Enhanced TL-LEACH routing protocol for large-scale WSN applications

1st Kulsoom Manzoor
dept. of Info. Tech.
University of Sindh
Dadu, Pakistan
kul.manzoor@yahoo.com

2nd Sana H. Jokhio
Independent Researcher
Melbourne, Australia
shoorjoks@gmail.com

3rd Tariq J. S. Khanzada
dept. of Comp. Sys. Eng.
Mehran University of Eng. & Tech.
Jamshoro, Pakistan
tariq.khanzada@faculty.muet.edu.pk

4th Imran A. Jokhio
Melbourne Institute of Technology
Melbourne, Australia
ijokhio@mit.edu.au

***Abstract*—Routing sensor data from sensor node to base station is a challenging task in a wireless sensor network (WSN) application. The sensor nodes have a number of constraints such as limited energy, low memory, processing capabilities, etc. It is important to consider these constraints while designing a routing protocol so that the overall network lifetime and the data robustness may be efficiently maintained. This research focuses on improving the Two-Level Hierarchy for Low Energy Adaptive Clustering Hierarchy (TL-LEACH) protocol to provide energy efficiency; in terms of communication overhead and making the communication among the end-nodes, cluster-heads and base station as robust as possible. Two major drawbacks of the TL-LEACH protocol have been focused in this research that are mainly related to using the protocol for large-scale WSN and making the communication among the nodes robust. A novel cluster-head selection mechanism has been introduced to improve the energy-efficiency of the TL-LEACH and the new version has been named as Extended TL-LEACH (ETL-LEACH). The simulation results show that the ETL-LEACH performs better in terms of energy consumption, node lifetime and the communication delay has been decreased to a significant amount.**

***Index Terms*—cluster-based, wsn, routing**

I. Introduction

WSNs have gained remarkable attention in the research community and have brought an important revolutionary change in technology with a great potential for improving many current applications. WSNs are befitting in various areas including habitat monitoring, building surveillance and forest surveillance, earthquake observation, etc [3] [4] [5]. These applications are physically environmental but nowadays these applications play a vital role in biological science, biomedical, health care, and vehicle tracking. In these applications sensors are frequently scattered remotely and are made to operate independently and autonomously. WSN has a number of constraints including limited energy, processing power, range, etc [9] [10].

Low power consumption and longer network lifetime are the two important attributes of any routing protocol designed for WSNs. To yield a long duration of connectivity from center is only possible if there is an equal distribution of energy within the nodes of network [11] [1] [12]. The sensor nodes in a WSN are equipped with tiny devices to sense phenomenon around them. Each node is capable of sensing, processing and communicating the data and/or information to the nearest neighbor and to the base station either directly or via the relay nodes [13]. One of the major challenges in WSN applications is to reduce the energy consumption and to enhance the overall life time of the network. The end nodes or the sensor nodes are targeted to minimize the overall energy consumption within the network by reducing the processing and communication overhead in each sensor node attached to the WSN [12]. A Two-Level Hierarchy LEACH (TL-LEACH) [3], an extension of the state-of-art LEACH algorithm has been proposed. It promises latency efficiency and efficient energy consumption. Some of the advantages that help in an improved energy efficiency are discussed below [3]:

1) Better and more attractive energy load allocating approach among the constituents of network, achieved through the random variation and alternative rotation in sensor nodes according to local cluster base stations such as primary cluster heads (CHs) and secondary CHs.
2) Cluster topology based on hierarchical model and localized coordination which helps the network to gain more progressive Scalability and improved robustness in the network.

In contrast to LEACH, average transmission distance can be achieved through the scheme of two-levels clustering, and reduced amount of nodes are involve to broadcast remote distances from the base station (BS) by the way of TL-LEACH. Two of the main TL-LEACH disadvantages have been focused that are listed as follows [10]:

- TL-LEACH $NotDeployedinwideareaapplications$ Although TL-LEACH has reduced average transmission distance in contrast with LEACH, but two-hop inter-cluster routing of TL-LEACH are not encouraging long distance communication networks or large applications, because it simply adopts two hops to send data from sources to the base station (BS) and for long-distance communications much energy consumption may occur.
- TL-LEACH (Ideal homogeneous network) Energy considerations play a vital role in CH election; unusually it will assist to insure load balancing processes, particularly in case of situation where nodes live through with different initial energy.

