

An Energy Efficient Routing Protocol in Wireless Sensor Networks

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ABSTRACT

The limited lifespan of sensor nodes in Wireless Sensor Networks (WSN) due to battery drains has drawn researchers' attention to improving the nodes' lifespan by developing communication protocols that efficiently utilize the limited available power. Many researchers have leveraged the well-established Low energy adaptive clustering hierarchical (LEACH) routing protocol to establish a better routing protocol to increase the network's overall lifespan. In this paper, an Enhanced Energy Efficiency LEACH protocol with equidistance based - Cluster Head (CH) selection is proposed to optimize nodes' energy consumption. The CH selection process was formulated to consider the residual energy and equal distance between the member nodes and the base station. Also, a modified Time Division Multiple Access (TDMA) schedule which considers the schedule of the largest cluster in the network was utilized. MATLAB R2018a was used for development and simulation. Results from simulations show that the proposed protocol improved the lifespan of the network by 50% and 117%. This implies that the developed model can significantly reduce the energy consumption of sensor nodes and is suitable for designing a WSN in real-time scenarios.

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INTRODUCTION

In recent times, the emerging field of wireless sensor networks (WSNs) is utilized as a paradigm for information collection in many different applications, including biomedical, home surveillance, monitoring of habitat and environmental conditions, forest fires, agriculture, data logging, industrial automation, detection, etc. (Amrieen *et al.*, 2020)

WSNs have many benefits, such as portability, low cost, high data processing capabilities, ease of deployment and the ability to self-organize. However, their main challenges are the limited resources in terms of communication, computation and energy. (Jorio *et al.*, 2018)

Since sensor nodes are battery-powered and have limited communication and energy storage capacity, there is an ongoing research interest in developing techniques and protocols that can be used to extend their useful

life while utilizing the available battery life. (Khalaf *et al.*, 2022)

Low Energy Adaptive Clustering Hierarchy (LEACH)

Heinzelman *et al.* (2000) introduced an energy-efficient clustering technique called LEACH (Low-Energy Adaptive Clustering Hierarchy). LEACH is a clustering technique which helps in optimizing the power consumption of sensor nodes by selecting a few Cluster Heads (CH) based on cluster rotation while other nodes join these cluster heads to form clusters. The sensed data are sent to the respective CH to be aggregated, and the data is then transmitted to the BS by the CH (Raj *et al.*, 2022)

LEACH works in rounds and each round is made up of two phases namely; the set – up phase and the steady state phase. In the cluster formation selection and CH takes place. The CH selection criteria of a member node are the

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recommended percentage P and the earlier record as a CH. If a node is not a CH in preceding $\frac{1}{P}$ rounds, it produces a number between zero and one ($0 - 1$). Only nodes with a generated number less than threshold $T(n)$ are eligible to become CHs. The formula used to calculate the value of threshold is given in equation 2.1 (Heinzelman *et al.*, 2000).

$$T(n) = \begin{cases} \frac{P}{1-P \times (r \bmod 1/P)} & \text{if } n \in G \\ 0, & \text{Otherwise} \end{cases} \quad (1)$$

Where n is a random number between 0 and 1, P is the probability of CH selection, G is the group of nodes not selected as CH in preceding $1/P$ rounds, and r is the current round.

LEACH, being the parent routing protocol received many enhancements. However, there are several drawbacks in LEACH protocol;

- i. Firstly, in choosing a node to serve as CH, the residual energy level of that node is not considered.
- ii. Secondly, when clusters are formed, the distance of the cluster nodes from the designated CH and to the base station (BS) is not considered.
- iii. Thirdly, sending of data to the base station is achieved via Time division multiple access (TDMA). This causes every cluster to send information at its allotted time, even when there is no new information to send.
- iv. Lastly, in sending information, nodes use the same energy level to send

message to CH and to BS irrespective of the distance between them.

Most research efforts geared towards improving the LEACH protocol in a homogenous sensing field have focused on the setup phase, providing interesting and often successful modifications and improvements to the conventional LEACH protocol. However, the drawback has been the persistent use of Time division multiple Access (TDMA) schedule for data transmission during the steady state phase which leads to multiple data transmission from small cluster sizes compared to larger cluster size, resulting in quicker energy dissipation and node death in smaller cluster sizes.

