LEACH-CR: Energy Saving Hierarchical Network Protocol Based on Low-Energy Adaptive Clustering Hierarchy for Wireless Sensor Networks

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***Abstract*— Wireless Sensor Network consists of hundreds to thousands of tiny sensor nodes deployed in the large field of the target phenomenon. Sensor nodes have advantages for its size, multifunctional, and inexpensive features; unfortunately, the resources are limited in terms of memory, computational, and in energy, especially. Network transmission between nodes and base station (BS) needs to be carefully designed to prolong the network life cycle. As the data transmission is energy consuming compared to data processing, designing sensor nodes into hierarchical network architecture is preferable because it can limit the network transmission. LEACH is one of the hierarchical network protocols known for simple and energy saving protocols. There are lots of modification made since LEACH was introduced for more energy efficient purposed. In this paper, hybridization of LEACH-C and LEACH-R and the modification have been presented for a more energy saving LEACH called LEACH-CR. Experimental result was compared with previous LEACH variant and showed to has advantages over the existing LEACH protocols in terms of energy consumption, dead/alive nodes, and the packet sent to Base Station. The result reflects that the consideration made for residual energy to select the cluster head and proximity transmission lead to a better energy consumption in the network.**

Keywords—LEACH, Wireless Sensor Network, energy efficient, cluster-based protocol

I. Introduction

The advancement of wireless technology nowadays has brought the future sensor technology called Internet of Thing (IoT). IoT consist of physical item and sensors communicate together via a wireless connection to exchange information. With the advantages such as tiny in size, multifunctional, and inexpensive features, sensor nodes are more favoured to be deployed in the large and harsh field of the target phenomenon. Sensor nodes composed of four basic units which are sensing unit, a processing unit, radio unit, and power unit that has limited resource in terms of energy, computation, and storage. Typically, Wireless Sensor Networks (WSNs) consist of many sensor nodes with an ability to communicate among themselves and to an external sink or a base-station [1]. Sensor nodes are deployed or scattered randomly in target environment for monitoring, controlling, and tracking purpose. Moreover, as the ad-hoc nature of sensor technology, it can be used in many applications such as military, industrial and manufacturing, healthcare, and surveillance purpose. [2] reviewed comprehensively about WSNs based on characteristic, architecture, existing hardware, prototypal implementations, and in-network processing.

On the other hand, WSNs routing protocol is categorized into flat-based, hierarchical-based and location–based structure depending on the network layer [3], [4] In flat-based structure, all nodes are given the same energy and responsibility and flat structure accomplished by data centric routing. In data centric routing process, query messages are sent out by base station (BS) to sensor nodes in a specific region. The sensor nodes then send their data back to base station. Meanwhile, in a hierarchical structure, some nodes with extra energy are appointed to bear an extra responsibility to ensure the scalability of the entire network. For instance, the selection of special nodes called cluster head, aggregator or intermediate is used to process or/and transmit the data in the network. Lastly, the location-based structure used the position of the sensor nodes to transmit the data to the target destination. The nodes position can be estimated based on the signal strength or using Global Positioning System (GPS), if available. [5] stated that hierarchical routing protocols are considered to deliver a better performance in respect of scalability and energy efficiency.

From the system architectural point of view, data aggregation is an important aspect of the design and deployment of large-scale WSNs [6]. In In order to ensure the availability of data at the BS for further analysis as well as to make important decisions, sensor nodes must operate as long as possible. As sensor nodes are powered by batteries embedded inside, it is inconvenient to change or recharge it after being deployed because sensor nodes are normally deployed in a harsh environment. According to [7], transmitting the data consumes more energy compared to processing the data itself. [4] stated that the hierarchical routing structure is one way for I to decrease the number of transmitted messages to the base station by performing data aggregation and data fusion. Moreover, it is inefficient for all nodes to transmit their data directly to BS, especially for long distance nodes. They consume extra energy and it will reduce their network lifetime of sensor nodes. Compared to other types of ad hoc network, WSNs have different network requirement and require different communication protocol as it is not well suited with the original network protocol and algorithm. For this reason, in order to reduce the energy computation and prolong the network lifetime, network architecture need to be carefully designed.