978-1-7281-2600-5/19/$31.00 ©2019 IEEE
DOI 10.1109/CCC.2019.00-12

In this paper, an extension to TL-LEACH has been proposed by providing a mechanism to overcome the above mentioned constraints. Rest of the paper has been organized as follows. Section 2 presents detailed description of the routing protocols LEACH, TL-LEACH to help understand the basic structure and the differences among the available and the proposed protocol extension. ETL- LEACH has been discussed in detail in section 3. Section 4 explains the simulations details, scenarios and thoroughly discusses the results and the graphical representation of the simulation outputs. Finally, section 5 concludes the findings, discusses some recommendations and provides a brief insight into the future work.

II. Background

Routing data or information among nodes in a wireless sensor network has been a challenging task with respect to the nature of various WSN applications and the sensitivity of the routed data. Globally, a wide variety of routing techniques have been proposed that address various challenges and provide a number of solutions for different issues related to routing [5] [12]. For a cluster based network hierarchical protocols have been proposed that target various goals. LEACH protocol is one of the state-of-art and widely used routing protocols for cluster based WSNs. Nevertheless, some variations of LEACH protocol have also been proposed targeting various weaknesses and aiming to improve the overall routing performance within a WSN [6] [7] [8]. TL-LEACH is one of the variations of LEACH protocol that offers multi-level communication concept [2]. Both LEACH and TL-LEACH protocols are briefly discussed below.

A. LEACH Protocol

LEACH is basically a hierarchical protocol aimed at routing data or information within a cluster based WSN [2]. Its advantages include properties such as self-organizing and self-adaptive. LEACH works in rounds. One round encompasses two stages; cluster setup and the steady-state, a set of nodes involved in each. The main aim of the steady-state is to save energy and eliminate the unnecessary energy consumption. Nevertheless, the latter is shorter than the former.

The CH selection rounds ensure that the nodes in a cluster are not given the CH responsibility twice hence increasing the chance for the remaining nodes in the cluster to become a CH. The round ends if there are no more nodes left for the CH selection. Once the CH formation round completes the nodes then start to communicate data with the cluster head. Transmission of data from CH to BS is based on frames that help in reducing energy consumption hence having multiple frames in the steady-state help reduce the overall energy cost of the network. LEACH is distributive in nature hence it does not require knowledge of entire network. However, the communication cost still matters and needs attention to make it light-weight. Moreover, increasing number of nodes in a cluster may also help in saving energy as it increases the chances for more nodes becoming a cluster head at some point in time.

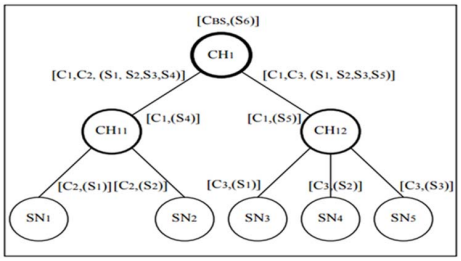

Fig. 1. TL-LEACH levels of hierarchy

B. TL-LEACH Protocol

This protocol uses the LEACH protocol as its bedrock and provides an extension to it by proposing multi-level communication [3]. It is aimed at providing better energy utilization among the WSN. A new level of hierarchy has been introduced that consists of two levels. The information or data sent from the end node to the cluster head does not directly go to the base station in TL-LEACH. Instead, it is sent to another or new level of hierarchy. This method not only increases the number of cluster heads in the network but also helps in decreasing the total distance traversed to BS. Hence decreasing the number of nodes needed to relay information to the BS. The hierarchical design involves two levels; primary and secondary. The primary CH are placed at the top in the hierarchy after BS and are labeled as CHi whereas the second level of hierarchy is formed at a lower level and labeled as CHij. At the end of the hierarchy are placed sensor nodes or also known as the end nodes. The computation is also divided as the basic processing is carried at the lower level that is the secondary CH level and then the data is only routed towards the BS with the help of the primary CHs level. The figure below illustrates the hierarchy.

