Improvement of Cluster Head Selection in LEACH for Reducing Energy Consumption in Wireless Sensor Networks

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Abstract- Sensor nodes (motes) are randomly dispersed in wireless sensor network (WSN) domains. Motes in WSNs coordinate for producing information of high quality and each scattered mote routes that information back to fixed or mobile base stations (BSs). One of the problems with sensor nodes is battery constraints that limit network lifetime, meaning mots contain limited power depending on size, battery life, and memory. Aggregation-based routing algorithm, low energy adaptive clustering hierarchy (LEACH), is envisaged as a highly adequate solution to reduce power consumption. The main objective of this work is to optimize the LEACH protocol primarily in terms of power consumption. There are two reasons to explore hierarchical routing. First, sensor networks have high density and there is a large amount of redundancy in communication. The second is to increase the scalability of the sensor network by considering the security aspects of the communication. In many studies using the LEACH algorithm, the performance analysis of WSNs with the MATLAB simulator has revealed some flaws that need to be eliminated in the algorithm. The proposed research uses the improved IV-LEACH protocol to ensure an even distribution of selected cluster heads of motes over the network to increase the efficiency of the LEACH protocol. Using MATLAB, average life, energy consumption, and efficiency are analyzed to determine mots suitability for use in WSNs. The IV-LEACH protocol outperforms the LEACH protocol, improving energy consumption, lifetime and throughput in a simulated network of 150 nodes.
Keywords: WSN; LEACH protocol; average lifetime; energy consumption.

1. Introduction

With technological advances, sensors are in high demand for monitoring and surveillance applications. Small, autonomous and inexpensive sensors can be used to monitor various parameters such as chemical structure, velocity, voltage and temperature. Most of these sensors wirelessly send the measured parameters to a base station (BS), i.e. a sink. Receivers and transmitters feed the sensors and enable wireless communication. These autonomous sensors are distributed in an area and communicate with each other to form a WSN. WSNs are typically used to monitor applications in areas where replacing or accessing sensor nodes is not possible or practicable from an economic point of view (for example, in high voltage substations) [1-2].

To ensure the continuity of these applications, short-lived sensors need to be operated for longer periods of time. Transmissions from sensor nodes in WSNs consume a significant amount of energy, which is considered one of the primary reasons for the premature failure of nodes. Therefore, network lifetime and energy consumption stand out as major concerns in WSNs. As WSNs grow in popularity in networking fields, researchers use a broad range of energy effective approaches to decrease the energy consumption of nodes and extend the network lifetime [3]. Despite their positive aspects, WSNs have some limitations. To overcome these formidable problems, multiple algorithms have emerged over time to increase network lifetime. These algorithms configure routes with minimal delay for sensor broadcast and communication, reduce power cost, and provide adequate, error-free data transmission. Among them, the Low Energy

Adaptive Clustering Hierarchy (LEACH) algorithm is consistently popular. LEACH is a cluster-based routing protocol that performs well and is an adaptive algorithm [4-9].

A modified LEACH algorithm is presented in [10], which calculates the optimal cluster head (CH) proportion in the selection of CH nodes, considering the residuary energy and current location problem, and uses the Stable Election Protocol (SEP) algorithm to compute the divergent CH selection probability for ahead and standard nodes. The enhanced energy efficient LEACH (EEE-LEACH) algorithm proposed in [11] decreases energy consumption in the WSN by utilizing multiple-input multiple-output (MIMO) method and selects the shortest route for data transmission in channel undergoing fading. The research in [12] first analyzes the basic operations related to LEACH and performs optimization using a Genetic Algorithm (GA) to make longer the life span of the network. A LEACH-based clustering algorithm, which minimizes the energy consumption from sensors pending data transmission, is presented in [13]. The LEACH protocol has been customized to extend the lifetime of the WSN. In [14], the high packet loss of LEACH routing is solved through network optimization by adding a Delay Tolerant Network (DTN) structure that allows transmission in exceptional conditions such as a crowded WSN. In the optimization algorithm based on the LEACH algorithm presented in [15], the energy efficiency of the BS is increased to share the energy consumption with the network, resulting in approximately twice the network's lifetime in contrast to the classic LEACH algorithm. A new CH selection mechanism is developed in [16] to increase energy performance of the Two-Level Hierarchy for the Low Energy Adaptive Clustering Hierarchy (TL-LEACH). Extended TL-LEACH outperforms in terms of energy consumption, node's service life, and communication latency is significantly reduced. In [17], a Residual Energy-Aware Clustering Transformation (REACT) protocol is proposed for LEACH, which improves its achievement by providing a clustering technique. A modified end-to-end reliable LEACH (ME-LEACH) algorithm is presented in [18] to boost the lifetime of a WSN by altering the data communication from a CH to the BS. Another proposed modified version of LEACH, which uses an intermediary CH to transmit data in [19], aims to extend network lifetime and forward a greater amount of data compared to the classic protocol.

