

# Work in Progress: LEACH-Based Energy Efficient Routing Algorithm for Large-Scale Wireless Sensor Networks

Eyman F. Ahmed<sup>1</sup>, Mohd Adib Omar<sup>1</sup>, Tat-Chee Wan<sup>1</sup>, Altahir A Altahir<sup>2</sup>

<sup>1</sup>*School of Computer Sciences, Universiti Sains Malaysia, 11800 USM, Penang, Malaysia.*

<sup>2</sup>*Dpt. of Comp. Eng., Faculty of Engineering and Technology, University of Gezira, Sudan.*  
*eymanelsmany@gmail.com*

**Abstract**—Wireless sensor network (WSN) is one of the active research topics which links telecommunication and micro-electro- mechanical system (MEMS). WSN has a broad range of important applications such as environmental monitoring, health monitoring, and various industrial and military applications. The various routing protocols in WSN manage the load balance, energy consumption and the expansion of the network. This study outlines the procedure of developing scalable, low energy and highly adaptive clustering hierarchy routing protocol. The main objective is to maintain the network lifespan over the network expansion. We refer to the proposed protocol as Energy-Efficient Scalable Routing Algorithm (EESRA). The EESRA protocol is expected to optimize the well-known LEACH protocol for more energy efficiency on a large scale WSN.

**Index Terms**—LEACH; MEMS; Scalability; Wireless sensor networks.

## I. INTRODUCTION

Wireless sensor network (WSN) is a combination of a massive number of low-cost, multifunctional, low-power, and intelligent sensor nodes with one or more base stations or sinks [1]–[3]. Despite the improvements in sensor technology, WSN's nodes still constrained by the limited battery power, bandwidth, computing capabilities, and memory [4]. Therefore, WSN's routing protocols must be highly adaptive and resource-aware to support the network lifespan. The massive number of nodes, low data rates, and the resources constraint limits the usability of the protocols which are designed for ad hoc networks. Recently, many hierarchical routing protocols have been proposed to provide efficient energy consumption [5]. LEACH (Low-Energy Adaptive Clustering Hierarchy) is considered as the first significant protocol with efficient energy consumption. However, the LEACH performance deteriorates sharply with the increase of the number of nodes in the network [6]–[10].

This study proposes developing scalable, low energy and adaptive clustering hierarchy routing protocol. The main objective is to maintain the network lifespan over the network expansion. The proposed protocol is denoted as Energy-Efficient Scalable Routing Algorithm (EESRA). The EESRA protocol is expected to optimize the well-known LEACH protocol for more energy efficiency on large scale WSNs.

Given the increase in the node density, the primary goal of this study is to outlines the procedure to maintain the network lifetime at an adequate measure. This target can be further divided into the following contributions:

- Applying cross-level multi-hop clustering communications that balance energy consumption and extended the network lifespan.
- Implementing a Hybrid (TDMA and CSMA/CA) MAC protocol, and utilizing an adaptive CHs cycle such to maintain topology rearranging. Moreover, reducing delivery delay, collision, and cost.
- Applying active and sleep strategy; the node is active only during function time and sleeps when it idles.
- Providing more flexibility to the WSN to handle the addition of the new nodes by implementing CSMA/CA MAC protocol for intra-cluster communication.
- Reducing CH overload and optimizing several selected CHs.

The rest of the paper is organized as follows: Section II discusses the recent literature. Section III outlines the proposed procedure. The conclusion is demonstrated in Section IV.

## II. LITERATURE REVIEW

According to the WSN architecture, the routing protocols are categorized into three classes: flat, hierarchical, and location-based routing protocols. In the flat routing architecture, all the sensor nodes perform similar roles in the routing procedure. Hence, they are set to forward the sensed packets to the specific base station. Hierarchical routing architecture classifies the sensor nodes according to their functionalities. The network is divided into clusters, and the activities within the cluster are managed by selected node known as cluster-head. The low-level nodes are responsible for sensing and collecting the data. X. Liu *et al.* [2],[11] classified hierarchical routing protocol in two subclasses: typical and atypical routing schemes. The typical routing protocols based on cluster shape are labeled as block-based clustering routing algorithms (E.g. LEACH [5], UCS [12], EECS [13], BCDCP [14]). Moreover, the sensor nodes in the location-based routing category are aware of their locations, and the distance between neighboring nodes which estimated based on the incoming signal strengths.