WSN Energy Dissipation Model

Energy is depleted in sensor nodes mainly as a result of its transmission and reception of data, and it depends largely on the distance between the transmitter and the receiver. Transmitting sensor node consumes energy to drive its radio subsystem which includes the radio electronics, and power amplifier while the receiving sensor node also dissipates energy to drive its radio electronics. The distance d between the transmitting sensor node and receiving sensor node usually computed in the form of a distance metric specifies the channel model used by the power amplifier (Rappaport *et al.*, 2010). Figure 1 shows a simplified WSN energy dissipation model. If the distance d is greater than a set threshold d_0 , the multipath model is assumed, else the free space channel model is used for $d < d_0$.

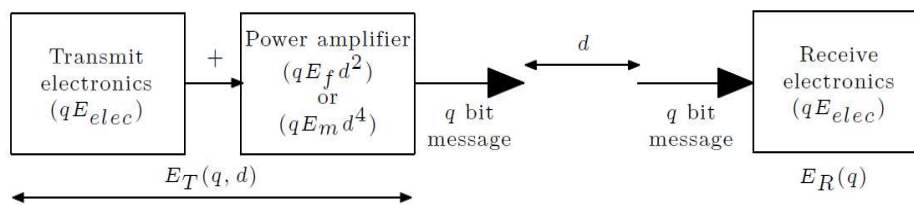


Figure 1: WSN Energy Dissipation Model. (Rappaport *et al.*, 2010)

Therefore, the required energy for a sensor node to transmit a q bit message is defined as (Rappaport *et al.*, 2010):

$$E_T(q, d) = \begin{cases} qE_{elec} + qE_f d^2, & d < d_0 \\ qE_{elec} + qE_m d^4, & d \geq d_0 \end{cases} \quad (2)$$

Where E_f is the energy dissipated by the power amplifier for the free space model, E_m is the energy dissipated by the power amplifier for the multipath model, E_{elec} is energy dissipated to drive the radio electronics, and, d_0 is transmission distance threshold. (Rappaport *et al.*, 2010)

LITERATURE REVIEW

In WSN, energy is consumed the most in the process of data transmission, hence energy efficient routing protocols are needed in order to improve the life span of WSN. Several routing protocols have been proposed in the literature by researchers in a bid to improve the lifespan of WSN. Amirthalingam *et al.*, (2016) proposed an improved LEACH algorithm by adopting a simple approach of adjusting the cluster head selection process from conventional LEACH, using a factor called Score-function one (SCRFN1). This factor is determined by the ratio of the node's current energy level to the node's expected maximum energy level. CRFN1 was combined with another factor called score-function two (SCRFN2) given by the ratio of node-distance to base station to farthest cluster node-distance to base station. The combination of the two score functions was used to obtain the cluster head for each round. The result showed significant efficiency improvement over conventional LEACH.

Similar to the work of Amirthalingam *et al.*, Singh, S. (2016) proposed an improved version of an earlier variant of LEACH referred to as the Optimization-LEACH (O-LEACH) routing protocol for WSN. An improved clustering algorithm was developed where the cluster head for each round is selected based on comparative residual energy of greater than 10% and the distance to base station of the qualified nodes.

Also the work of Kumar *et al.*, (2016) presented a modified version of the LEACH called Enhanced-LEACH protocol. The protocol presented adopted a neighboring table system for neighbor node

logging to keep track of node condition for cluster head election and data forwarding. The proposed scheme adopts a method of each node calculating its distance to base station and CH from the position of a neighbor node, using a weighing factor. Results presented indicated an improvement in delay and adaptability for heterogenous network compared to conventional LEACH.

On the other hand, Bongale *et al.*, (2017) presented a modified protocol named Energy Influenced Probability based LEACH (EiP-LEACH). They achieved this by modifying the conventional LEACH cluster head election process by including a factor current energy of node by the initial average energy of the entire network. In their proposal, every eligible cluster head during election, is compared to all other eligible cluster heads in terms of residual energy only, so that the most qualified is selected. Results presented by the authors showed some improvement in network lifetime when compared to conventional LEACH and also a more gradual energy depletion curve.