The issue of energy consumption is very important in WSNs, so it is vital to decrease energy consumption and increase network lifetime. As mentioned above, LEACH is one of the major accepted routing protocols, as it is characterized by saving energy, resulting in increased network lifetime by random selection of the CH. However, this protocol has some limitations; the CH excludes the residual node energy in the selection process, resulting in the node's death. Also, the distance between the BS and the nodes is excluded when choosing CH. The power consumption process of the CH distant from the BS is higher than the nodes' power consumption near to the BS. These limitations need to be evaluated when designing the WSN protocol. The main factor to consider is the amount of energy consumed by the sensor and how reducing the energy consumed increases the network lifetime.

In this article, an optimized LEACH-based protocol has been developed. It takes advantage of the energy features of protocols such as TL-LEACH, E-LEACH and PEGASIS to increase the efficiency of the LEACH protocol by establishing the even distribution of the selected CHs in WSN. Using MATLAB®, the performance of the proposed protocol has been validated compared to several LEACH-based protocols. The LEACH algorithm is a cluster-based protocol of routing, so it performs well and is adaptable.

2. Theoretical Background

2.1 Protocols Used in WSN

The most important purpose of routing a WSN is to provide highly efficient, continuous networks. Flat direction, hierarchical direction, and positional (location-based) direction are three possible classifications for the protocol based on the shape of the network [20-22]. The protocols used in WSNs are shown in Fig. 1.

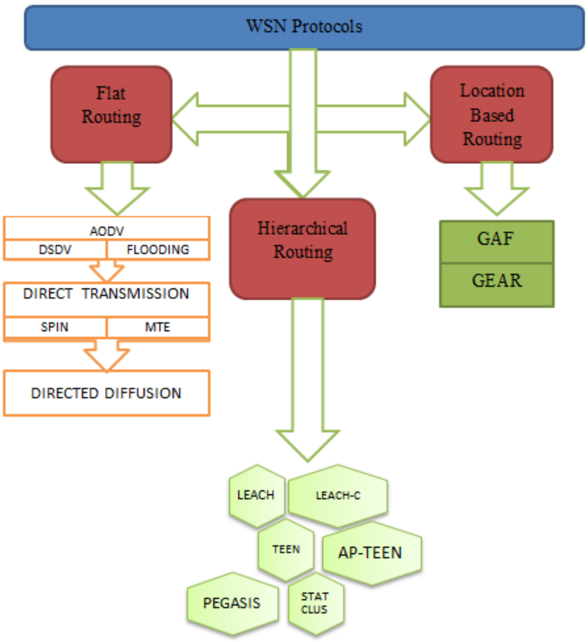

Figure 1: WSN protocols

Flat Routing Protocol: The flat routing protocol can be defined as a multi-hop protocol in which each node has a fixed functional role, all nodes participate in the operation to complete the sensing process, and each node cannot be identified individually as a result of many nodes. Flat routing consists of several protocols as: Ad-hoc On-demand Distance Vector (AODV), Flooding, Minimum Transmission Energy (MTE), Sensor Protocol for Information via Negotiation (SPIN), Destination Sequenced Distance Vector (DSDV), Direct Transmission and Directed Diffusion (DD).

