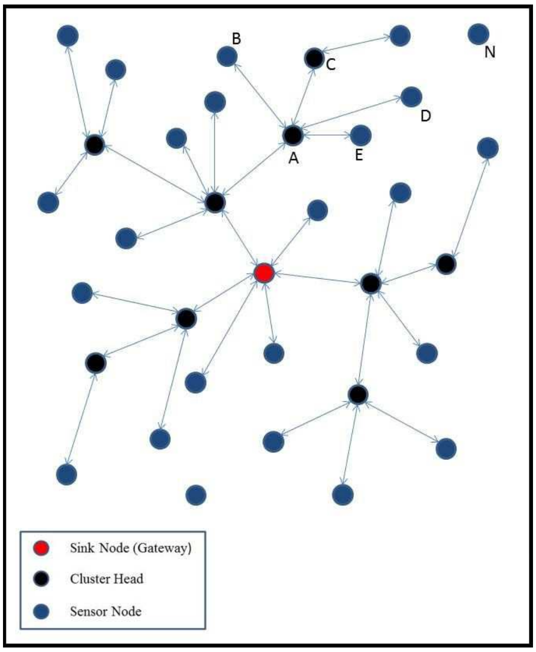

Fig. 1. Hierarchical Architecture

$$Priority = \frac{Current\ energy}{Inital\ energy} \times Connectivity \quad (1)$$

$$P(CH) = Priority \times \frac{Preferred\ number\ of\ CHs}{Number\ of\ nodes} \quad (2)$$

Because nodes are not stationary, it is not always possible to reach all the nodes at a given time, node N in Fig 1 is temporarily out of reach but the maintenance of clusters with each beacon and the dynamic election of CHs and BCHs makes a best effort to manage the mobility of nodes and maintain a path to the sink.

Every node waits for a beacon signal according to the IEEE 802.15.4 standard and updates its parameters based on the presence or absence of a beacon, the residual energy, and the current node status as shown in Fig 2. Some protocols try to avoid the additional delay of using CSMA/CA but this is not possible in dense networks with high probability of collisions [15], DCHEP is targeted for dense networks so it employs slotted CSMA/CA mechanism to reduce collisions between different clusters and throughout the network. In addition to that, CHs assign a random time reference for each child node within the cluster, the nodes use this timing to communicate with their parent nodes and minimize collisions within the cluster [16].

Using the clustering tree simplifies processing at the network layer because most of the routing decisions are made in the MAC layer and each node sends information only to its parent CH while the network layer is responsible for assigning addresses and packet encapsulation/decapsulation process. The short 16-bit version of IEEE 802.15.4 standard is deployed by default to make sure that future integration with the Internet of things (IoT) is possible.

B. Network Management

Network availability and lifetime are important measures for WSNs because of the limitations in energy and processing. Availability is measured for each node to have a connected path to the sink node. To extend the lifetime of the network while ensuring an available path to the destination, the distribution of energy consumption should be fairly divided for all the nodes. Because CHs are responsible for beaconing and data aggregation, they consume more energy than normal nodes and fail sooner than others declining both energy efficiency and network availability.