A cluster-based routing protocol, which is one type of hierarchical routing structure, will be a solution to overcome the excessive communication in WSNs. Moreover, direct communication between every node in the large network area to BS is an unrealistic approach due to the high communication cost, especially in energy consumption. In clustered WSNs, non-cluster head (NCH) nodes forward the sensed data to a cluster head (CH), then CH processes the data and forward it to the BS directly or in multi-hop fashion [8]. Many routing protocols based on clustering topology have been proposed in the past years, namely LEACH, HEED, and CLUDDA and Cougar. In this paper, new hierarchical routing protocols based on the hybrid LEACH protocol was proposed, called LEACH-CR. The advantages of two variants LEACH namely LEACH-C and LEACH-R are combined to reduce the extra energy consumption in the network while prolonging the network lifetime. Meanwhile, the modification is made to relay the cluster head that is located near to base station in order to reduce the number of data transmission to the BS.

The rest of the paper is organized as follows: related work on energy efficient approaches in WSNs and data aggregation algorithm are discussed in Section 2 and Section 3 respectively. Section 4 provides detail on the proposed LEACH-CR algorithm, followed by implementation of the proposed LEACH-CR and the experimental result in Section 5. Section 6 concludes this paper.

II. RELATED WORK

There are many protocols and approaches that have been proposed to design an efficient energy WSNs. [9] has presented the taxonomy of energy saving approaches in WSNs. They identified, three main approaches commonly used to minimize the energy consumption in WSNs—namely duty cycling, data-driven approaches, and mobility. Duty cycling approach consists of topology control and power management schemes which complementary to each other. Topology control can be achieved by exploiting nodes redundancy in the network while selecting minimum subset of nodes for continuous communication in the network. On the other hand, after the active node is selected in topology control, the sleep/wake-up operation of the radio transmission can be managed by power management scheme. The main idea of data-driven approach is to reduce the number of sensor data while maintaining the data sensing accuracy. The data-driven approach can be categorized into data reduction schemes and energy-efficient data acquisition schemes. The data reduction scheme is mainly designed to reduce the unneeded samples. Meanwhile, data acquisition schemes focus on reducing the amount of sensing and communication in the network. Data reduction scheme is further grouped into in-network processing, data compression, and data prediction. Lastly, the mobility-based scheme is considered when some of the sensor nodes are mobile in some cases. For instance, sensor nodes are equipped with mobilizer or sensor are attached with mobile elements like animals or transport.

In this paper, the focus is on in-network processing approach to design the energy efficient network protocol in WSNs. Meanwhile, sleep/wake-up protocol was used to schedule the transmission time for sensor node during the data transmission phase that presents less energy consumption. As stated by [9], in-network processing is performing data aggregation (e.g., computing the average of some values) at intermediate nodes between the sources and the sink. Data aggregation in WSNs aimed to fuse the data together (i.e., in the small cluster, in the same level or in near neighborhood) to efficiently use sensor nodes energy while increasing the network lifetime. In terms of network layer, data aggregation technique is categorized into hierarchical network structure of WSNs. The key idea of data aggregation is to combine the data coming from different sources which eliminate redundancy, minimizes the number of transmissions, and thus saves energy [10]. Therefore, data aggregation techniques can increase network energy efficiency since it reduces the number of data transmission

III. DATA AGGREGATION NETWORK TOPOLOGY

Aggregation structures can be categorized into a structure-based [11], while [1] categorized aggregation structures into flat network and hierarchical network. Clearly, structure free is expensive since there is no specific network architecture design and it may consume excessive energy. Nevertheless, extra communication and computation, especially at sink nodes in the structure-free will shorten the network lifetime. On the contrary, hierarchical network minimized the data transmission by grouping sensors and fused data into special nodes; hence, prolong the network lifetime.

On the other hand, [12] illustrated the data aggregation process as Figure 1. The processes include of data collected, implementing data aggregation algorithm, aggregated data before sending the output to the base station for further action.

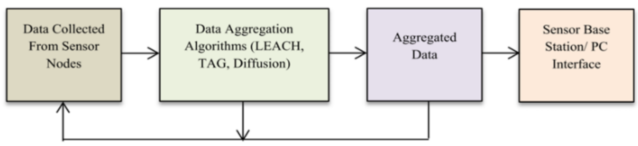

Fig. 1. Data aggregation process [12]

As mentioned earlier, data aggregation technique is classified into flat networks and hierarchical network [13]. The hierarchical network is then further classified into cluster-based, chain-based, and tree-based. Meanwhile, data aggregation networking structures are categorized into tree-based, cluster-based, multi-path approaches and hybrid data aggregation approach in [14]. The in-network processing approach can reduce the amount of data during the data traveling from the source to the sink. Furthermore, designing the network structure is used to deal with the problem of forwarding packets in order to facilitate the in-network aggregation of the information therein [14]. Flooding and gossiping, *Direct Diffusion* and *Sensor Protocol for Information Via Negotiation* (SPIN) are the protocols designed based on the flat network. Few hierarchical structures—namely tree-based, cluster-based, chain-based, grid based, and hybrid-based have been proposed in hierarchical data aggregation.