Furthermore, Joiro *et al.*, (2018) presented a modification to the conventional LEACH called the Identifier-Energy Cluster Algorithm (IECA). The authors proposed an efficient Cluster Head (CH) replacement scheme, whereby residual energy levels of all sensor nodes within the network were compared to an established threshold within and outside the cluster. Result presented show that the IECA algorithm gives a significant improvement in terms of energy and lifetime gains, compared to LEACH.

Research Objectives

This research is aimed at developing an Efficient LEACH protocol for Wireless Sensor Networks. It focuses on modifying the existing TDMA to provide a balanced data transmission without overtaxing the nodes in smaller clusters. Its cluster head selection process was formulated to consider the residual energy and the distance between the member nodes and the base station. The goal of the study is to contribute to the ongoing research interest in developing techniques and protocols that can be used to

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extend their useful life while utilizing the available battery life

METHODOLOGY

The developed Efficient LEACH model has two phases, namely set-up phase and steady-state phase. In the set-up phase, cluster formation and Cluster Head (CH) selection was performed, while communication in the network was established between the nodes and Base Station (BS) via CHs in the steady-state phase. The details of both phases have been provided in the sub-sections below;

Set-up Phase

The set-up phase consists of cluster head selection and cluster formation stage.

Cluster Head Selection

At initial deployment, there are no CHs. For each round r of the simulation, cluster head selection is performed by considering the identification number assigned to each node and the node's residual energy determined by;

$$C_k = (r \bmod |S_k|) \quad (4)$$

Where

$|S_k|$ = the total number of nodes in the cluster k .

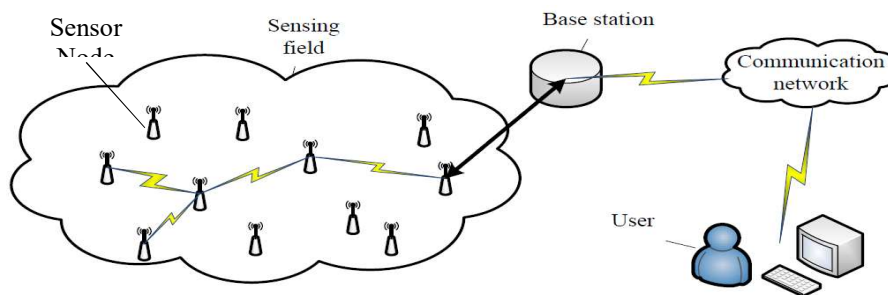


Figure 2: Typical Wireless Sensor Network Arrangement (Chris et al., 2011)

For a node to be selected as cluster head, its residual energy must be greater than its minimum energy (threshold). E_{min} is the minimum energy required of a node to receive, aggregate and transmit the compressed data to the base station.

$$E_r > E_{min} \quad (5)$$

Distance Based Cluster Formation

After the selection of cluster heads at each round, each cluster head sends a broadcast message which including its distance to the base

station to all sensor nodes in the network using carrier sense multiple access (CSMA) MAC protocol. The other nodes receive these broadcast messages from all cluster heads and then selects the cluster head which is closest to the midpoint between itself and the sink (BS) as its communication cluster head in order to minimize energy dissipation. Figure 4 below illustrates our simplified distance-based cluster selection model where the cluster member (node), cluster head and base station are all evenly distributed.

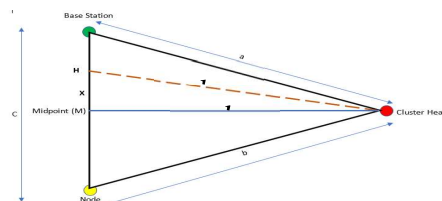


Figure 3: Distance Based Cluster Formation Model

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Where;

a: Distance between cluster head and Base station

b: Distance between node and cluster head

c: Distance between node and sink

Midpoint (halfway) between Node and Base station is defined as **M**

The distance between cluster head and **M** is defined as **X**.

