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Energy Neutral Protocol Based on Hierarchical Routing Techniques for Energy Harvesting Wireless Sensor Network

Umar B. Muhammad[1, b)], Absalom E. Ezugwu[1, 3, c)], Paulinus O. Ofem[1, d)], Jyri Rajamäki[2, 4, a)] and Adewumi O. Aderemi[3, e)]

[1]*Department of Computer Science, Federal University Lafia, Nasarawa State, Nigeria*
[2]*Laurea University of Applied Sciences Vanha maantie 9, FI-02650 Espoo, Finland*
[3]*School of Mathematics, Statistics and Computer Science, University of Kwazulu-Natal, Westville Campus, Private Bag X54001, Durban 4000, South Africa*
[4]*Faculty of Information Technology, University of Jyväskylä, P.O.Box 35,FI-40014 University of Jyväskylä, Finland*

[a)]Corresponding author: jyri.rajamaki@laurea.fi
[b)]kdjumar98@yahoo.com
[c)]EzugwuA@ukzn.ac.za
[d)]paulinusofem@gmail.com
[e)]Adewumia@ukzn.ac.za

Abstract. Recently, researchers in the field of wireless sensor networks have resorted to energy harvesting techniques that allows energy to be harvested from the ambient environment to power sensor nodes. Using such Energy harvesting techniques together with proper routing protocols, an Energy Neutral state can be achieved so that sensor nodes can run perpetually. In this paper, we propose an Energy Neutral LEACH routing protocol which is an extension to the traditional LEACH protocol. The goal of the proposed protocol is to use Gateway node in each cluster so as to reduce the data transmission ranges of cluster head nodes. Simulation results show that the proposed routing protocol achieves a higher throughput and ensure the energy neutral status of the entire network.

1. INTRODUCTION

The application of Wireless Sensor Networks (WSNs) in various fields such as industrial control, tactical military applications, environmental and security monitoring, is widely acknowledged [1, 2]. In wireless sensor networks, sensor nodes are often powered by non-rechargeable batteries. As soon as a battery gets exhausted, then the battery lifespan is totally brought to a halt and must be replaced. Despite several research efforts, energy consumption has remained a key challenge during the design of battery-powered WSNs [3]. Energy harvesting is a technique that recently found its way into the networking spheres. It was solely introduced for wireless sensor networks. It provides an additional source of energy that can be collected from environments that include solar and wind energy. According to [4, 5], the technique has the capacity to tremendously extend the span of life of wireless sensor networks. It not only prolongs life span but also enables sensor nodes run continually.

In WSNs, routing is often used to prolong the lifespan of a network, since wireless sensor nodes are power-constrained devices. There is plethora of research done over the past few decades in the area of routing protocol for WSNs and this is due to its present day significant and applications to the field of sensor networks [6]. Given the limitations of resources available to a sensor network, it is not promising to have each node deliver data to the base station. Network scalability has been achieved by way of creating clusters which are composed of grouped sensor nodes. The cluster head (CH) is used to denote the leader of each cluster. The benefits of clustering include route localization, reduction in overhead accruing to topology maintenance, reduction of rate of energy intake, reduced volume of packets to be relayed [7, 8].

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This work majorly extends the traditional routing protocol known as “Low-energy adaptive clustering hierarchy” (“LEACH”) to “Energy Neutral LEACH”. Energy neutral “LEACH” attempts to minimize the transfer range of cluster heads (CHs) by introducing a Gateway Node (GN) to each cluster. The “EN-LEACH” does not only inherit the benefits of “LEACH” but helps to keep all sensors in an energy neutral state and by so doing, the amount of energy taken by all the sensors is less than the amount of energy harvested at a particular time [8]. Overall network throughput in energy collection is improved in wireless sensor networks.

This paper is organized as follows: In Section 2, review of related works is presented, and in Section 3 we provide the proposed system model. Then we explain “Energy Neutral LEACH” in details in Section 4, and in Section 5 we discuss the performance evaluation of EN-LEACH through computer simulations. In Section 6 we provide some further discussion of results and future directions for research.