While each data aggregation structure has their advantages, there are still few drawbacks and rooms for improvement. The tree structure is constructed level by level connected with the intermediate node. However, if the intermediate nodes were disconnected from the network, the rest of the subtree will be disconnected too. Furthermore, reconstructing the tree aggregation will consume more energy. In cluster structure, data transmitted from long distance cluster head consumed more energy. A few enhancements to relay the long-distance transmission have improved the cluster-based energy efficiency. Basically, the idea of chain-based is to mitigate the long-distance transmission in the network by transmitting data to the closest neighbor. However, due to the random deployment of sensor nodes, some neighbor might be far away from each other; thus, consumes more energy. Again, as the chain-based structure is linked to each other, link failure will affect the data transmission to the base station. Based on the data aggregation approach, many solutions are proposed in the tree-based and cluster-based categories while very few studies use the multi-path and hybrid approaches [14]. Nevertheless, a hybrid approach has combined tree-based in the Tributaries and Deltas protocol. In this work, the cluster-based protocol was adopted to design energy efficient WSNs and details will be discussed in the next subsection. Nevertheless, there are many hierarchical protocols emerged based on the idea of LEACH [15], [16].

LEACH protocol was proposed by [17] based on the idea of random rotation of CH among the sensor nodes. LEACH algorithm operates in round and each round consists of setup phase and steady-state phase. In order to minimize overhead, the steady-state phase is longer than the set-up phase. LEACH presents the advantages on less energy consumption by randomizing the roles of CH among the nodes in the cluster. However, LEACH protocol offers no guarantee about the placement and/or a number of CH nodes [18]. And, regardless the residual energy of the sensor nodes, low energy node may be selected as CH. Due to the roles of CH to perform data aggregation and data transmission to BS, the energy of CH nodes will quickly deplete. When selected CH has low energy die prematurely before completing its round [19], this will affect the performance of the entire network. [20] mention LEACH is more economic and appropriate choice for small and and average zone. Therefore, many algorithms are proposed based on original LEACH to mitigate LEACH limitations.

Few survey on LEACH variants such as in[21]–[24] discussed the variation of LEACH improvement especially in energy efficient. Few parameters are listed out including for it such as location of the node, node density, distance from the BS, mobility, energy harvesting nodes, optimal number of CHs [21] other than energy parameter during CH selection. On the other hands, the deterministic clustering methods increase the complexity and energy consumption, as they use different approaches like fuzzy- logic based, weight-based, heuristic-based, and compound based approaches [21]. Meanwhile, [22] suggested other important subcategories includes the residual energy, energy efficiency, distance, network coverage, and routing path as strong influence on the network lifetime.

LEACH-C have been proposed in [25] to overcome the randomization of CH selection. In contrast to the original LEACH protocol, where nodes organized themselves into local clusters, LEACH-C used BS as a central control to determine the CH node and broadcast the CH node identity to the nodes in the network. Similar to LEACH, LEACH-C involved two stages operation. In order to limit the data transmission for the next process, other variants of LEACH called LEACH-R [26]has been suggested to select one relay node to mitigate the long-distance nodes problem that consumed extra energy for data transmission. This relay node is selected among the cluster heads based on the residual energy and their distance from BS. Thus, CH node that is located far from the base station will transmit this data to relay nodes in order to minimize the length of the communication.

IV. PROPOSED LEACH-CR

LEACH operation depends on forming sensor nodes clusters in perspective of got signal strength and use neighbourhood CHs as switches to the sink [27]. Moreover, the distance-based cluster formation improves the LEACH protocol in enlarging the lifetime of the network [28]. Our proposed LEACH-CR take the energy level based on signal strength and the nodes distance to propose the energy efficient LEACH protocol. Fig 2 shows an overview of our proposed LEACH-CR. Like original LEACH, the proposed LEACH-CR consists of setup and steady-state phases. In our proposed LEACH-CR, cluster head selection, relay node selection, and cluster formation processes will take place in setup stage. Meanwhile, the steady-state phase consists of data transmission and aggregation processes. The transmission for CH to relay data either to relay nodes or directly to BS will also be executed in steady-state phase.