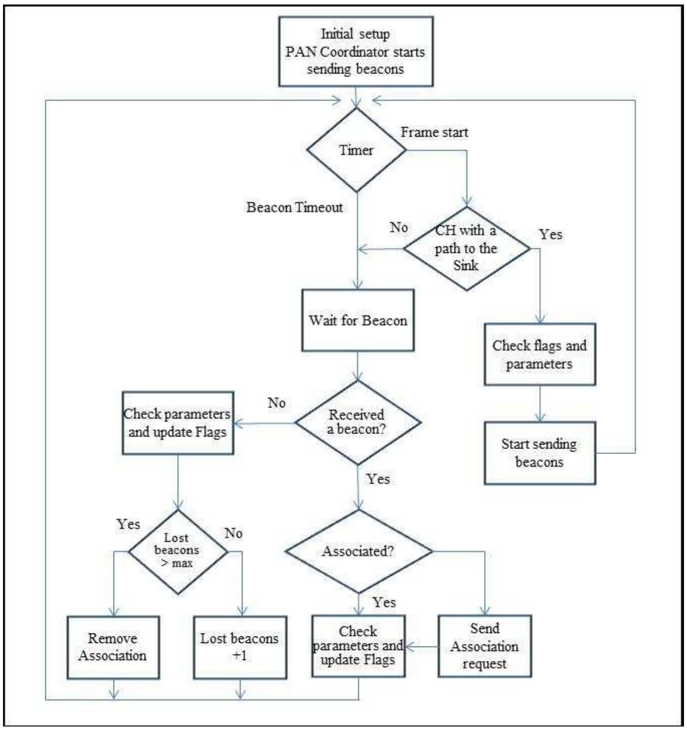

Fig. 2. Association and Dissociation

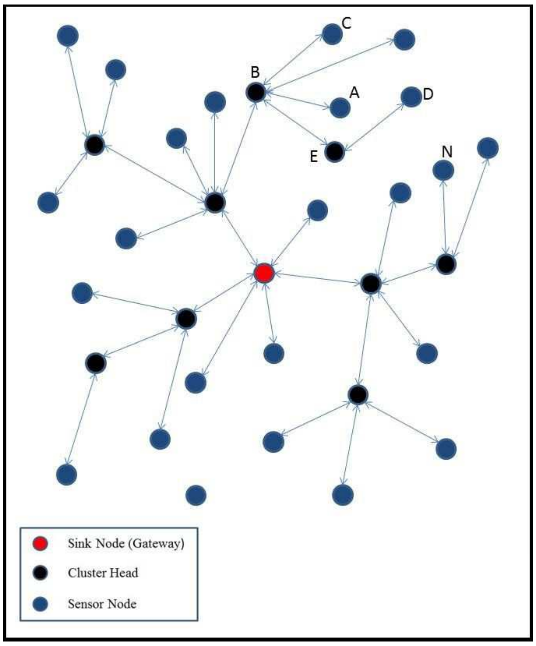

Fig. 3. Association and Dissociation

The mobility of a node or of its parent introduces another challenge to routing especially if it is a CH. The node is forced to lose connectivity from time to time and requires a mechanism to maintain the connected tree and to ensure the availability of a path to the sink. To achieve that without overwhelming the network with extra control signals and overhead, each node has to decide when and how to take action.

Nodes receive periodic beacons from their parent CH to maintain connectivity and so they can operate normally. A number of factors including the mobility of nodes or the presence of collisions can result in a failure in receiving the beacon signal. When a connected node misses a beacon, it calculates its priority based on the level of residual energy to prepare for possible changes, if it misses a predefined maximum number of beacons, it dissociates from its former parent and waits for a beacon from a new one. Once connected, it uses the calculated priority value to determine the probability of becoming a CH itself as shown in Fig 3.

This way, nodes with higher residual energy will have a better chance to become a cluster head as long as they have a path to the destination. If a CH reaches a threshold value of residual energy or is disconnected from its parent, it becomes a normal node and follows the same approach in deciding its new status. This ensures that energy consumption is distributed among all the participating nodes in a controlled manner without using extra control signals leading to a better lifetime for the network. In areas where there are too many collisions and high interference with neighbouring clusters, the nodes might miss some beacons and be forced to reform the clusters in that area leading to a better formation but consuming extra power for the dissociation and association process.

IV. Simulation Results and Analysis

The proposed routing protocol DCHEP is simulated using Castalia WSN simulator [17], a number of scenarios were considered according to the simulation parameters in table I to obtain results and validate the efficiency of DCHEP in terms of energy consumption and availability. Because other protocols assume a static CH or use control signals for the election process and cannot adapt to a large number of nodes, the simulation results are compared with the original standard assuming an energy aware LEACH based rotation of CHs to measure the advantages of using DCHEP especially for WSNs with high density and random mobility.

TABLE I. Simulation Parameters

Parameter	Value
Simulation Area	500m x 500m
Number of Nodes	100, 200, 500, 1000
Application Packet Rate	5 Packets/Second
Mobility Model	Random, 0 to 2 m/s [18]
Simulation Time	3 Hours
Radio	CC2420

The results obtained in Fig 4 measure the average availability of a path to the sink node as a percentage of time, it is affected by the time needed for a node to join a cluster and by how many times it changes clusters. CHs do not send beacons unless they are connected to a parent node in order to form the cluster tree, for this reason, the fact that a node is connected implies that it has a path to the sink although it doesn't necessarily mean that it is a reliable path.