Heinzelman W, *et al.* [5] proposed the Low Energy Adaptive Clustering Hierarchy protocol, which is low-cost and self-adaption protocol. LEACH utilizes randomization to distribute the energy load equally between the nodes. The CHs are responsible for communicating with the local point (sink). Each CH collects the data from the cluster- member

and transfers it to the sink. LEACH operation consists of the initiation of clusters and data transmission, the total time of these steps is called round. The operation of LEACH consists of many rounds, each round takes place in two phases: The first phase is the set-up, where the clusters for the current round are established. The second phase labeled as the steady-state, in this phase, each node sends sensed information to CH at its allotted TDMA schedule. The cluster head aggregates, compresses and transmits the sensed data to the base station. Figure 1 shows the topology of LEACH protocol. LEACH protocol has become one of the bases for designing the protocols or enhancing existing one in WSNs. However, the direct link between the CH and distant BS restricted applying LEACH for large scale WSN [7]–[9], [15]–[17]. Further, LEACH suffers from the hot-spot problem (i.e. the CHs consumes their energy more quickly due to extra duties [18]). Thus, LEACH does not compensate sufficiently for further energy exhaustion during CH role.

The next subsections discuss the LEACH-extended protocols which are specifically modified intra or inter-cluster communication approach to enhance network scalability. Table 1 presents the LEACH-variants protocols.

#### A. TL-LEACH

A two-levels hierarchy routing protocol (TL-LEACH) is an extension of LEACH protocol introduced by [19]. TL-LEACH utilizes two techniques randomized and adaptive, self-configured cluster formatting and localized control for data transfer. After the data collection, part of CHs which are between CH and BS are chosen to transmit the data, instead of a direct transmission to BS. The top cluster-head titled primary cluster-head ( $CH_i$ ) and the second level composed of secondary cluster-head ( $CH_{ij}$ ).

#### B. MS-LEACH

In [20] MS-LEACH was proposed based on the critical value to improve the network lifetime. MS-LEACH combines the single-hop transmissions and multi-hop transmissions in the clusters. The critical value of the cluster area size is calculated by analyzing energy consuming of multi-hop as well as single-hop broadcasts. The selection between single-hop or multi-hop transmissions is based on the critical value of the cluster area size  $Q$  critical.

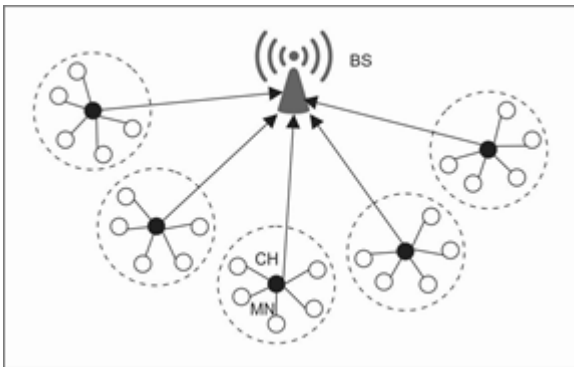


Figure 1: LEACH basic topology.

#### C. LEACH-MF

LEACH-MF utilizes multi-layer clustering and redundant information elimination to balance the energy consumption and to extend the network lifetime for large-scale wireless sensor networks [9]. In multi-layer clustering mechanism, all

CHs are formed in one cluster, and new CHs will be chosen to be super-CHs. The selection of super-CHs depends only on the site of CHs without power consideration that may cause energy depletion. Each CH stores other CHs and BS locations. Moreover, abstract redundant information processes can raise nodes overhead.