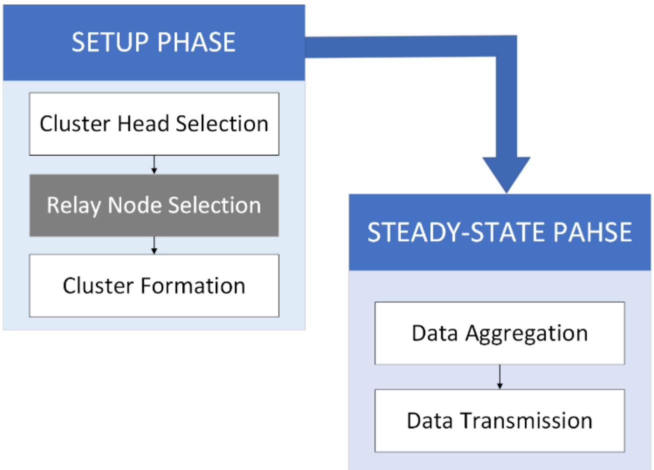

Fig 2. Overview of the LEACH-CR [18], [26]

In the setup phase, all nodes will be organized into few clusters and selection of cluster head nodes and a relay node will be performed. Performing clustering network architecture will reduce the number of data transmission in the network and consume less energy. Steady-state phase involves of data transmission and data aggregation based on allocation time provided in cluster formation process.

In the proposed LEACH-CR algorithm, all nodes begin to send their location and energy information to the BS to begin the cluster head selection. The base station will calculate the average energy in order to evenly distribute energy among the nodes in the network in the first round and nodes with energy above the average are selected as cluster heads.

For the next round, rather than using the calculation in original LEACH for the cluster head selection process, this LEACH-CR algorithm uses calculation that is used in LEACH-R [18]. In this calculation, it considers the residual energy of the nodes and shows in Eq. (1).

$$T(n) = \begin{cases} \frac{P}{1-P*(r \bmod \frac{1}{P}} \left[\delta P + (1-\delta P)\frac{E_{residual}}{E_0}\right] & if\ n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

The calculation includes δ, which represents a number of consecutive rounds that nodes have not been selected as CH and this value is reset to 0 when they become CH. This parameter gives the opportunity to all eligible nodes to become cluster head in next rounds while ensuring a fair distribution of the network lifetime. Meanwhile, represents nodes' current energy. To ensure nodes with low energy are not selected as cluster heads, only nodes with higher residual energy will be considered. After the cluster head selection process finished, relay node will be selected in the next process.

Relay node selection is incorporated in this LEACH-CR based on the LEACH-R. Unlike LEACH-R, relay node selection is performed after the cluster heads are selected. A relay node will be selected among the cluster heads and based on threshold calculation. Eq. (2) shows how the threshold is calculated.

$$\lambda = \frac{Node_{energy}}{Node_{distance}} \quad (2)$$

In LEACH-CR, we modified data only from cluster heads located far from the base station will be relayed. This can be achieved by calculating the average distance of all cluster heads using Eq. (3).

$$\mu_{CH} = \frac{\sum CH_{distance}}{\sum numbers\ of\ CH} \quad (3)$$

This calculation will be used for next data transmission process to ensure cluster heads near to base station to directly transmit their data to base station. Therefore, it will reduce the energy consumption in relay node as well as less number of data transmission.

For cluster formation process, non-cluster head nodes will be organized into the cluster by joining one of the selected CH. This process can be achieved by determining the closest CH. Measuring the closest CH node means its' received signal strength is stronger than other CH. After the CH is found, these non-cluster nodes are considered as member to the CH node of the cluster. The term 'associate nodes' is given to these newly added nodes. Then, the CH will schedule every associated node to transmit the data. Setup phase is complete when cluster heads and relay nodes are selected, and all nodes are grouped into cluster.

Data transmission begin when associated nodes within the cluster sending their data to the CH. To ensure that energy is used efficiently, sensor nodes are awake during their transmission time and it will sleep when their time slot expires. This assumption is used to reduce energy dissipation. On the other hand, CH must be awake all the time to receive data from the associated nodes within the cluster region. Relay node will be executed when there is a long-distance transmission between CH and the BS. Based on Eq. (3), distance of CH from BS will be compared with . If distance is more than , CH will use relay node to send data to BS, otherwise BS will directly send data to BS. After all the data from associated nodes are received, CH will proceed with data aggregation process.