The distance between node and cluster head with respect to the midpoint between the node and fixed base station can be computed as;

$$a^2 = h^2 + \left(\frac{c}{2} - x\right)^2 \quad (6)$$

$$b^2 = h^2 + \left(\frac{c}{2} + x\right)^2 \quad (7)$$

$$a^2 + b^2 = h^2 + \left(\frac{c}{2} - x\right)^2 + h^2 + \left(\frac{c}{2} + x\right)^2 \quad (8)$$

$$\therefore 2h^2 + \frac{c^2}{2} + 2x^2 \quad (9)$$

$$\text{Thus gives, } x^2 + h^2 = d^2 \quad (10)$$

$$\text{Conversly, } x^2 = d^2 - h^2 \quad (11)$$

$$\text{Hence, } a^2 + b^2 = 2h^2 + \frac{c^2}{2} + 2d^2 - 2h^2 + \left(\frac{c}{2} + x\right)^2 \quad (12)$$

To determine the cluster head nearest to the midpoint between the base station and node location, the node computes the distance;

$$d_{toCH} = \frac{M}{\sqrt{2 \times \pi c}} \quad (13)$$

Also,

$$d_{toBS} = \frac{G \times M}{2} \quad (14)$$

Steady State Phase

In the steady state phase, each cluster member of a cluster transmits the sensed data to its cluster head based on the modified TDMA schedule and then turn-off its radio when there is no data to send. This prevents data retransmission and prolongs the lifetime of the sensor nodes. Details of the modified TDMA schedule is provided below;

Modified TDMA Schedule.

To minimize the energy dissipation in small clusters, the TDMA of conventional LEACH was modified such that the schedule of the largest

cluster was considered. The process is outlines as follows;

Step 1: Each cluster head computes the number of sensor nodes assigned to its cluster based on the number of receiving requests.

Step 2: Each cluster head will broadcast a message including the number of its own nodes to the entire cluster heads in the WSN. To this end, each cluster head knows the capacity of the largest cluster.

Step 3: The capacity of the largest cluster is selected to be the implemented duration of the TDMA schedule in all clusters for steady state phase.

Step 4: Each sensor node within each cluster has a chance to transmit data according to modified TDMA in steady state phase. So, all nodes will send the same amount of data to their cluster heads. Thus, all nodes will drain the same amount of energy. Clusters that contain a small number of nodes after sending their amount of data for the current steady state phase, they go into the sleep mode during the remaining time of steady state phase.

Once the cluster heads receive all the data from its cluster members, it performs data aggregation and compression and sends the compressed data to the base station. When transmission from all the cluster heads is completed, a new round begins and repeats the process explained in "Set-up phase" and "Steady phase" sections respectively. Figures 4 and 5 depicts the communication flow in the Enhance LEACH protocol both in the setup phase and the steady state phase.

Simulation

The WSN considered in our study consists of 100 nodes deployed randomly across a sensing field of square area of $100 \times 100 \text{ m}^2$ as shown in figure 3. Each of the sensor node was assigned a unique identification number randomly between 1 to $N = (100)$, to differentiate it from all

other nodes in the network. The base station was located at a fixed location with coordinate (100m, 250m) meter and assigned identification number $N+1= (101)$.

Simulations were performed in MATLAB software and performance metric such as number

of alive nodes, network lifetime, throughput, average energy consumption for each node, and percentage of dead nodes are analyzed through multiple simulations.