2. RELATED WORK

According to [13, 14], higher energy nodes can be employed in the processing and transmission of information whereas low energy nodes can be employed in sensing in the proximity of the target in a hierarchical architecture. The implication of this is that making clusters and assigning them to cluster heads to perform special tasks has the potential to improve overall system scalability and energy productivity. In [15], “hierarchical routing” presents a two layers of routing in which one of the layers is applied to the selection of cluster head while the other is applied to routing. A reduction in energy intake by a cluster is better achieved through “hierarchical routing” coupled with the application of data aggregation. Fusion can equally be applied so as reduce the volume of messages delivered to the BS. It is however worthy to note that some of the techniques that fall under this class are not concerned with routing, instead, the boarder on “who and when to send or process or aggregate information. According to [9, 10] and other literature we came across, the “LEACH” protocol still appear to be the most preferred “hierarchical clustering” algorithm used for wireless sensor networks (WSNs) owing to its energy efficiency. The “LEACH” has the capability to select nodes that serve as cluster heads at random, and intermittently switch roles by sharing energy-loads to all the network sensors. The mathematical relation below gives the probability that any given node is selected to represent a cluster head.

$$P_i(r) \begin{cases} \dfrac{P}{1 - P \times \left(r mod \dfrac{1}{P}\right)} & if\ i \in G(r) \\ 0 & otherwise \end{cases} \tag{1}$$

Where P_i denotes the likelihood that node i can serve as a cluster head, P indicates the node number percentage that can serve as cluster heads in any given round, r indicates the index of the current round under consideration. $G(r)$ represents the node-set that have not served as cluster head in the most recent r mod $(1/\ p)$ round.

Several routing protocols have been proposed based on LEACH. The basis for these propositions stems from ease, scalability, and above all, the ability to create a balance in energy throughput in the whole network. The “Power-Efficient Gathering in Sensor Information System” (PEGASIS) creates several networks of node sensors instead of clusters. Theses sensor nodes are able to deliver packets of information to the BS. This implies that individual sensors can receive and also send data from neighboring nodes. However, the complex nature of the aforementioned algorithm is not appealing to designers and therefore dissuades them from its real use. The “”Hybrid Energy-Efficient Distributed Clustering (HEED) presented in [11] builds on the foundation of the “LEACH” algorithm by way of introducing residual energy and sensor node closeness to other nodes in the CH-node selection. It however pays little or no focus to neither sensor node densities nor distribution. The “Threshold sensitive Energy Efficient Protocol” (TEEN) [12], works in a way that is similar to “LEACH”. The difference comes from the fact that sensor nodes do not require data to be delivered. TEEN appear more adapted to sensor networks that are reactive because it has the ability of processing of time-bound critical data.

3. SYSTEM MODEL

3.1 System Architecture

In our architecture, we make the assumption that 300 energy harvesting sensor nodes will be arbitrarily positioned over sensor field area spanning100 x 100 m. We further separate the whole network is divided into layers and the BS is positioned around (50, 175). Three classes (CH, CN, and GN) of sensor nodes form each cluster. The *CH* class collects and aggregates information it obtained from the cluster member (CM*)*. The CM class of sensors sense information and relay same to their CH counterpart. What is relayed takes the form of packets of data with a corresponding data rate. The GN class of sensors delivers the data aggregated by the CH class of sensors to the BS. Sensors that are elected as CH or GN node are released from the task of sensing. This in turn minimizes their energy intake. Figs. 1 and 2 present an illustration of Random deployment of sensor and Network Models.