For a WSN with 100 nodes, DCHEP achieves around 40% slightly higher than the original standard, it goes up while increasing the number of nodes up to 90% for DCHEP at 500

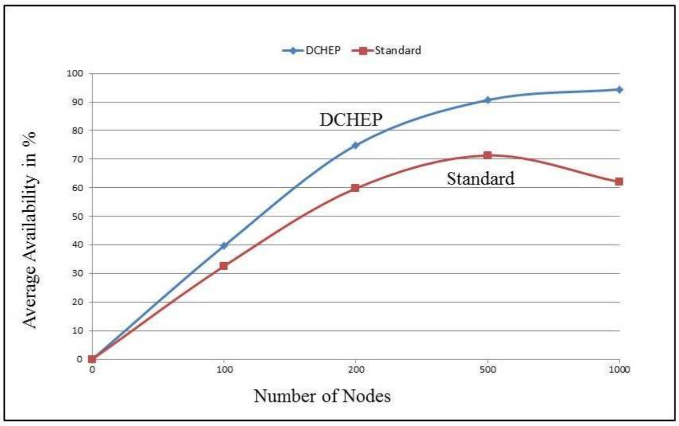

Fig. 4. Network Availability

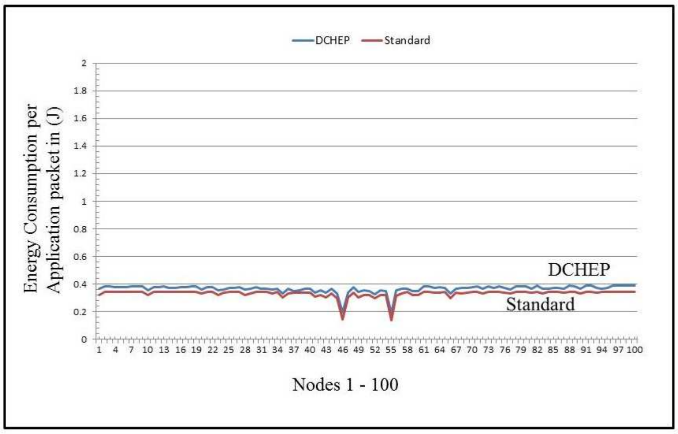

Fig. 5. Energy Consumption, 100 Nodes

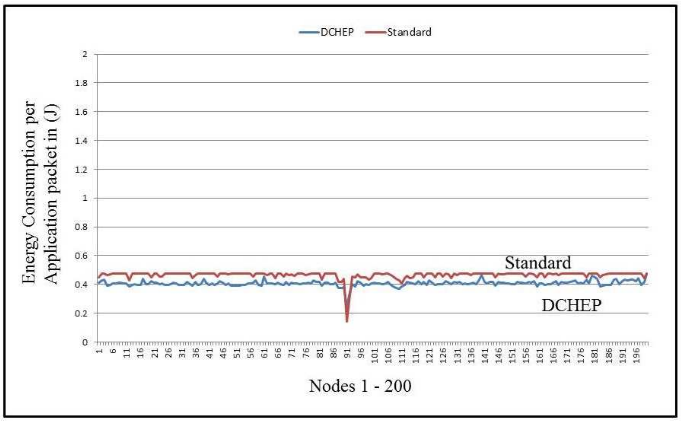

Fig. 6. Energy Consumption, 200 Nodes

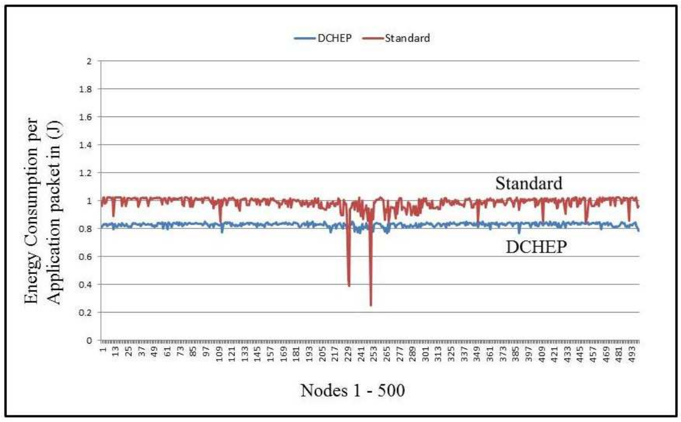

Fig. 7. Energy Consumption, 500 Nodes

nodes compared to the 71% of the original standard. After 500 nodes, the availability of DCHEP keeps going higher up to 94.4% at 1000 nodes while the LEACH based rotation of CHs fail to accommodate the higher density and starts to deteriorate down to around 60%. DCHEP performs significantly better because of the efficient method of CH election and mobility management.