Hierarchical Routing Protocol: Hierarchical algorithms divide nodes into subregions called clusters. One CH is selected from each cluster to allow communication between clusters. CHs are then responsible for the management and transmission of data aggregated inside of the area they supervise. Hierarchical or cluster-based routing generally comprises of two layers of routing: one layer is related to CH selection and the other is related to routing [23]. Hierarchical routing consists of several protocols as: LEACH, LEACH-Centralised (C), Threshold-sensitive Energy Efficient sensor Network (TEEN), Adaptive TEEN (APTEEN), and Power Efficient GAthering in Sensor Information Systems (PEGASIS).

Location-Based Routing Protocol: Location-based algorithms use a node's location information to find and transmit data to a destination in a specific network area [23]. Network nodes do not require complex calculations to find the next hop in this protocol; direction decision is based on location information. This protocol consists of a set of facts of network nodes. First, the nodes must be identified by a Global Positioning System (GPS) device. Second, each of the nodes must know the location of adjacent nodes. Third, the source node must be aware of the destination node's location [24]. Location-based routing consists of several protocols, such as Geographic Adaptive Fidelity (GAF) and Geographical and Energy-Aware Routing (GEAR).

2.2 LEACH Protocol

This protocol is a self-organizing, adaptive clustering protocol that uses randomization to uniformly allocate the energy load between the sensors in the network. Nodes here arrange themselves into local clusters with one node performing as the local BS or CH. To prevent premature death of selected CHs LEACH involves random rotation of the high-energy CH location to rotate between diverse sensors i.e. precautions are taken to avoid draining the battery of a single sensor [4]. When CH is selected, it sends a message to other nodes to join that cluster. However, sensor nodes other than CH select their CH based on the minimum transmit energy required for communication. After a cluster is created, the CH determines the communication schedule for its nodes [25]. The topology of the LEACH clustering structure is illustrated in Fig. 2.

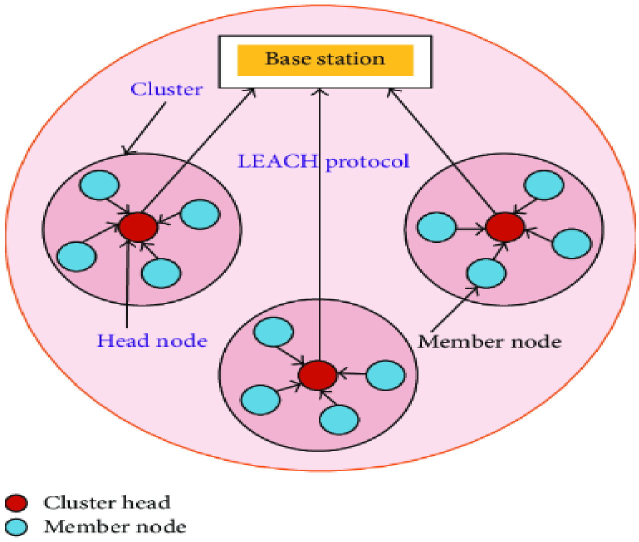

Figure 2: LEACH clustering structure [25].

LEACH Algorithm: The LEACH process is separated into rounds. Every round starts with the set-up phase where the clusters are arranged. Following this is the steady-state phase where data is transmitted to the BS. To reduce the overhead, the steady-state phase is longer compared to the set-up phase [4]. The main steps involved in the operation of LEACH are listed below.

I. Set-up Phase

At this phase, the nodes are dynamically divided out into various clusters and per cluster, a CH is randomly selected from among the cluster nodes. During the time that clusters are created, a random number in the range of 0 to 1 is chosen and compared with the threshold *T(n)*. If the selected value is smaller than *T(n)*, the node is made as a CH for the present round; else, the node remains a member node [26]. The threshold *T(n)* is calculated using the following equation:

$$T(n) = \begin{cases} \frac{p}{1-p\times(r \bmod \frac{1}{p})} & if\ n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

where p is the percentage of the CHs amid all the nodes, r is the number of the round, and G is the collections of the nodes that have not been CHs in the course of the last $1/p$ rounds [4].

After some nodes are identified as CH, the entire network is announced by sending control message packets. These messages are received by all network nodes and then stored in their memory. These nodes then determine whichever cluster to participate based on the strength of the received signal. The strength of the signal indicates the distance between nodes and CHs. Nodes will be closest to one of the clusters. This process helps reduce energy consumption. After the cluster to join is determined, standard nodes (not CHs) send a control packet to the CHs, informing them that they have joined certain clusters [25].