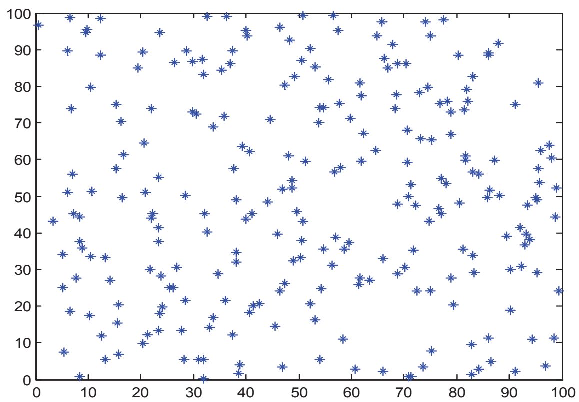

FIGURE 1. Arbitrary Positioning of Sensor

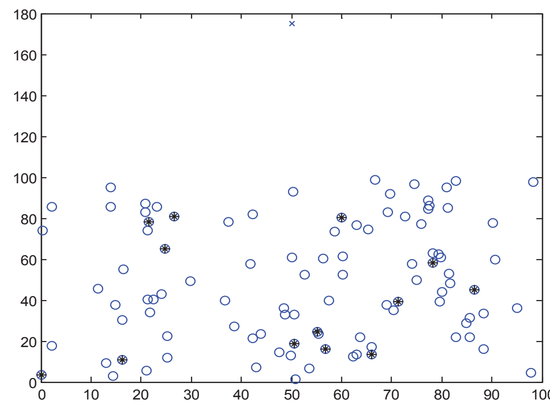

FIGURE 2. Network System Model

Fig. 3 presents the design that fully describes the operation of EN-LEACH. It is basically separated into slices. Each slice has mainly two segments which include a set up segment and a steady- state segment. The set-up segment comprised of cluster head selection, gateway selection and cluster formation. It is further made up of a gateway and cluster selection, and cluster formation algorithms.   The EN-LEACH further comprises of three algorithms, which include the cluster formation algorithm, the gateway and the cluster selection algorithm. Once CHs, GNs, and TDMA cluster schedules are created, data delivery takes place. In our proposed protocol, and in the cluster maintenance segment, two different types of transmissions (intra-cluster and inter-cluster) occur.