#### D. Cell-LEACH

The problem of data redundancy in LEACH protocol had been eliminated in Cell-LEACH [21], in Cell-LEACH the network before its deployment is divided into sections (cells). One sensor node of this cell will be chosen as the head of the cell. Each seven cells within easy reach formed a cluster under control of one CH. Clusters and cells are forming in the preliminary setup phase then remain the same as long as the network is working while cell-heads and CHs are inconstant. Due to the static nature of the cells and clusters, Cell-LEACH suffers from scalability.

#### E. Multi-Level LEACH

The Multi-level LEACH is proposed to alter the LEACH protocol transmission scheme from a single hop to multi-hop between CH and BS [22]. The network is partitioned to levels, in level1, every node is categorized as leaf nodes with equal energy [23]. In level2 CHs are selected based on the residual energy and distance between nodes. Level2-CHs receive the aggregated data from the level1-CHs and transfer it to level3. Similarly, level3, level4 are formed and that provide the multi-hop mode of transmission between the CHs and the BS.

#### F. LEACH-WM

Weighted and intra-cluster multi-hop energy-efficient a distributed scheme for wireless sensor networks presented in [24]. In LEACH-WM the authors assume that the BS supplied with a GPS. Similar to LEACH protocol, the operations are divided into rounds while any round is broken into set-up and steady phase. Before setup phase, the BS advertises the entire network about its location. Then based on the received signal strength indicator (RSSI) all network nodes compute their locations and forwarded back their location information to the BS. During the setup phase, the CHs are randomly selected from all the sensor nodes, and several clusters are formed. Finally, the steady phase is divided into frames. In each frame, non-CH nodes in the network transmit the data packets to its CH into their time slots. When the round is finished, non-CH nodes send data packet appendix by their weight; hence the CH choose the next hop node as which it calls weight relay (WR), based on residual energy and distances to BS.

#### G. FLLEACH

FLLEACH has two phases per operation round same as LEACH protocol; set up and steady state phase [25]. However, for more energy efficiency, FLLEACH introduces one super cluster head (SCH) between the CHs and BS. The aggregated data which is transmitted from sensor nodes to their CHs passed through SCH as next hop to BS. Remaining battery power, Mobility, and Centrality are the three fuzzy inputs to compute the chance of each node to be the SCH. SCH and all CHs are static, but BS is mobility to nominate many various paths that to avoid a collision when receiving the data from the SCH.

Table 1  
Compression of LEACH-Extended Protocols

Merits	Protocols						
	TL-LEACH	MS-LEACH	LEACH-MF	Cell-LEACH	Multi-Level LEACH	LEACH-WM	FLLEACH
Year	2005	2010	2011	2012	2014	2016	2016
Cluster-head selection	Random	Random	Random	Random/ Adjust	Adjust	Random	Random
Load Balancing	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Control Approach	Distributed	Distributed	Distributed	Distributed	Distributed	Distributed	Distributed
Data Aggregation	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Algorithm Complexity	Low	Low	Low	Low	Low	Low	Low
Intra-Cluster topology	Single-hop	Single-hop/ multi-hop	Single-hop	Multi-hop	Single-hop	Single-hop	Single-hop
Inter-Cluster topology	Multi-hop	Single-hop	Multi-hop	Multi-hop	Multi-hop	Multi-hop	Multi-hop
Self-organization	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Scalability	Moderate	Moderate	Moderate	Bad	Moderate	Moderate	Moderate
Modification	Cluster formulation: presented a new level of hierarchy that to transmit the data to a BS via two various levels	Data Transmission: based on Qcritical value data may send to CH via single-hop or multi-hop approach.	The data is sent from CH to BS through super cluster-heads (SCHs)	To send the data from CH to BS utilizing multi-hop communication topology via cell-heads. To send the data from each node to CH utilizing multi-hop communication topology.	Cluster formulation: presented a new level of hierarchy that to transmit the data to a BS via three above various levels	Data transmission: CH choose the next hop node as which it calls weight relay(WR), based on residual energy and their distances to BS to transfer the sensed data to BS	Cluster formulation: Used Fuzzy Inference Technique to select the SCHs as Relay Nodes to transfer the data to BS

H. Literature Discussion

Despite the heavy reliance on LEACH protocols, the LEACH performance deteriorates sharply with the increase of the network density [6]–[10]. Moreover, the multi-hop based LEACH algorithms have some disadvantages that can degrade their performance, such as the implementation of the optimum number of CHs has to be revised when multi-hop transmission strategy is applied [26]. Additionally, the CH overload must be considered to avoid the hot-spot problem. Further, multi-hop based LEACH algorithms lack CHs data transfer arrangement to single BS which may lead to a collision. All these reasons make the LEACH a very active research with great demands to achieve WSNs applications requirements.