The figure illustrates that the nodes CH11 and CH12 as cluster-head at an intermediate level. They process the data received from sub-cluster C2 and C3 or simple nodes SN1, SN2 and SN3, SN4, SN5 respectively. This protocol consists of 4 phases:

1) Advertisement Phase (round as LEACH) every node decide to participate in current round, (primary CHi)
2) Cluster Setup Phase similar to the LEACH protocol CH formation
3) Schedule Creation data transmission schedule via CDMA
4) Data Transmission Data transmitted to BS via the primary CHs.

Nearer nodes will take advantage to transmit their data to the base station in the cluster and lesser the number of nodes are which are away from the BS. This idea has been used to make this advantage more enhanced in a way where higher number of hierarchy levels may be used for this purpose. The proposed enhanced TL-LEACH protocol is discussed in the next section.

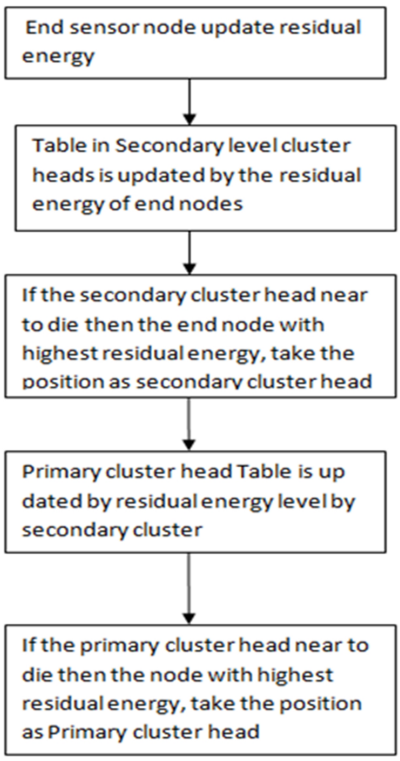

Fig. 2. Primary CH Selection Process in ETL-LEACH

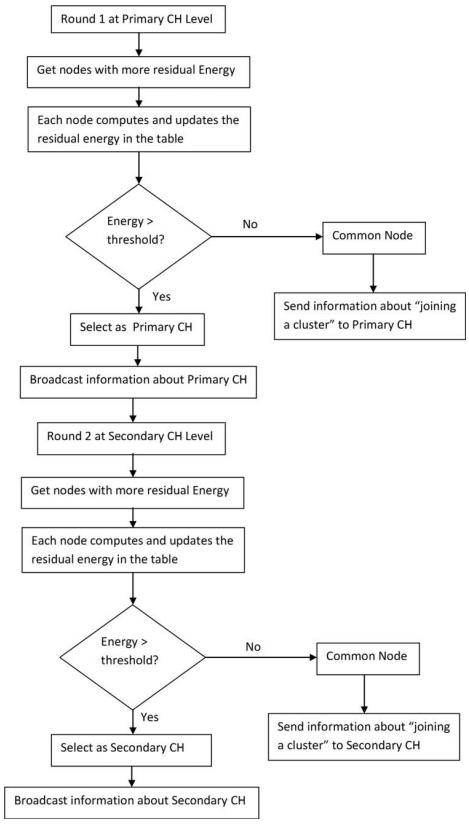

Fig. 3. Working of ETL-LEACH

III. Enhanced Two-Level-LEACH Protocol

In a cluster-based wireless sensor network, the cluster head plays an important role. It not only connects the end nodes to the base station but is also responsible for maintenance of the received data from sensor nodes of the cluster and communicates the information with the base station. TL-LEACH maintains two levels of CHs known as primary and secondary. The proposed enhanced version firstly focuses on the overall network lifetime which can only be guaranteed when the secondary level of CHs are alive. ETL-LEACH uses the bedrock of TL-LEACH while improving the overall energy consumption of the network to eliminate one of the disadvantages of the TL-LEACH. The secondary CHs work as relay nodes between the primary cluster heads and the end nodes which is similar to TL-LEACH. The working of ETL-LEACH has been illustrated in the flowchart given below (figure 2)