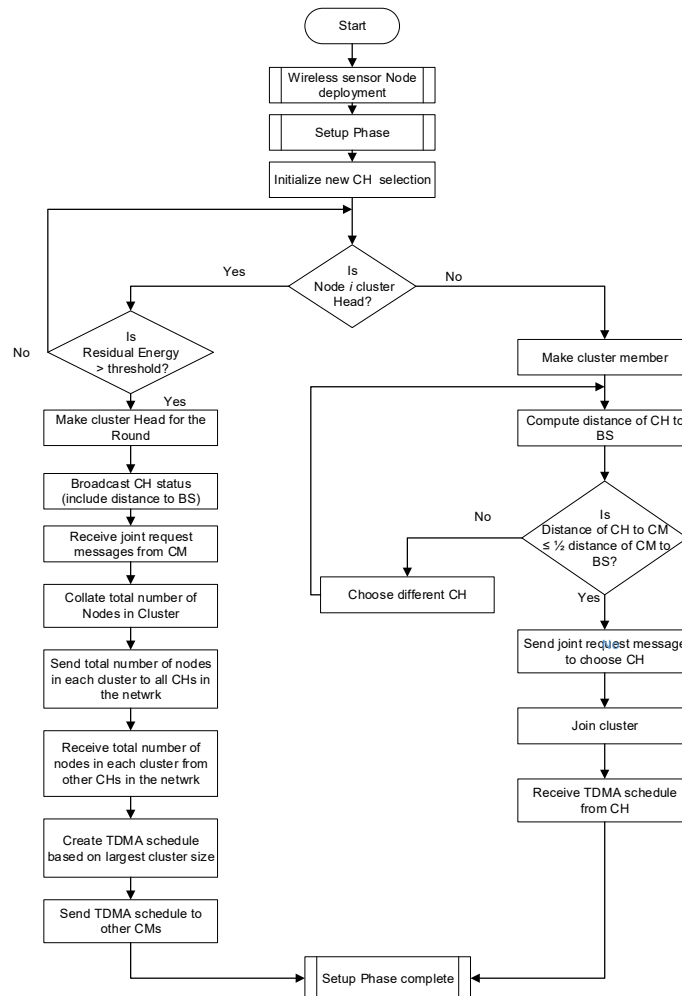


Figure 4: Flowchart of Developed Enhanced LEACH Routing Protocol (setup phase).

The lifespan of a sensor network is the time it takes for the First Node, Half of the nodes or Last Node to die, which is often referred to as FND, HND or LND measures. In this study, the number of rounds before the First Node Death (FND) was used as a measure. The throughput

can be considered as the total number of packets successfully received at the base station at some specific time. While the measure of energy consumption indicates how uniform the residual energy of the sensor nodes is being expended during the lifetime of the node.

Table 1: Simulation Parameters.

PARAMETERS	VALUES
Sensing Field	200m*200m
Base Station Coordinates	(100m, 250m)
Number of Nodes	100
E_{elec} (Residual energy Threshold of CH)	50 nJ/bit
ϵ_{fs} (Amplification energy) at $d \geq d_0$	10 pJ/bit/m ²
ϵ_{ms} (Amplification energy) at $d \leq d_0$	0.0013 pJ/bit/m ²
E_{DA} (Data aggregation energy)	5 nJ/bit/message
E_o (Sensor node Initial energy)	0.5 J
E_{ms1} (Amplification Energy CM to CH)	$\epsilon_{ms}/10$
E_{fs1} (Amplification Energy CH to BS)	$\epsilon_{fs}/10$
Message Size	4000 bits

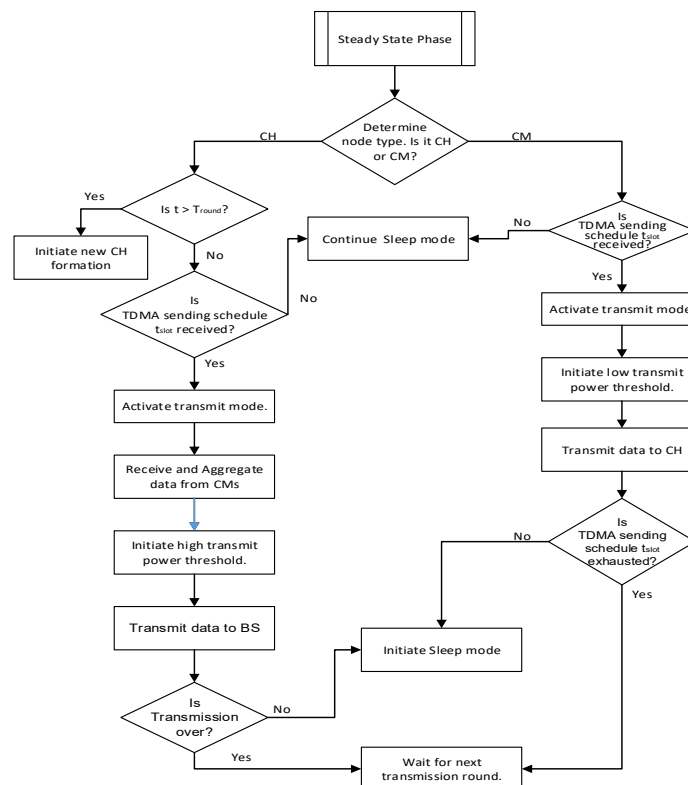


Figure 5: Flowchart of Developed Enhanced LEACH Routing Protocol (steady state phase).