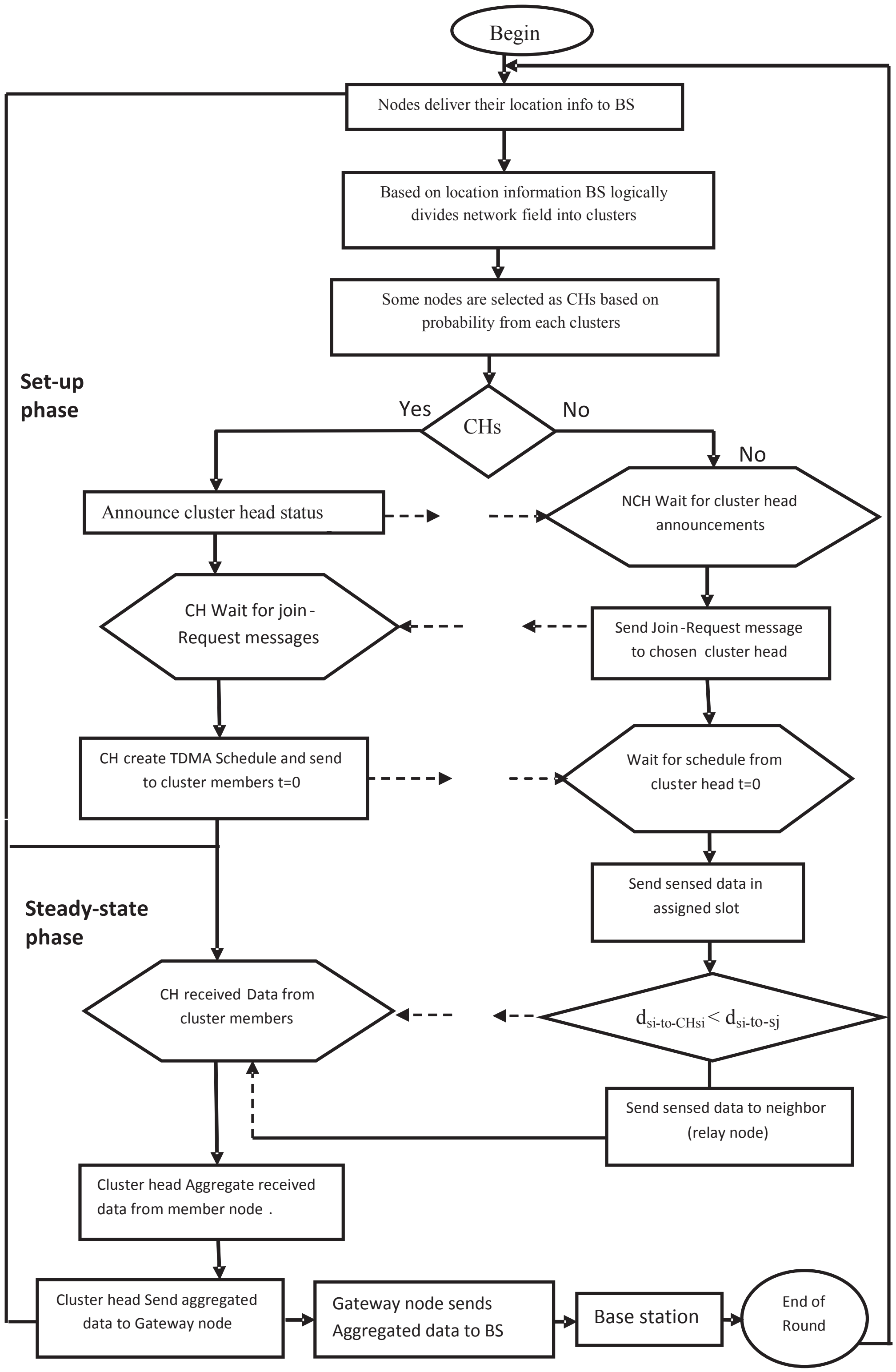

FIGURE 3. EN-LEACH Operation Flow Model

3.2 System Energy Intake Model

The energy transmission cost is proportional to distance between the two communicating nodes. Thus, there exists a significant relationship between energy intake and distance of delivery in the process of delivery of data. Given the increased distance of delivery, power transmission dies rapidly. So, in this paper, we first consider the energy intake occasioned by information transmission and also adopt a simplified power model discussed in [8], [9]. The transmission of *k*-bit data among two nodes given the distance *d*, the energy intake is calculated thus:

$$E_{T_x}(k,d) = \begin{cases} k \times E_{elec} + E_{amp} \times d^2 & ,if\ d < d_0 \\ k \times E_{elec} + E_{fs} \times d^4 & ,if\ d \geq d_0 \end{cases} \tag{2}$$

Where E_{elec} the base energy is required to run the transmitter or receiver electronics; d_0 is the distance threshold. E_{amp} and E_{fs} are the unit energy required by the transmitter amplifier, which depends on both the distance and propagation model to approximate the power loss [10].

$$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}} \tag{3}$$

To receive k-bit data, the radio expends energy

$$E_{R_x}(k) = k \times E_{elec} \tag{4}$$

Therefore, the energy consumption of CH_i for a round is:

$$E_c(CH_i) = \sum_{i=1}^{m} E_{R_x}(k_i) + E_{DA}(k) + E_{T_x}(k_u, d(CH_i, GN_i)) + E_s + E_i \tag{5}$$

In this equation, m is the number of cluster member nodes of CH_i; $E_{DA}(k)$ is energy consumption for data aggregation with k bits data. E_s and E_i are the energy consumption in sensing and idle state, respectively and $E_{T_x}(k_u, d(CH_i, GN_i))$ is the energy expend by CH in forwarding the aggregated data to the GN_i. Where $E_{T_x}\left(k_j, d(GN_i, BS)\right)$, is the energy expended by GN in forwarding the CH aggregated data to BS. The energy consumption of a cluster member node j in cluster i^{th} for a round is [10].

$$E_c(j) = E_{T_x}\left(k_j, d(j, CH_i)\right) + E_{R_x}(k_i) + E_s \tag{6}$$

4. ENERGY NEUTRAL LEACH

This part of the paper extends the famous LEACH protocol to the "energy neutral LEACH" protocol. The work of EN-LEACH is separated into segments, and each segment comprises of two major phases which are namely: the setup and stable state phases as shown in (Fig.4).

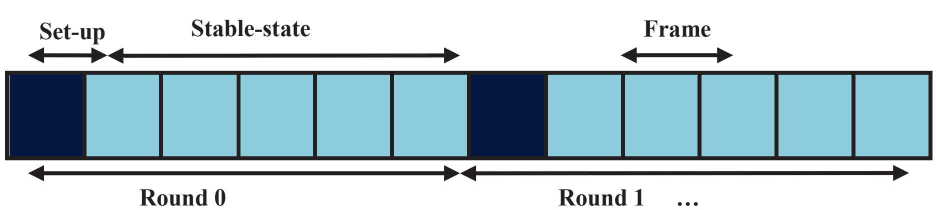

FIGURE 4. Time-Mark Indicating EN-LEACH

4.1 Set up Phase

The cluster head and gateway selections together with cluster formation make up the set-up phase. Also included are the gateway and cluster selection algorithms and the cluster creation algorithm this is shown in Fig. 5.