The cluster formation process for the ETL-LEACH maintains an energy table at the primary and the secondary cluster heads of the WSN. The table ensures that the secondary cluster head knows the residual energy of the end nodes attached to that cluster. This step helps in the cluster head role switching phase. In other words when the energy level of a secondary cluster head decreases and falls below an acceptable threshold, the cluster head requests for a role switch and with the help of the table the node with the highest residual energy is then selected for the role hence assuring that the secondary cluster head of that cluster can still communicate the data of the cluster to the base station. The process is similar for the primary cluster heads role switching. This ensures an overall increase in the lifetime of the cluster based wireless sensor network. The figure 3 below illustrates node joining process and primary cluster head selection.

Periodically, the nodes in the network update their residual energy to the secondary CH where the CH is responsible for maintaining a table with two columns named node ID and residual energy. Once the table is created, the CH performs the relay function and broadcast the information regarding its own energy level once the residual energy falls below the acceptable threshold. The selected node broadcast the role switch message to ensure that the end nodes attached to the cluster direct the data to that node as a new secondary CH. The communication within the cluster improves as the nodes switch the role of the CH among themselves ensuring robust data communication with the base station.

Due to issues with the network lifetime and residual energy, TL-LEACH has been designed for smaller networks spanning over a smaller geographical region with limited number of nodes in the network. A number of scenarios have been designed to verify the scalability of the proposed ETL-LEACH. The simulation details and the results are discussed next.

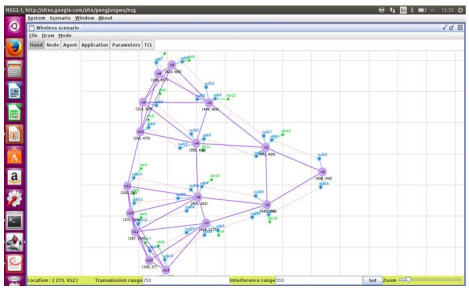

Fig. 4. A part of simulated WSN illustrating primary and secondary cluster heads

IV. Simulation and Results

ETL-LEACH uses the CH switching role technique to ensure that the communication between the end nodes and the base station is smooth and robust. Network Simulator has been used test the proposed ETL-LEACH and its performance. The network size was varied to identify the challenges and issues with respect to scalability of the proposed technique. The details are discussed below.

The considered number of nodes for the first simulation scenario was 100 and was gradually increased to 250. Each node had initial energy of 2J (joules). Energy consumption, communication delay and network throughput were evaluated during the simulation. Figure 4 below illustrates a part of the simulated network to evaluate the performance of ETL-LEACH.

The network under consideration in figure 4 consists of 50 nodes. The view illustrated in the figure 4 shows 16 nodes where n0 represents the base station, nodes n1 and n2 are primary cluster heads for the cluster comprising of the nodes n3, n4, n6 and n7. Similarly, these nodes carry out the task of the secondary CHs for the 2nd level hierarchy of the cluster based WSN. Moreover, for the scenario with 100 nodes the considered number of Primary cluster heads is 4, there are 20 secondary CHs and 76 end nodes.

Energy consumption plays a vital role in determining the lifetime of the deployed network. The performance may also depend upon the fact that the nodes save their energy to put it for better use when needed. The figure 5 below shows the energy consumption with respect to LEACH, TL-LEACH and ETL-LEACH protocols. It can be seen that the residual energy with respect to the proposed enhanced version of the TL-LEACH protocol is higher as compared to TL-LEACH and LEACH protocols. The reason behind higher energy consumption in LEACH protocol is mainly due to direct transmission to BS as it has been assumed that the nodes are equipped with high power and are capable of sensing data or information directly to the BS or the closest CH. Therefore nodes use high power in transmission of data hence energy consumption increases. TL-LEACH on the other hand waste more energy in CH selection phase and has limited CH options on each hierarchy. Hence advertising the CH frequently results an increase in the energy cost.