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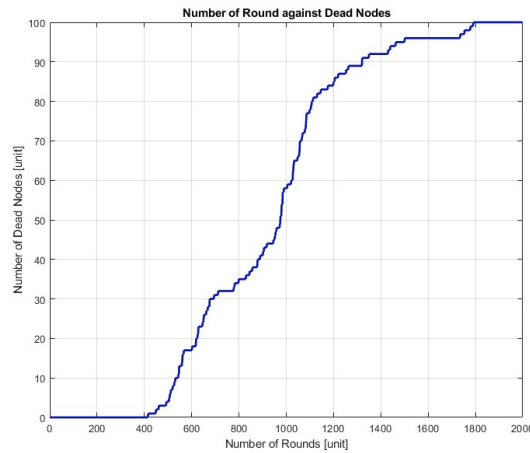


Figure 6: Plot of Nodes that are Alive vs Number of Rounds

RESULTS AND DISCUSSIONS

Network Lifetime

In Figure 6, the number of alive sensor nodes against the number of rounds was plotted for the 100 nodes in the sensing field. From the Figure, it can be observed that the FND occurred after 431 rounds, HND occurred after 879 rounds and the LND occurred after 1817 rounds. This improvement was due to the implementation of the

distance-based CH selection in the set-up phase and the new TDMA schedule in the steady state phase.

A plot of the dead nodes against the number of rounds is presented in Figure 7. The plot shows a negation to the alive nodes to give an indication of how fast the nodes are dying out. From the plot, it can be deduced that after 1000 rounds, a total of 64 nodes died out.

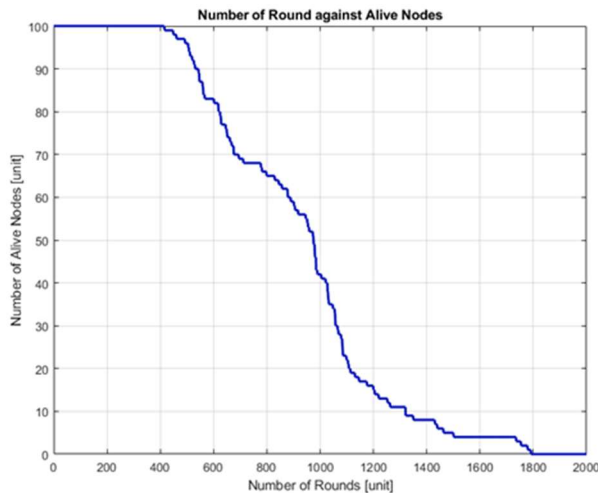


Figure 7: Plot of Dead Nodes against Number of Rounds

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Throughput Assessment

Figure 8 presents a plot of number of packets sent to CHs per round during the lifetime of the network. The result shows that the packet

transmission rate is dependent on the cluster size and also the number of alive nodes during the transmission round.