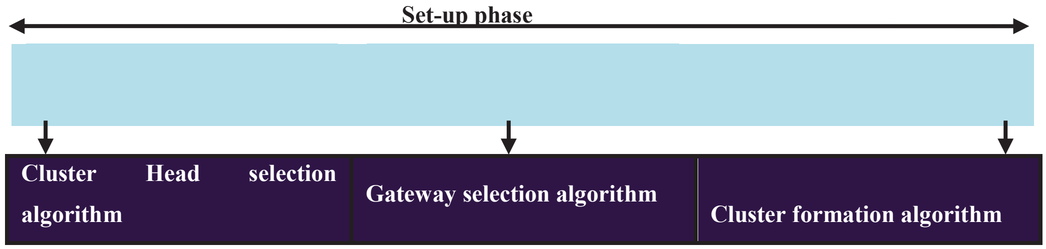

FIGURE 5. Time-Mark Indicating Set-up Phase

4.1.1 Cluster Head Selection

The design of LEACH is better suited to WSNs that run on batter power. The scheme used for cluster heads selection in a way turns the nodes into cluster heads thereby bringing about an even energy intake among nodes. Nodes with high energy collection rate are expected to have higher likelihood to be selected as cluster heads. It is also expected that no time limit is placed on a node to become the cluster head. In "Energy Harvesting Wireless Sensor Networks (EH-WSNs)", energy is unlimited and the energy harvesting rates tend to vary between nodes. The energy collected by any sensor node cannot withstand the heavy energy intake of a CH in practice. According to [9], [10], one option to salvaging this situation is the application of a cluster head rotation scheme as is applied to the conventional clustering algorithms.

4.1.2 Cluster Formation

On the initial deployment, the base station (BS) delivers a layer-one signal using minimal energy level. Nodes listening on this broadcast message reset their layer to 1. Subsequently, the base station upturns its energy power to achieve the next layer in order to deliver a layer-two signal. In this case, all nodes listening on the new broadcast message but were unable to set the previous layer are able to set their layer to 2. This process proceeds accordingly pending when the BS delivers matching messages to all layers respectively. After dividing the network into layers and picking the CH, individual nodes can choose any cluster of interest and relay such interest to the CH. It then becomes a member of cluster. In choosing the cluster, nodes have to pay attention to proximity with the CH. In order to avoid collision individual nodes have to relay the information to the CH via "Carrier Sense Multiple Access (CSMA) MAC" protocol. Each CH obtains all the communications from the sensor nodes that wish to be contained in the cluster, and given their volume, generates a "time division multiple access (TDMA)" schedule of equivalent size. This takes place after several time intervals. The subsequent step is to relay to each one of its cluster node when it will again deliver information according to the TDMA schedule which is disseminated across to the nodes in the cluster.

Algorithm 1: Algorithm for setup phase

```
for each (node j)
    j selects random number y between 0 and 1.
        If (y < T (j))
            j becomes CH.
            j broadcasts an advertising message for its CH status   then.
            CH waits for join-request
        Else
            j becomes a NCH node then.
            NCH chooses the CH, this selection is based on RSS of   Advertise.
            NCH send join request to CH and become a member of its Cluster.
    End if.
     for each (CH)
            CH creates TDMA schedule for NCH.
            Each NCH communicates to the CH in its time slot.
    End for
End for
```

4.1.3 Gateway Selection

Controlling the rate of data delivery is an attempt to keep the volume of transmissions at a minimum thereby saving more energy. The distance of each cluster may be quite long in which some CHs dies while trying to exchange messages directly with the BS. In order to resolve this situation, individual CH utilizes several transitional nodes along the path towards the BS to relay CH data. The role of BS is to identify all GNs in each cluster. The *id* and the corresponding locations of gateway nodes together with the chosen CH are transmitted by the BS. There is a predefined total number of nodes which are allocated to be GNs and CH. Given that the *id* and the locations of gateway nodes are transmitted, individual CH have to select the nearest as the middle node and notifies it. The gateway nodes play the role of linking the CH to the BS. They also control delivery of packets received from the CH to the BS. This means that the CH can conserve energy during the course of data delivery.