After formation of the clusters, all CHs decide on the communication timeline for their cluster. CH and other members utilise Time Division Multiple Access (TDMA) for communication within the cluster. The CH shares out the data transmission time slot when each cluster member can transmit data to its CH. TDMA time schedule assists nodes reduce the number of unneeded communications [27].

II. Steady-State Phase

In the steady-state phase where the data transmission occurs, every sensor node accumulates data from the environment and transmits it to its own CH. Each sensor node acts in accordance with the timeline for communication. CHs acquire data from cluster members and conduct data fusion. Data fusion process brings down large amounts of data and shrinks data packets, which assists CHs utilize far less energy to send data to the BS. Sending data packets from CHs to the BS constitutes the final stage for the steady-state phase [27].

Later, the network goes back to the cluster creation procedure, which involves new set-up and steady-state phases. The periodic process keeps going on until the entire network dies [27]. The description of the two phases above explains how individual clusters communicate between nodes in the respective cluster. But radio, by its very nature, is a broadcast medium. Therefore, transmission in one cluster has an effect on (and therefore disrupts) communication in the neighboring cluster. To lower such interference, each cluster transmits utilizing different CDMA codes [4]. The first-order radio model, consisting of both transmitter and receiver electronics, and a transmitter amplifier presented in [4], [27-30], provides a simple low-energy radio model in terms of energy requirements suitable for a complete analysis of radio signals to be filtered from neighboring clusters. Fig. 3 shows the flowchart of LEACH.

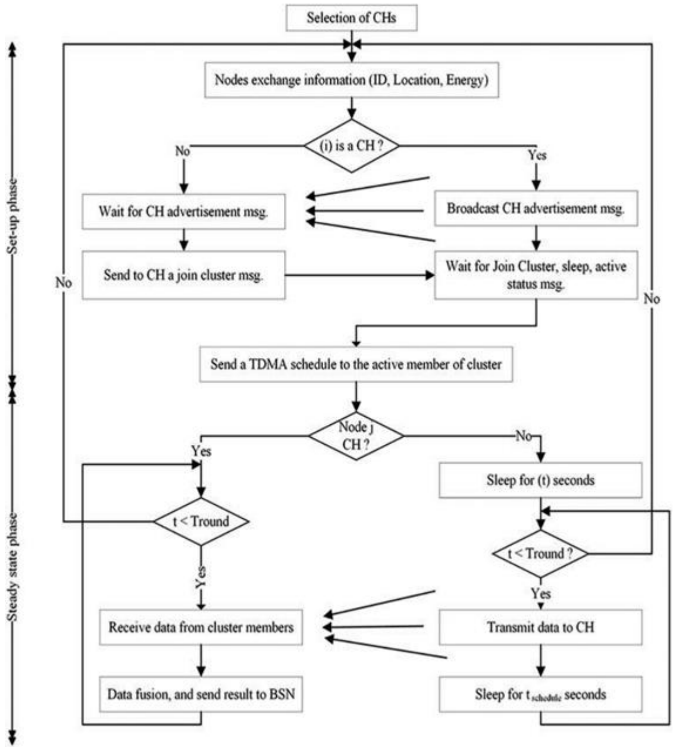

Figure 3: Flowchart of LEACH algorithm [31]

3. Overview of the Proposed IV-LEACH Protocol

At the core of the proposed IV-LEACH protocol, besides the original protocol of LEACH, there are advantages provided by TL-LEACH and E-LEACH protocols for energy consumption, and there is also the PEGASIS protocol used for equal distribution of energy in the WSN [32]. The flow diagram of the IV-LEACH protocol is displayed in Fig. 4. The most substantial features of the protocols incorporated in the IV-LEACH are described in the sections below.

3.1 TL-LEACH Protocol

Different from the LEACH, where CHs send data directly to the BS in a single hop, the TL-LEACH protocol introduced in [33] works in a two-level hierarchy [5]. TL-LEACH applies arbitrary rotation of local cluster BSs (primary CHs and secondary CHs) [33], that is, it uses one of the CHs located between CH and BS as a relay terminal. The bi-level nature of TL-LEACH decreases the number of nodes allocated for data transfer to BS and then efficaciously lowers the overall energy consumption [7], [9]. TL-LEACH utilizes two methods to attain energy and delay efficiency: random, adaptive, self-configuring cluster formation and localized control for data transmissions [22].