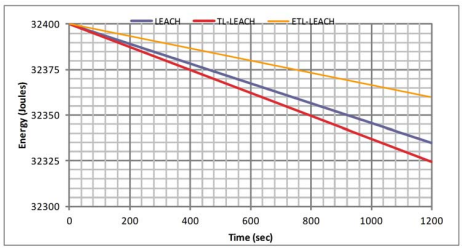

Fig. 5. Energy Consumption and the Residual Energy

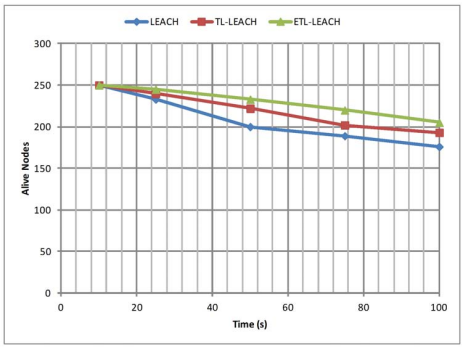

Fig. 6. Alive nodes

The number of sensor nodes alive in the network over some time duration was also evaluated to better understand the total improvement in the network lifetime. The figure 6 below illustrates the comparison between the LEACH, TL-LEACH and the ETL-LEACH protocols. It is clear that the ETL-LEACH has extended network lifetime compared to the two protocols.

A comparison with respect to required memory was also carried out among LEACH, TL-LEACH and ETL-LEACH only to enhance the performance of the proposed version. The graph in the figure 7 shows that the ETL-LEACH has slightly higher memory requirement as compared to the LEACH protocol due to maintenance of the residual energy table of the nodes in a cluster. ETL-LEACH has similar internal substructures as TL-LEACH though here each node updates its energy to its head, when a cluster head has energy lower than safe limit then it will select a node from member nodes. The new cluster head then broadcast its energy. During the process the residual energy table is updated and maintained.

Graph in the figure 8 shows the total processing time required to for each protocol. Each protocol has different rounds requirements. After an increase in the number of rounds the results figure 8 show that the proposed enhanced version of TL-LEACH forms better than the original one.

The simulation results show ETL-LEACH is light-weight in terms of energy consumption during communication by secondary and primary cluster head. Nevertheless, it helps improve the overall lifetime of the network hence providing better solution to be used for communication in cluster based wireless sensor networks.

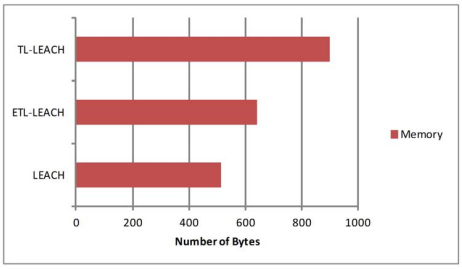

Fig. 7. Memory Comparison

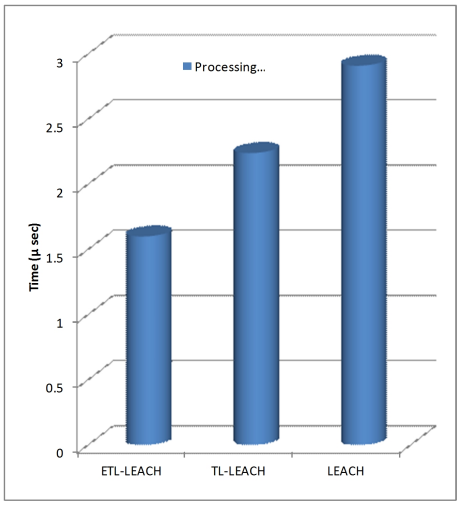

Fig. 8. Processing Overhead Comparison

V. Conclusion

An extension to the TL-LEACH protocol ETL-LEACH has been proposed in this paper that basically focuses on two major disadvantages of the TL-LEACH protocol. TL-LEACH itself is an extended version of the state-of-art LEACH protocol and works on the LEACH structure but in two levels. ETL-LEACH takes into account the CH election with respect to residual energy and latency in the communication. The proposed work has been analyzed and evaluated with the help of simulations and scenarios designed with varying number of nodes in the network for better evaluation of the proposed ETL-LEACH. The simulation results show that the proposed ETL-LEACH not only enhances the two level cluster head algorithm but it also supports the large-scale network application scenarios. Updating the residual energy of the end nodes frequently to the sub-cluster heads helps in maintaining the balance in energy consumption among the end nodes hence achieving better network lifetime. ETL-leach protocol should be tested on heterogeneous WSN. The future work includes expansion of the ETL-LEACH and use of a mobile sink to ensure successful data delivery. Other future efforts include improved hierarchical design which should be more flexible in term of mobility.