4.2 Steady State Phase

Immediately following the formation of CHs, GNs cluster, and TDMA-based schedules, delivery of data commences. The cluster head that are not nodes obtains the sensor data and delivers same the cluster head within their apportioned time slices. The radio within the cluster head node has to be on in order to receive the data from the nodes that are in the cluster. The amount of information transmitted by a sensor determines its energy intake. It is therefore worthy of mentioning that in order to energy neutral operation must be taking into consideration in the design of routing protocols. In our proposed protocol, two kinds of message exchanges occur in the cluster maintenance segment. They are namely: “intra-cluster” communication and “inter-cluster” communication.

4.2.1 Intra-Cluster Communication

For each cluster, the data generated by sensor node is delivered to the CH. These packets of data are sent to the neighboring node having the shortest distance from CH. The following node relays towards the CH in a similar way. Intra-cluster communication is performed by means of “TDMA” technique. In this time interval, CH allocates time slices to the node in the cluster. Algorithm listing 2 presents the Intra-cluster communication execution process.

Algorithm 2: Algorithm for Intra-cluster communication

for each *(Cluster)*
  for each *Non-Cluster head S_i and S_j*
    for each *Cluster Head (CH)*
      S_i wishes to send its sensed data to CH
      if $\left(d_{S_i-to-CH_{S_i}} < d_{S_i-to-S_j}\right)$
        S_i transmits data to CH
      Else
        S_i transmits data to S_j (S_j is a Relay node)
        S_j transmits data to CH
      End if
    End for
  End for
End for

In the intra-cluster algorithm; $d_{S_i-to-CH_{S_i}}$ represent the space between sensor node S_i and cluster head CH_{S_i}, $d_{S_i-to-S_j}$ is the distance between sensor node S_i and its neighbour S_j.

4.2.2 Inter-Cluster Communication

In [9, 10], LEACH expects cluster members to exchange messages using the single hub with CH class of sensors. The CHs then assembles the information obtained from cluster members for onward direct delivery to the BS. But during the inter-cluster communication in EN-LEACH (see Fig. 6), individual CH gets packets of data from with its cluster members. The acceptance of all data is followed is followed by the aggregation of the data by individual CH. This results in a single composite message. The aggregated message is then delivered to its gateway node and yet again the data is delivered to the BS through the multi-hub path the gateways are utilized in this process. That is, cluster Heads-Gateway nodes-cluster heads…repeatedly until it reaches the BS. During this process, the other nodes are kept asleep to save energy (see algorithm listing 3.

Algorithm 3: Algorithm for Inter-cluster communication

for each *(Layer i)*
  for each *Cluster Head (CH_i)*
    for each *Gateway node (GN_i)*
      CH received data from Non-cluster head
      CH aggregate the received data
      if $(i == 1)$
        CH_i transmits aggregated data to GN_i then
        GN_i transmits aggregated data to BS
      Else
        CH broadcast data to the next Layer CH
      End if
    End for
  End for
End for

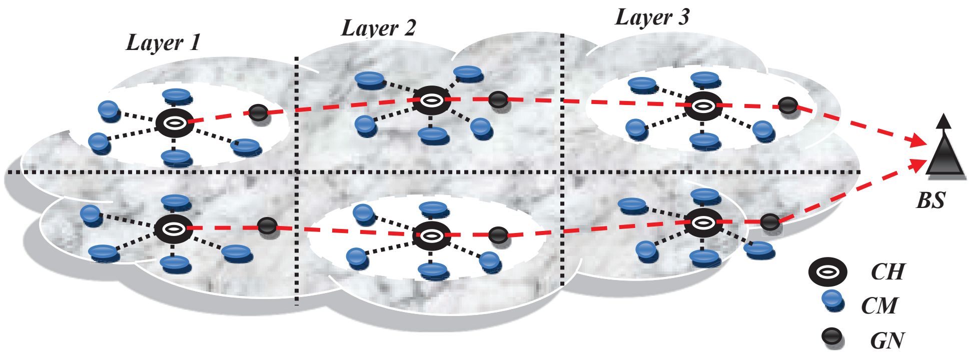

FIGURE 6. Clustering Model of Proposed Routing (EN-LEACH) Protocol

5. OUTCOME OF SIMULATION EXPERIMENTS

In this section, we report the outcome of simulating the performance of the "Energy Neutral LEACH" (EN-LEACH) algorithms with respect to energy intake by cluster heads, coupled with the throughput of the network. MATLAB is used for this simulation. The results obtained are given by Figs. 7, 8 and 9 respectively. The parameters used in the experiments are also given in Table 1.