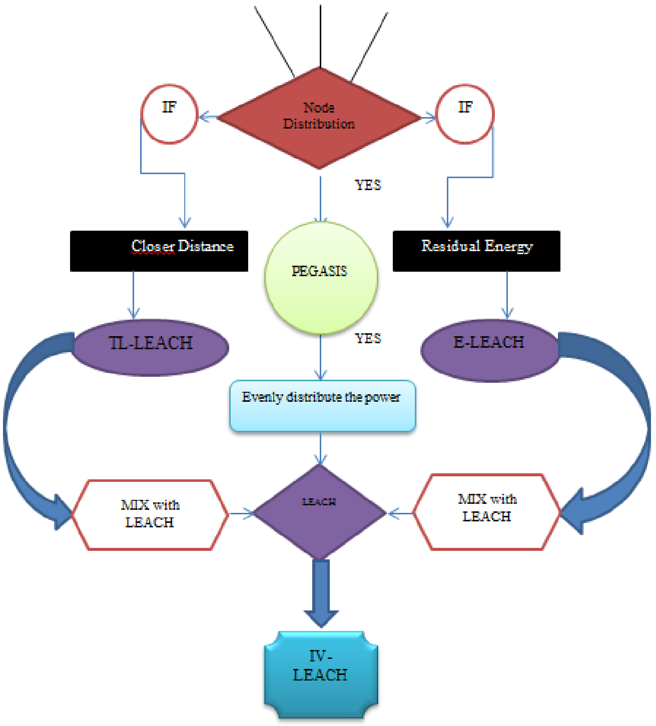

Figure 4: Flowchart of the proposed IV-LEACH protocol

3.2 E-LEACH Protocol

Enhanced-LEACH (E-LEACH) upgrades the CH selection process by making the residual energy of the node the primary metric in determining whether the node is a CH in the next round [9]. In the E-LEACH protocol, initially all nodes have the same energy and the same probability of being the CH, i.e. in the first round, each node has a chance to be the CH, indicating that the selection is random like in the LEACH protocol [5]. After the first round, the remaining energy of each node is determined and considered in the selection of CH. Communication between CHs and BS requires more energy than communication between CHs and cluster members. E-LEACH selects nodes with large residual energy at the root node as CH [7]. LEACH-E extends the service life of the network by balancing the energy load between all nodes in the network [5].

3.3 PEGASIS Protocol

PEGASIS is an improved near-optimal chain-based protocol over LEACH. In PEGASIS, every node communicates solely with its nearby neighbor and transmits to the BS in turn, hence decreasing the amount of energy consumed per round [34]. The chain is created using the greedy method and the leader of chain is responsible of transmitting the data to BS, where every network node changes its task as the leader permitting a better even distribution of energy load among WSN nodes and thus the energy consumption for each round is balanced [35]. In PEGASIS, the sensor nodes are randomly located, and each of them is capable of data sensing, wireless communication, data fusion and positioning. The energy load is evenly shared out between the sensor nodes in the WSN [22].

control. It also shows the definition of the server name, server port, and key assigned to the server.

3.4 IV-LEACH Protocol

The IV-LEACH protocol uses distributed clustering method unlike LEACH. The entire sensor area is divided into sub-regions that are similar to each other. Cluster head selection from each sub-region is provided by the threshold method as selected in the LEACH protocol. Every regular node in this network can be shut down until the allotted time of transmission, minimizing the energy consumption in the nodes [32].

The inclusion of the E-LEACH protocol is to improve the CHs selection procedure. After the first round, the main measure in deciding which nodes can be CHs is the residuary energy of each of the nodes. Like the LEACH, the E-LEACH algorithm is divided into rounds. In round 1, each of the nodes has the same probability of turning into CH. This is an indication that CH is chosen at random. In subsequent rounds, since the residuary energy of each of the nodes differs after the first round of communication, it is used in the selection of the CHs. Nodes higher in energy become CHs.