References

[1] 1. V. Loscri, G. Morabito, S. Marano, A Two-Levels Hierarchy for Low-Energy Adaptive Clustering Hierarchy (TL-LEACH), Vehicular Technology Conference, 2005. VTC-2005-Fall. 2005 IEEE 62nd , pp 1809 1813, 25-28 Sept., 2005.

[2] K. Singh, "WSN LEACH based protocols: A structural analysis," 2015 International Conference and Workshop on Computing and Communication (IEMCON), Vancouver, BC, 2015, pp. 1-7.

[3] C. Li, H. X. Zhang, B. B. Hao, J. D. Li, A survey on routing protocols for large-scale wireless sensor networks. Sensors 2011, 11, 34983526.

[4] C. Wei, J. Yang, Y. Gao, Z. Zhang, Cluster-Based Routing Protocols in Wireless Sensor Networks: A Survey. In Proceedings of 2011 International Conference on Computer Science and Network Technology, Harbin, China, 2426 December 2011; pp. 16591663

[5] M. Haneef, and Z. Deng, Design challenges and comparative analysis of cluster based routing protocols used in wireless sensor networks for improving network life time. Adv. Inf. Sci. Serv. Sci. 2012, 4, 450459

[6] G. Ran, H. Zhang, and S. Gong, Improving on LEACH protocol of wireless sensor networks using fuzzy logic. J. Inf. Comput. Sci. 2010, 7, 767775

[7] H. M. Abdulsalam, L. K. Kamel, W-LEACH: Weighted Low Energy Adaptive Clustering Hierarchy aggregation algorithm for data streams in wireless sensor networks. In Proceedings of IEEE International Conference on Data Mining Workshops (ICDMW), Sydney, Australia, 14 December 2010, pp. 18

[8] J. Hong, J. Kook, S. Lee, D. Kwon, S. Yi, T-LEACH: The method of threshold-based cluster head replacement for wireless sensor networks. Inf. Syst. Front. 2009, 11, 513521

[9] D. Zhang, G. Li, K. Zheng, X. Ming and Z. H. Pan, "An Energy-Balanced Routing Method Based on Forward-Aware Factor for Wireless Sensor Networks," in IEEE Transactions on Industrial Informatics, vol. 10, no. 1, pp. 766-773, Feb. 2014

[10] B. Y. Kushal and M. Chitra, "Cluster based routing protocol to prolong network lifetime through mobile sink in WSN," 2016 IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT), Bangalore, 2016, pp. 1287-1291.

[11] A. Yan and B. Wang, "An adaptive WSN clustering scheme based on neighborhood energy level," 2017 IEEE 3rd Information Technology and Mechatronics Engineering Conference (ITOEC), Chongqing, 2017, pp. 1170-1173.

[12] Naveen Sharma and Anand Nayyar, A Comprehensive Review of Cluster Based Energy Efficient Routing Protocols for Wireless Sensor Networks, IJAIEM,Volume 3, Issue 1, January 2014

[13] S. Misra and R. Kumar, "A literature survey on various clustering approaches in wireless sensor network," 2016 2nd International Conference on Communication Control and Intelligent Systems (CCIS), Mathura, 2016, pp. 18-22.

[14] M. Usha, S. Sreenithi, M. Sujitha and S. Swarnalatha, "Node density based clustering to maximize the network lifetime of WSN using multiple mobile elements," 2017 International conference of Electronics, Communication and Aerospace Technology (ICECA), Coimbatore, 2017, pp. 10-15.