III. NETWORK MODEL AND ALGORITHM DESCRIPTION

As stated in the literature, the clustering routing protocols such as LEACH suffer from hotspot problem. That is, those protocols do not suit the extensive area coverage applications with inter-cluster multi-hop communication. This study attempt to fill the gap by proposing a cluster-based Energy-Efficient Scalable Routing Algorithm (EESRA). The proposed protocol considers the key design concepts of LEACH while addressing the hotspot and scalability issues via applying multi-hop intra and inter-clustering approaches and low-level CSMA/CA MAC. In our proposed study these assumptions have been considered to fulfill efficient data routing and improve network lifetime and scalability. In the proposed study the following assumptions have been considered to fulfill efficient data routing and improve network lifetime and scalability:

- The sensor nodes are homogeneous, randomly distributed in a two-dimensional plane and initially having the same power level.

- All sensor nodes and BS are stationary.
- Communication is symmetric between any two sensors.

The EESRA protocol proposes merging clustering and multi-hop routing strategies. The core topology of proposed protocol “EESRA” is shown in Figure 2.

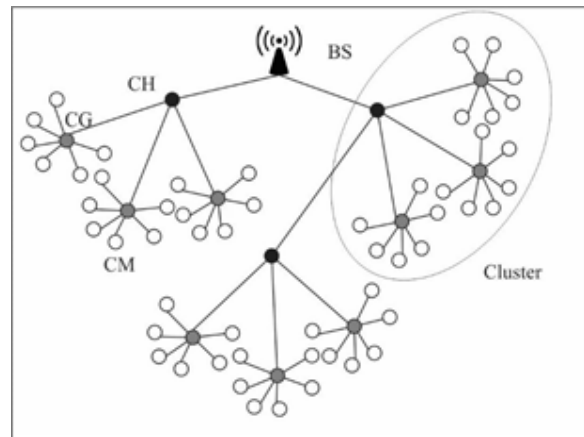


Figure 2: EESRA topology

The operation of EESRA is composed of rounds. The rounds take place in two phases; the first phase is denoted as the set-up phase, where the cluster-heads are selected using the LEACH’s scheme of stochastic rotation. As described earlier, the election of the CHs is meant to balance the energy consumption. Following that, the clusters of the current round are established, and the chosen CHs perform the following functions:

- Broadcasts to all cluster nodes ADV message using CSMA/CA MAC protocol. ADV message composes of

CH's ID and control information (each node has unique ID).

- Receives from each non-CH nodes a join request message (REQ) using a CSMA/CA MAC protocol. REQ message consists of Node's ID, CH's ID, and node energy information.
- Based on Equation (1), the CH calculates the energy mean 'E<sub>mean</sub>'.

$$E_{mean} = \frac{\sum_{i=1}^N E_i}{N} \quad (1)$$

where: E<sub>mean</sub> = Energy mean  
E<sub>i</sub> = Energy of node i  
N = Number of nodes

- In each round, based on the E<sub>mean</sub> and the distance; the CH defines which node can be labeled as a congregation (CG). A count of congregations per cluster depends on cluster size.
- Create a TDMA transmission schedule to dedicate a slot time for any CG to send the sensed data to CH, and broadcasts the TDMA schedule to all CGs.
- Broadcasts the congregation's list to all the cluster members 'CM'.
- Receives the aggregated data from CG.
- Transfers the data to BS, and maintain and control the cluster.
- Consequently, the CM nodes which are labeled as congregations 'CG' have the following tasks:
- Receives an ADD message from CMs to be as a CG-group member.
- Receives sensed data CG-group member nodes.
- Aggregates and compress received data then transmits aggregated data to CH at its allotted TDMA time slot.