In IV-LEACH, to further increase energy efficiency, one of the CHs located between the cluster and the BS is used as a relay point, as in the TL-LEACH, instead of transferring data straight-forward to the BS.

Like the LEACH, IV-LEACH has 2 phases: set-up and steady-state phases. The protection mechanism detailed in [27] has also been added to the IV-LEACH protocol to lower the number of re-clustering operations required.

Once cluster heads are selected, a WSN uses the CSMA MAC protocol to announce its state. The remaining nodes make CH decisions in the current round relying on the strength of the received signal of the advertisement message. A TDMA schedule is applied to all cluster group members to send a message to the CH. Then CH sends the data to BS. When a CH is selected for a particular area, the steady-state phase begins. A flowchart of this distributed clustering algorithm is shown in Fig. 5 [36].

As soon as the clusters are formed and the TDMA time schedule is determined, the transmission of data begins and the steady-state phase is initiated. Assuming that the nodes always contain all the data, the nodes communicate during the transmission times allocated to the CH. Such a type of transmission utilizes minimum energy (the level is selected according to the received strength of the CH advertisement message). Then the radios of the nodes are closed until the allocated transmission time. The IV-LEACH protocol ensures a homogeneous distribution of selected CHs throughout the network.

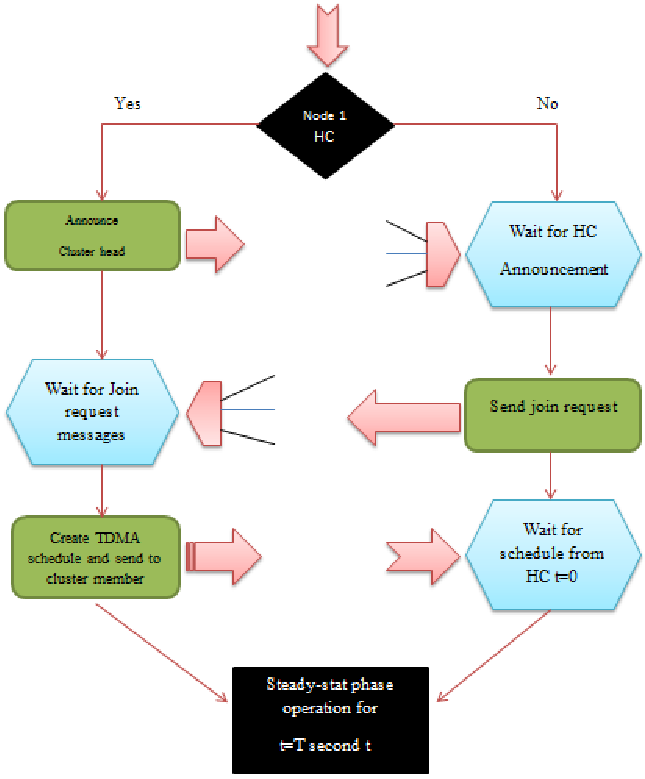

Figure 5: Cluster formation algorithm flowchart for IV-LEACH [36]

4. Protocol Performance Simulation and Analysis

The efficiency of the IV-LEACH protocol is validated by using MATLAB simulation tool and evaluation is peformed based on the period of network stability, i.e. network throughput, network lifetime and energy dissipation. Parameters used in simulations are categorized in Table 1. The nodes of the WSN are simulated to be randomly distributed over an area of 900×900 m^2 with the BS located at the central point (450, 450), as is shown in Fig. 6.

Table 1. Simulation parameters

Parameter	Value
Sensing area (W×L)	900 × 900 m^2
Number of nodes (N)	150
Initial energy of nodes (E_0)	0.5 J
Desired percentage of cluster heads	0.1 J
Position of BS	X = 450, Y = 450
Packet size for CH per round	6400 bits
Max number of simulated rounds	500
The energy of free space model amplifier	0.34 nJ
Energy for transmitting and receiving one bit	50 nJ
Amount of energy that is spent by the amplifier for transmitting bits	100 pJ
Energy of data aggregation	5 nJ