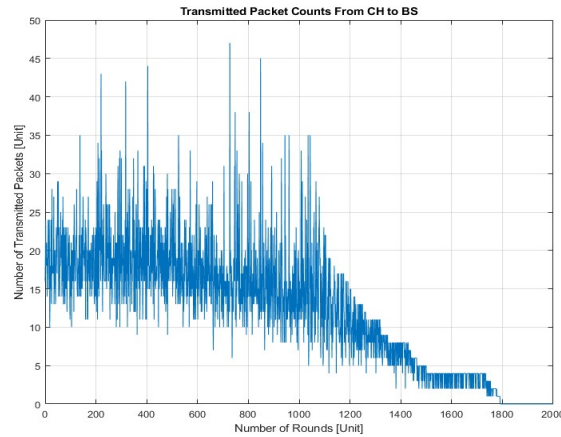


Figure 8: Plot of Packet Transmitted to Cluster Heads Per Round

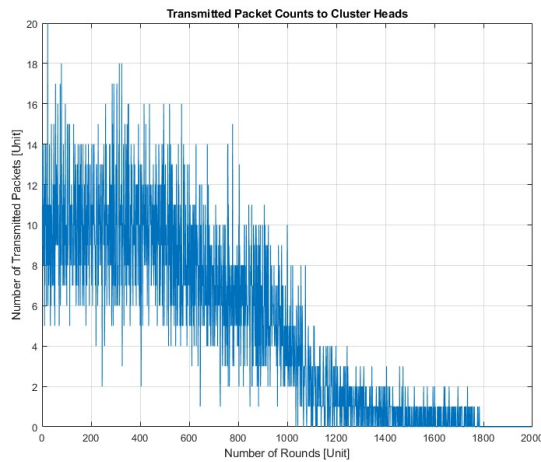


Figure 9: Transmitted Data Packets from Cluster Heads to Base Station

In Figure 9, the overall packet transmitted from the CH to the Base station is shown. An average high of 20 packets was transferred from the CHs to the base station at the

early life of the network, and a low of about 4 packets was transferred during the later life stage of the network.

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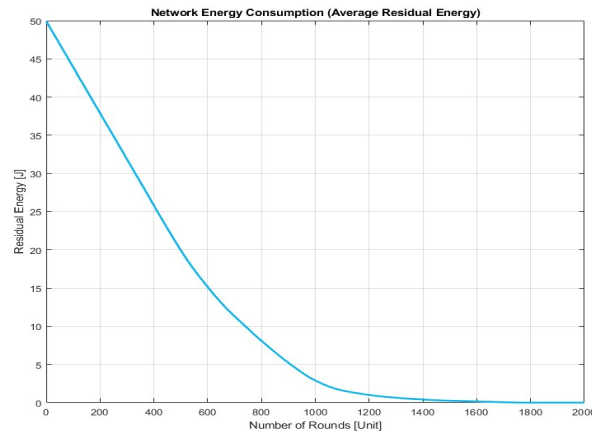


Figure 10: Overall Network Energy Consumption

Energy Consumption

From Figure 10, it can be observed that the energy consumption is uniform and gradual across the entire network. Starting with a residual energy of 0.5 joules per nodes and a total of 50 joules across the entire network of 100 nodes, the energy in the network after 200 rounds dropped to 37.67 Joules uniformly across the network (approximately 75.34% energy). After a total of 800 rounds, approximately 15% energy was left across the network, and only about 1% energy was remaining after a total of 1412 rounds. This indicated that the load was evenly distributed in the network when the CH was placed at

equidistance between the cluster members and base station.

Result Comparison

To validate the performance of the results obtained from the developed protocol, it was compared to the results presented by Identifier-Energy Cluster Algorithm (IECA) by Jorio *et al.*, 2018 in terms of network lifetime, energy consumption and throughput. For this purpose, the network was simulated with varying number of nodes, and varying values of initial residual energy.

Lifetime Comparison

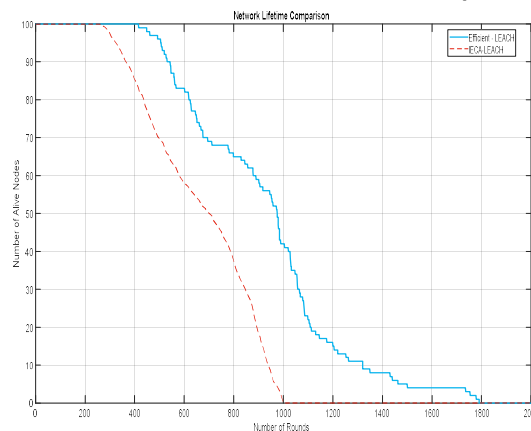


Figure 11: Network Lifetime Comparison

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The first node death recorded on IECA-LEACH protocol is at 288 rounds compared to at 431 rounds for the efficient protocol. HND and LND for IECA protocol occurred at 691 and 998 respectively, while same is recorded at 879 and 1817 respectively for the developed protocol.