Finally, the cluster member nodes perform the following tasks:

- Based on distance send REQ message to CH to be as a cluster member.
- Receives CGs list.
- Transmits ADD message to CG.
- Convoys sensed data to CG using CSMA/CA MAC protocol.

The second phase is denoted as steady-state. In this phase, each node set its radio communication modules to be turned on to send sensed data to CG according to its subgroup at its allotted TDMA time slot. So, the node is active only during function time and sleeps when it idles. The CGs aggregate, compress and forward the data to CH. The CH conveys its data to the closest cluster head in the trend of the BS. Subsequently, when BS receives all the data, CH checks its power level. Accordingly, if the residual energy of current CH less than the threshold (E<sub>mean</sub>), CH send END message to the cluster member for new CH selection for next round. Otherwise continue as CH, such to avoid continual topology rearranging.

The set-up phase is shorter compared to the steady-state phase that to reduce power consumption. EESRA; is expected to achieve high energy efficiency by balancing the energy dissipation of nodes (e.g. CHs & CGs role rotation), and scalability (through low overhead hierarchical partition).

#### IV. CONCLUSION

The broad goal of developing EESRA is to maintain the network lifespan over the network expansion. Moreover, a hybrid (TDMA and CSMA/CA) MAC protocol has been proposed to adopt sleeping and collision avoidance mechanisms. To validate the proposed protocol, the MATLAB based simulation is proposed with the specifications of the CC2420 transceiver as a hardware platform. The EESRA (routing and MAC) protocol is expected to optimize the well-known LEACH protocol through minimizing the energy costs, reducing delivery delay and relatively improving the network scalability on large-scale WSN.

#### REFERENCES

- [1] E. C. I.F. Akyildiz, W. Su, Y. Sankarasubramaniam and Broadband, "Wireless Sensor Networks: A Survey," *Comput. Networks*, vol. 38, no. 4, pp. 393–422, 2002.
- [2] X. Liu, "Atypical Hierarchical Routing Protocols for Wireless Sensor Networks: A Review," *IEEE Sens. J.*, vol. 15, no. 10, pp. 5372–5383, 2015.
- [3] M. gherbi, C., ALIOUAT, Z. and Benmohammed, "A Survey on Clustering Routing Protocols in Wireless Sensor Networks," *Sens. Rev.*, vol. 37, no. 1, pp. 12–25, Jan. 2017.
- [4] S. . Mundada, M.R., Kiran, S., Khobanna, S., Varsha, R.N. and George, "A Study on Energy Efficient Routing Protocols in Wireless Sensor Networks," *Int. J. Distrib. Parallel Syst.*, vol. 3, no. 3, pp. 311–330, 2012.
- [5] W. R. W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks," in *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences*, 2000, vol. 0, no.c, pp. 3005–3014.
- [6] K. Akkaya and M. Younis, "A Survey on Routing Protocols for Wireless Sensor Networks," *Ad Hoc Networks*, vol. 3, no. 3, pp. 325–349, 2005.
- [7] X. Liu, "A Survey on Clustering Routing Protocols in Wireless Sensor Networks," *Sensors (Switzerland)*, vol. 12, no. 8, pp. 11113–11153, 2012.
- [8] D. K. Patel, M. P. Patel, and K. S. Patel, "Scalability Analysis in Wireless Sensor Network with LEACH Routing Protocol," in *Computer and Management (AMAN), 2011 International Conference on. IEEE*, 2011, pp. 1–6.
- [9] J. F. Yan and Y. L. Liu, "Improved LEACH Routing Protocol For Large Scale Wireless Sensor Networks Routing," in *Electronics, Communications and Control (ICECC), 2011 International Conference on. IEEE*, 2011, pp. 3754–3757.
- [10] M. T. and H. Y. Amira Ben Ammar, Ali DZIRI, "Multi-Hop LEACH Based Cross-Layer Design for Large Scale Wireless Sensor Networks," in *Wireless Communications and Mobile Computing Conference (IWCMC), 2016 International. IEEE*, 2016, pp. 763–768.
- [11] X. Liu and J. Shi, "Clustering Routing Algorithms in Wireless Sensor Networks: An Overview," *KSH Trans. INTERNET Inf. Syst.*, vol. 6, no. 7, pp. 1735–1755, 2012.
- [12] S. Soro and W. B. Heinzelman, "Prolonging the Lifetime of Wireless Sensor Networks via Unequal Clustering," in *19th IEEE International Parallel and Distributed Processing Symposium*, 2005, p. 8–pp.
- [13] J. Ye, M., Li, C., Chen, G. and Wu, "EECS: An Energy Efficient Clustering Scheme in Wireless Sensor Networks," in *IPCCC 2005. 24th IEEE International Performance, Computing, and Communications Conference, 2005.*, 2005, pp. 535–540.
- [14] and A. O. F. Muruganathan, Siva D., Daniel CF Ma, Rolly I. Bhasin, "A Centralized Energy-Efficient Routing Protocol for Wireless Sensor Networks," *IEEE Commun. Mag.*, vol. 43, no. 3, pp. S8–13, 2005.
- [15] R. P. Mahapatra and R. K. Yadav, "Descendant of LEACH Based Routing Protocols in Wireless Sensor Networks," *Procedia Comput. Sci.*, vol. 57, pp. 1005–1014, 2015.
- [16] G. S. Arumugam and T. Ponnuchamy, "EE-LEACH: Development of Energy-Efficient LEACH Protocol for Data Gathering in WSN," *Eurasip J. Wirel. Commun. Netw.*, vol. 2015, no. 1, pp. 1–9, 2015.
- [17] R. Velmani and B. Kaarthick, "An Efficient Cluster-Tree based Data Collection Scheme for Large Mobile Wireless Sensor Networks," *IEEE Sens. J.*, vol. 15, no. 4, pp. 2377–2390, 2015.
- [18] A. U. Rahman, A. Alharby, H. Hasbullah, and K. Almuzaini, "Corona