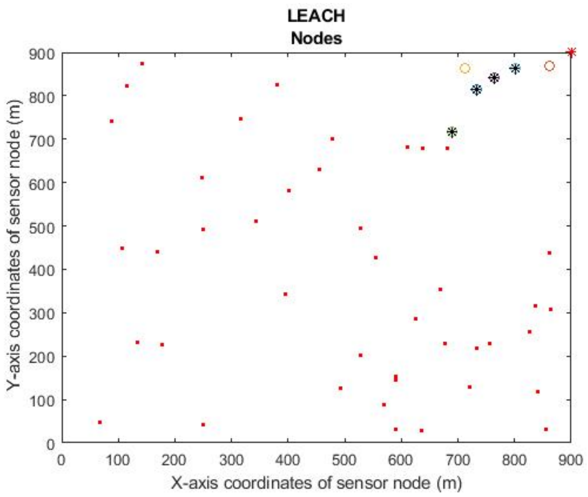

Figure 6: Location of nodes in WSN

4.1 Performance Analysis of IV-LEACH over LEACH

Lifetime of the Network: Network's lifetime represents the interval of time from the start of communication to the sensor node's death. Following 460 rounds of the IV-LEACH protocol and 300 rounds of the LEACH protocol, 10 live nodes remained. This is demonstrated in Fig. 7.

Total Energy Dissipation: The performance of WSN is greatly improved with IV-LEACH protocol over traditional LEACH protocol. As shown in Fig. 8, the average residual energy was 300 J after 250 rounds were completed in the conventional protocol, while it was 300 J over 480 rounds for the IV-LEACH protocol.

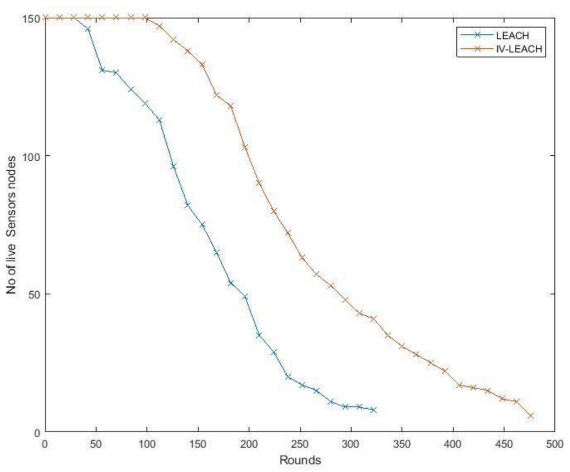

Figure 7: Lifetime of the sensor nodes

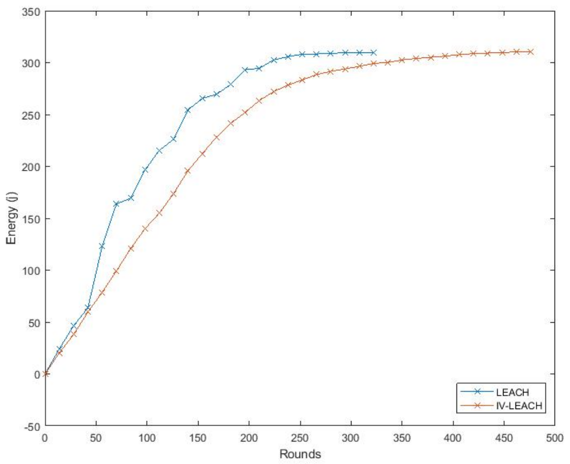

Figure 8: Total energy dissipation

Throughput of the Network: The IV-LEACH protocol outperforms the original LEACH protocol regarding the throughput of the network i.e. the number of the received data packets, as shown in Fig. 9. In the LEACH protocol, the number of packets was 7.5×10^5 per 300 rounds. But in the IV-LEACH protocol, the number of packets was 11×10^5 in 300 rounds.