To measure the energy efficiency of the proposed protocol, we calculated the average energy consumption for delivering an application packet from each node. This value gives an indication of the energy efficiency and the lifetime of the network.

DCHEP and the original standard both have low availability with 100 nodes and the results in Fig 5 show that they both have a good distribution of energy consumption but DCHEP consumes slightly more energy for delivering application packets because of the added processing in the election process. Some nodes consume less energy than others depending on their distance from the sink and their role in the cluster tree, this is directly affected by the mobility of these nodes, those who change clusters less frequently and serve as CHs for a shorter time can be seen as dips in the results and they get fewer and less obvious with longer simulation times.

For a mobile WSN with 200 nodes, the higher density leads to more interference and more hops to the sink. As shown in Fig 6, DCHEP outperforms the original standard consuming less energy for delivering application packets because of the improved election of CHs. The results show that DCHEP makes better decisions in selecting CHs to maintain good availability and ensure longer lifetime.

With higher density at 500 nodes, the efficiency of DCHEP becomes more obvious and the gap with the original standard increases further. The election of CHs is also affected by interference and DCHEP gains an advantage of having higher

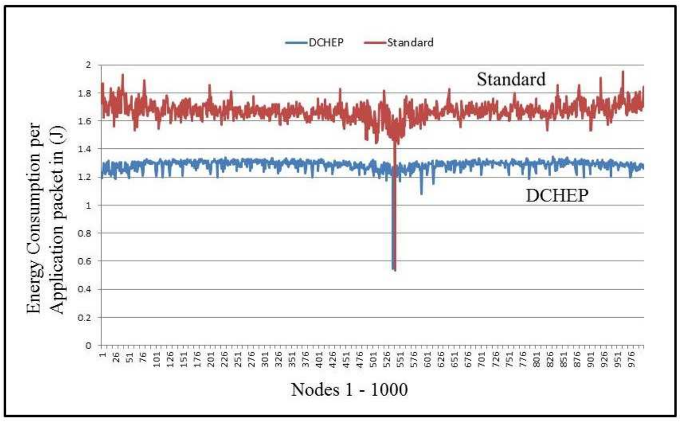

Fig. 8. Energy Consumption, 1000 Nodes

probability for nodes with lower interference to become CHs because they have a better chance to transmit and receive beacons. Fig. 7 shows that while both protocols maintain good distribution of energy consumption for almost all nodes, DCHEP provides a much better energy efficiency, it is also obvious that the energy consumption is going higher while increasing the number of nodes and that is due to added information sources and higher interference.

In Fig 8, the gap between DCHEP and the original standard increases even further. As shown earlier in Fig 4 DCHEP maintains much better availability for a network with 1000 nodes and this gives it an advantage compared to other protocols. The high density and interference lift the energy consumption for any routing protocol but the simulation results prove that DCHEP adapts much better to these changes making it a good candidate for mobile and dynamic networks.

V. Conclusion and Future Work

The Dynamic Cluster Head Election Protocol (DCHEP) is implemented to provide network connectivity for beacon-enabled mobile WSNs under the IEEE 802.15.4 standard using backup cluster heads to improve the availability and lifetime of the network when all nodes including cluster heads are mobile. Simulation results show that DCHEP maintains inter-cluster and intra-cluster connectivity in a proactive manner to distribute energy consumption among the participating nodes while maintaining connectivity.

Because of the nature of mobile networks especially with random mobility, no routing protocol can guarantee a 100% availability of a path to the sink for all the nodes but according to the simulation results DCHEP does provide and average availability of 75% and up to 94.4% in dense networks. Unlike other protocols, DCHEP is highly scalable and has an improved performance for dynamic and dense networks, it is also highly flexible and nodes can be easily added to the network at any time. DCHEP improves the availability and lifetime of the network by 33% and 26% respectively compared to the original standard.

The hierarchy of the clustering tree and the default addressing scheme of IEEE 802.15.4 makes it also a good candidate for IoT applications and this area is planned to be further investigated in future work.