V. RESULT AND ANALYSIS

The experiment was done to evaluate the performance of the LEACH-CR. Evaluations were done and measured based last/residual energy, number of nodes dead /alive and total amount of data packet received at BS.

Network and parameter setup are shown in Table I. This parameter setup was made based on common LEACH experiment but closely based on the LEACH-C and LEACH-R experimental setup.

TABLE I. VALUE OF THE PARAMETER USED IN THE EXPERIMENT

PARAMETER	VALUE
Number of nodes	100
Network grid	100 x 100
BS position	(50,175)
Initial energy	50nJ/bit
Size of data packet	500 bits
E_{amp}	0.0013pJ/bit/m^4
E_{fs}	10pJ/bit/m^2
E_{elec}	50nJ/bit
E_{DA}	5nJ/bit/signal

Table II shows the summarization of results executing LEACH, LEACH-C, LEACH-R and LEACH-CR for 1000 rounds. Our proposed LEACH-CR demonstrated a lot of gains compared to LEACH, LEACH-C, and LEACH-R, especially in terms of total dead and alive nodes, packet received at the BS, and residual energy remains after 1000 rounds.

TABLE II. RESULTS OF EXECUTION FOR 1000 ROUNDS LEACH, LEACH-C, LEACH-R, LEACH-CR

	LEACH	**LEACH-C**	**LEACH-R**	**LEACH-CR**
First node dead (round)	179	570	***102***	139
Total nodes dead /Total nodes alive	94/6	68/32	58/42	***57/43***
Packet sent to Base Station (bits)	16 x 10^3	6 x10^3	20 x10^3	***51 x10^3***
Residual Energy (nJ/bit)	0.5328	0.7523	5.6762	***8.3999***

Total 94 nodes are dead in LEACH protocol which is almost 100% of total nodes in the network. Meanwhile, LEACH-C shows 68 dead nodes which represent almost 20% improvement of network lifetime compared to original LEACH protocol. Moreover, only 58 and 57 dead nodes are reported in LEACH-R and proposed LEACH-CR respectively. These results give more than 40% improvement compared to the original LEACH. The first dead node is reported at round 500 for LEACH-C protocols, whereby other protocols reported the first node dead after 100 rounds

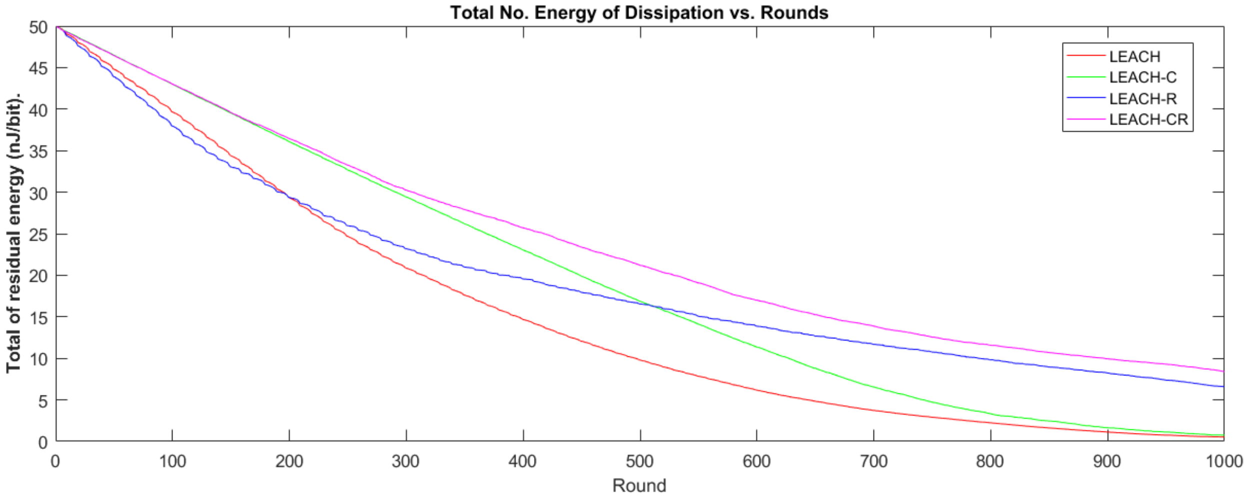

Fig. 3. Residual energy comparison between LEACH, LEACH-C, LEACH-R and proposed LEACH-CR.

including our proposed LEACH-CR. However, the numbers of dead nodes increased rapidly after the first node dead for LEACH-C which make a total of dead nodes is 20% higher than LEACH-R and LECH-CR at 1000 rounds.