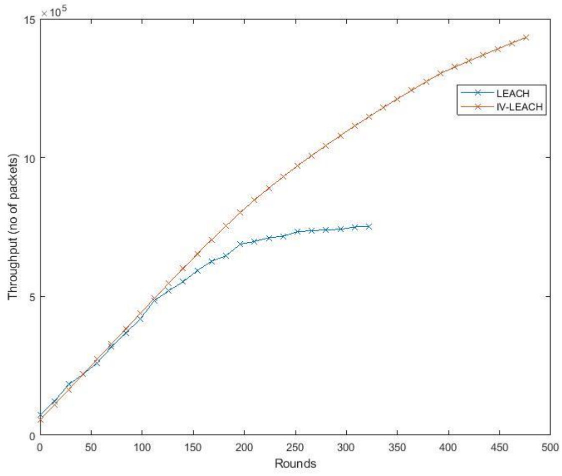

Figure 9: Throughput of the network

4.2 Comparison of Network Stability Period

The stability period of the network is represented by the first dead node (FDN), i.e. the moment when the death of the 1st sensor node occurs relative to the time after the start of the rounds. The simulation results show that the IV-LEACH protocol has higher stability compared to the E-LEACH, TL-LEACH and LEACH protocols. As shown in Fig. 10, after several simulation runs, FDN for LEACH, E-LEACH and TL-LEACH protocols occurs in five seconds, six seconds, and seven seconds, respectively. FDN for the IV-LEACH protocol takes place in eight seconds.

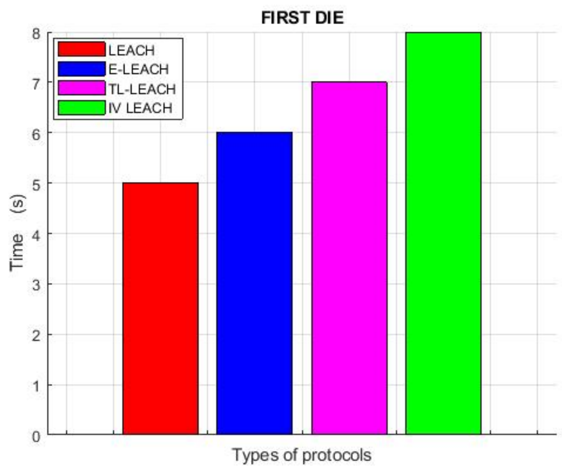

Figure 10: FDN lifetime of different LEACH protocols

Similarly, the last dead node (LDN) is also used for network stability. As shown in Fig. 11, LDN for the LEACH protocol occurs in 150 seconds. For the E-LEACH and TL-LEACH protocols, LDN occurs in 225 and 325 seconds, respectively. In the IV-LEACH protocol, LDN occurs in 450 seconds.

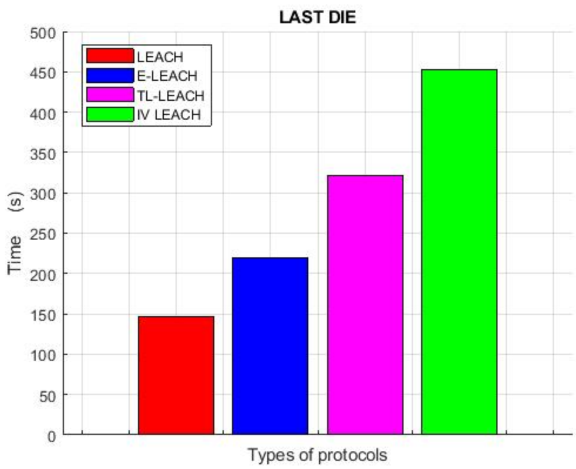

Figure 11: LDN lifetime of different LEACH protocols

5. Conclusion

Energy saving is an important issue in WSNs. In order to enhance energy efficiency and extend the service life of sensor nodes, multiple energy-aware cluster-based techniques are developed. CH selection is an essential step in cluster formation that affects network lifetime and throughput. The IV-LEACH protocol presented in this paper provides the advantageous features of E-LEACH, TL-LEACH and PEGASIS protocols as well as the selection of cluster heads evenly distributed throughout the network. The IV-LEACH routing protocol has been optimized to extend the lifetime of the sensor nodes, taking into account their residuary energy and their distance from the BS. This protocol makes it possible to extend the lifetime of the WSN. Network stability cycle is still considered short for many applications requiring reliable network feedback. IV-LEACH has been modified to enhance the stability of the network by increasing the FDN and LDN times. The simulation results obtained indicate that the IV-LEACH protocol can come through the restrictions of the LEACH protocol in terms of energy consumption, throughput and network lifetime.

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