The results indicate that the network lifetime using the developed protocol have been significantly improved, indicated by an approximately 150% increase in lifetime before the FND occurrence, and 127% lifetime

improvement on the HND, likewise a 182% improvement for the LND.

Average Network Energy Consumption

Comparing the two results shows that at 50 joules (0.5 joules per node) initial network energy, the developed protocol ensures a gradual and balanced energy consumption across the entire network such that the residual energy after 200 rounds of transmission was recorded to be 38 joules compared to 32 joules for IECA. Also, the

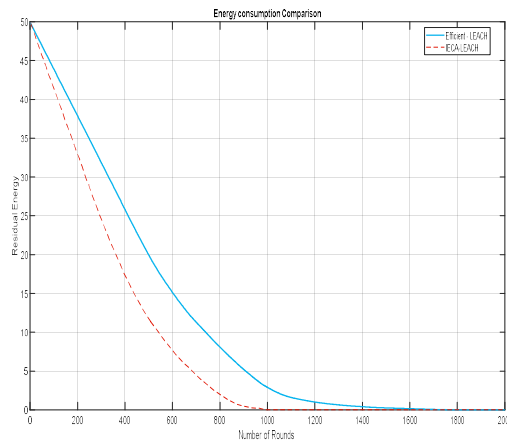


Figure12: Network energy consumption comparison

residual energy after 800 rounds is 9 joules for Efficient LEACH, compared to only 2 joules for the IECA protocol, providing over 4 times energy

saving capabilities indicated in figure 12. This improvement is as a result of the sleep – wake feature introduced in the steady state phase.

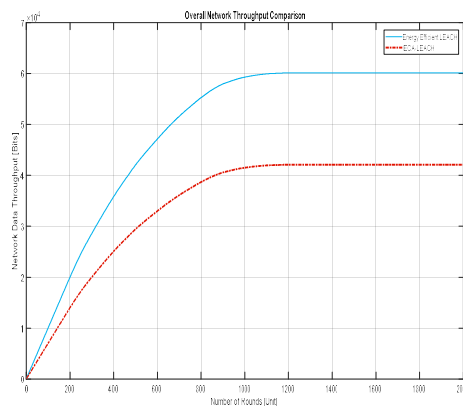


Figure 13: Network Throughput Comparison

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Throughput Comparison

From Figure 13, the overall network throughput obtainable after 200 rounds from IECA-LEACH was recorded at about 15,500 bits compared to 20,200 bits recorded for the developed protocol. Significant improvement was recorded as the number of rounds of transmission of the network increases towards maximum. At about 1200 rounds, the throughput from the

CONCLUSION

Improving the Lifespan of WSN require that the limited energy provided by battery life is efficiently utilized to enable the sensor node perform its function for as long as possible within the network. This paper presents an Efficient LEACH model for homogenous wireless sensor networks. In this model, nodes join a cluster only when their distance to the CH is less than half the distance between them and the base station. An improved TDMA schedule was adopted which is dependent on the cluster with highest number of nodes dictating the frequency of data transmission within the network while nodes in smaller clusters enter into sleep - wake state when not transmitting to save energy.

The results obtained shows that the presented protocol exceeds the IECA LEACH protocol in terms of network lifetime by approximately 150% when the FND times are compare, while overall network energy consumption drops by 74% after 600 transmission rounds, and throughput improved by 43% after 1800 rounds. This therefore indicates that an improved distance-based cluster formation, largest cluster dependent TDMA scheduling significantly improves the energy efficiency of the wireless sensor nodes, thereby increasing overall useful lifespan of the network. So, we can say that the presented work is suitable for designing a wireless sensor network in a real-time scenario.

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developed protocol was measured at 89,540 bits across the network, while that recorded for IECA-LEACH is 62,750 bits.

Similarly, after 1800 rounds the IECA-LEACH recorded 65,350 bits while the developed protocol recorded 93,360 bits. This shows that the network throughput obtained using the developed protocol exceeds that of IECA by 43%.

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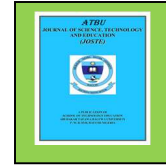
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