VI.

References

[1] K. Machado, D. Rosário, E. Cerqueira, A. A. Loureiro, A. Neto, and J. N. de Souza, "A routing protocol based on energy and link quality for internet of things applications," *sensors*, vol. 13, no. 2, pp. 1942–1964, 2013.

[2] R. Devika, B. Santhi, and T. Sivasubramanian, "Survey on routing protocol in wireless sensor network," *International Journal of Engineering and Technology*, vol. 5, no. 1, pp. 350–356, 2013.

[3] S. K. Singh, M. Singh, D. Singh *et al.*, "Routing protocols in wireless sensor networks–a survey," *International Journal of Computer Science & Engineering Survey (IJCSES) Vol*, vol. 1, pp. 63–83, 2010.

[4] A. M. Popescu, N. Salman, and A. H. Kemp, "Energy efficient geographic routing robust against location errors," *IEEE Sensors Journal*, vol. 14, no. 6, pp. 1944–1951, 2014.

[5] L. Karim and N. Nasser, "Energy efficient and fault tolerant routing protocol for mobile sensor network," in *Communications (ICC), 2011 IEEE International Conference on*. IEEE, 2011, pp. 1–5.

[6] D. Goyal and M. R. Tripathy, "Routing protocols in wireless sensor networks: A survey," in *Advanced Computing & Communication Technologies (ACCT), 2012 Second International Conference on*. IEEE, 2012, pp. 474–480.

[7] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in *System sciences, 2000. Proceedings of the 33rd annual Hawaii international conference on*. IEEE, 2000, pp. 10–pp.

[8] X. Liu, "A survey on clustering routing protocols in wireless sensor networks," *Sensors*, vol. 12, no. 8, pp. 11 113–11 153, 2012.

[9] G. Xin, W. H. Yang, and B. DeGang, "Eehca: An energy-efficient hierarchical clustering algorithm for wireless sensor networks," *Information Technology Journal*, vol. 7, no. 2, pp. 245–252, 2008.

[10] U. Sutar and S. Bodhe, "An energy efficient hierarchical multiple backup cluster head algorithm for wireless sensor networks," in *Proceedings of the International Conference and Workshop on Emerging Trends in Technology*. ACM, 2010, pp. 465–470.

[11] M. Aslam, N. Javaid, A. Rahim, U. Nazir, A. Bibi, and Z. Khan, "Survey of extended leach-based clustering routing protocols for wireless sensor networks," in *High Performance Computing and Communication & 2012 IEEE 9th International Conference on Embedded Software and Systems (HPCC-ICESS), 2012 IEEE 14th International Conference on*. IEEE, 2012, pp. 1232–1238.

[12] C. Zhang, J. Liu, H. Li, and X. Jiang, "Two-level routing protocol for mobile sensor network based on leach algorithm," in *Intelligent Computing and Integrated Systems (ICISS), 2010 International Conference on*. IEEE, 2010, pp. 950–953.

[13] S. A. Awwad, C. K. Ng, N. K. Noordin, and M. F. A. Rasid, "Cluster based routing protocol for mobile nodes in wireless sensor network," *Wireless Personal Communications*, vol. 61, no. 2, pp. 251–281, 2011.

[14] L. Mengual Galan, R. Torres Tandazo, and L. Enciso Quispe, "Improving availability of mobile networks using a cluster routing protocol with redundant cluster head," 2012.

[15] N. Salman, I. Rasool, and A. H. Kemp, "Overview of the ieee 802.15. 4 standards family for low rate wireless personal area networks," in *Wireless Communication Systems (ISWCS), 2010 7th International Symposium on*. IEEE, 2010, pp. 701–705.

[16] Y. Al-Nidawi, N. Salman, and A. H. Kemp, "Mesh-under cluster-based routing protocol for ieee 802.15. 4 sensornetwork," in *European Wireless 2014; 20th European Wireless Conference; Proceedings of*. VDE, 2014, pp. 1–7.

[17] A. Boulis *et al.*, "Castalia: A simulator for wireless sensor networks and body area networks," *National ICT Australia Ltd, Australia*, 2009.

[18] J. Rezazadeh, "Mobile wireles sensor networks overview," *International Journal of Computer Communications and Networks (IJCCN)*, vol. 2, no. 1, 2012.