- Based Deployment Strategies in Wireless Sensor Network: A survey,” *J. Netw. Comput. Appl.*, vol. 64, no. 2016, pp. 176–193, 2016.
- [19] V. Loscrì, G. Morabito, and S. Marano, “A Two-Levels Hierarchy for Low-Energy Adaptive Clustering Hierarchy (TL-LEACH),” in *IEEE Vehicular Technology Conference*, 2005, pp. 1809–1813.
- [20] T. Qiang, W. Bingwen, and D. Zhicheng, “MS-LEACH: A Routing Protocol Combining Multi-Hop Transmissions and Single-Hop Transmissions,” in *Circuits, Communications and Systems, 2009. PACCS’09. Pacific-Asia Conference on. IEEE*, 2009, pp. 107–110.
- [21] A. Yektaparast, F. H. Nabavi, and A. Sarmast, “An Improvement on LEACH Protocol (Cell-LEACH),” in *Advanced Communication Technology (ICTACT), 2012 14th International Conference on*, 2012, pp. 992–996.
- [22] and N. K. A. Kodali, Ravi Kishore, “Multi Level LEACH Protocol Model Using NS-3,” in *Advance Computing Conference (IACC), 2014 IEEE International. IEEE*, 2014, pp. 375–380.
- [23] I. Publishing, “A Review on State of Art Variants of LEACH Protocol for Wireless Sensor Networks,” *Sensors & Transducers*, vol. 186, no. 3, pp. 25–32, 2015.
- [24] Y. Zhang, J., Chen, J., Xu, Z. and Liu, “LEACH-WM : Weighted and Intra-Cluster Multi-Hop Energy-Efficient Algorithm for Wireless Sensor Networks,” in *Control Conference (CCC), 2016 35th Chinese. TCCT*, 2016, pp. 8325–8329.
- [25] P. Nayak and A. Devulapalli, “A Fuzzy Logic-Based Clustering Algorithm for WSN to Extend the Network Lifetime,” *IEEE Sens. J.*, vol. 16, no. 1, pp. 137–144, 2016.
- [26] 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.