The proposed LEACH-CR is more energy efficient compared to LEACH, LEACH-C, and LEACH-R. This is due to the election of relay nodes that help to relay long distance CH nodes for data transmission and consumes less energy. Meanwhile, when CH is near to BS, direct transmission is more energy consuming rather than sending it to relay node and to BS. This modification helps to reduce transmission to BS. Moreover, as CH node selection need to consider energy and distance, it contributes to prolonging the node lifetime. The short distance data transmissions contribute less energy dissipation compared to long distance data transmission. Besides, selecting nodes with more residual energy not only prolongs the network lifetime but it also helps to sustain the node lifetime. Furthermore, when CHs are dead, it affects the network lifetime; therefore, decrease accuracy for the next analysis at the BS.

Results of LEACH and LEACH-C show that the total energy dissipation is near 0 nJ/bit at 1000 rounds execution. From Figure 8, the residual energy for LEACH-R and proposed LEACH-CR are still more than 5nJ/bits; however, the proposed LEACH-CR outperform the LEACH-R result. The performance of LEACH is lower because LEACH has limitation in randomization for CH selection where it did not concern about the nodes' residual energy which led it to select low energy nodes to become CH. CHs need more energy for the process, aggregate, and transmit the data. This leads to the early death of the low energy CH. Hence, LEACH-C is aimed to use centralized clustering by getting information of residual energy and location from sensor nodes. This means that BS did the CH selection process. Apart from considering only residual energy during CH selection, LEACH-R is proposed to elect relay nodes among the CH for relaying data of CH located far from BS. The motivation of selecting relay node is to solve long distance transmission from CH to BS. Therefore, by combining both advantages of LEACH-C and LEACH-R, the hybrid LEACH-CR helps to consume less energy than for LEACH, LEACH-C, and LEACH-R. Moreover, in our proposed LEACH-CR, another enhancement is made by direct transmission of CH located near to BS. Despite the CH nodes with proximity to BS transmit their data to relay nodes, this improvement again reduced the long transmission. Moreover, the improvement has minimized the number of transmissions in the network

In cluster-based routing protocol, the CH aggregate data was transmitted from sensor nodes in the cluster then transmits the aggregated data to BS. The more data the BS receives, the more accurate its view of the remote environment will be [17]. The average number of packets sent in LEACH and LEACH-C protocol is lower compared to LEACH-R and LEACH-CR. This is due to the lengthy network lifetime for both LEACH-R and LEACH-CR. Hence, a number of packets received is more than LEACH and LEACH-C. Moreover, compared to the original LEACH, almost 40% of the nodes are still alive when experiment reached 1000 rounds for both protocols. While demonstrates the scalability of the network, both LEACH-R and especially LEACH-CR contributes to the quality of data communication in the network.

VI. CONCLUSION

In this paper, energy efficient data aggregation based on cluster-based topology was proposed to overcome the excessive energy consumption in this resource-constrained network of WSNs. The new hybridized LEACH-CR protocol which combined the idea of LEACH-C and LEACH-R protocol was proposed to develop a more energy-efficient LEACH protocol. LEACH-C was proposed to overcome the limitation of original LEACH; selecting low energy nodes to be cluster head in randomization strategy. Meanwhile, LEACH-R was proposed to assist a far cluster head node to transmit data in long distance range by electing a reliable cluster node as a relay node. By combining both ideas, the proposed LEACH-CR presented 40% more energy-efficient LEACH in terms of network lifetime, network energy efficient, and the appropriate packet transfer as compared to LEACH, LEACH-C, and LEACH-R protocol. Further experiment was conducted to evaluate the scalability of LEACH-CR. Comparison was made between LEACH-CR and LEACH-R. The overall results showed that the proposed LEACH-CR gave better results than LEACH-R. As the aim of proposed LEACH-CR is to efficiently consume the energy in the network, energy can be conserved by limiting the data transmission. As literature reported that transferring a data is equal to process as much as thousands of data; this proposed LEACH contradicts that by showing a lower data transmission compared to the previous LEACH.

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