Table 1: Simulation Parameters

Parameters	Values
Network field	100m x 100 m
BS Location	(50, 175)
E_{elec}	50nJ/bit
E_{fs}	10pJ/bit/m^2
$Ea_{mp.}$	0.0013 pj/bit/m^4
E_D	5nJ/bit/signal
d_o	87m
$E_{bgt.}$	54joule
Packet size (K)	4000bits
Number of node	300

5.1 Energy Objectivity Test

Usually, simulation experiments can be undertaking to possibly test energy neutrality with respect to any neutral-hierarchical energy protocol that is being proposed and even the "LEACH" protocol. The duration of any cluster failure is used to measure energy neutrality of the network. Cluster failure is mainly as a result of CH failure. In LEACH protocol, Cluster heads directly communicates with BS. The consequence of this direct communication is unfair energy intake between cluster heads. Cluster heads that appear far distant from the BS attract huge energy load as a result of long distances in communication links. Consequent upon this, they die early hence cluster failure. Fig. 7 indicates that the "EN-LEACH" is able to maintain energy neutrality in the network. It achieves this with an insignificant duration of failure in clusters. The implication of this is that packets of data can be delivered to the BS non-stop. It is worth to note that this is possible because EN-LEACH uses gateways as intermediate node between cluster head to balance the energy intake.

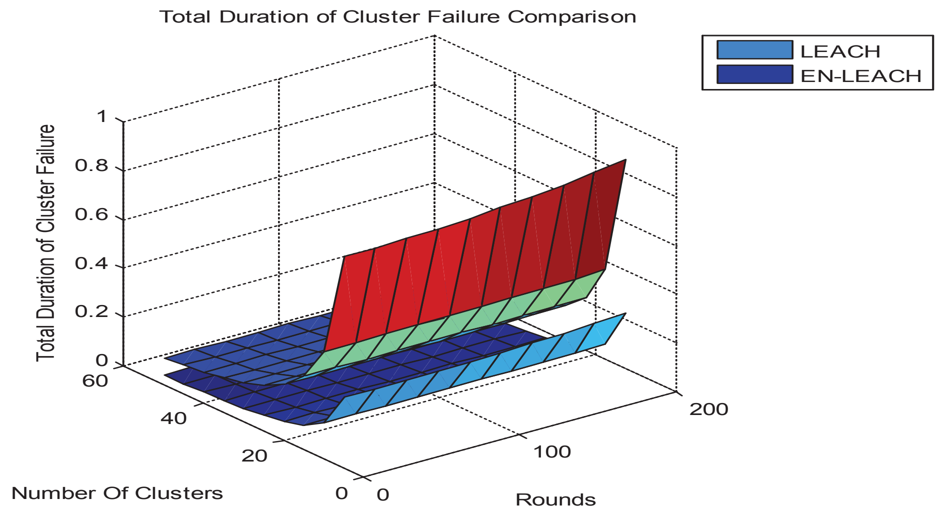

FIGURE 7. Total Duration of Cluster Failure Comparison

5.2 Energy Consumption of CH Review

In Fig. 4, we show the outcome of "EN-LEACH" in comparison with the more typical "LEACH" protocol. The comparison is on the basis of energy intake per cluster head. The application of gateway nodes in the delivery of data via heads of clusters to sink coupled with energy intake in the entire network is far lessened. This so happens because energy that could have been lost is conserved by the cluster heads for use by the BS. As the graph indicates, it is obvious EN-LEACH is better able to attain double energy conservation which is not the case with LEACH protocol. The illustration in Fig. 8 indicates energy intake by cluster head in terms of cluster number and round totals. As one will expect, energy intake is less if cluster number is high. The total energy intake by cluster heads for each round in EN-LEACH with respect to the increase in the volume of clusters is far less than that found in the LEACH. This is so because cluster heads within the LEACH protocol has the capacity to deliver data straight to the BS. This is addition to the fact that energy intake becomes greater. Therefore, the energy consumption is much higher. In the case of energy neutral LEACH; gateway nodes obtain data to from the cluster heads thereafter deliver same to the BS. This arrangement significantly conserves more energy.

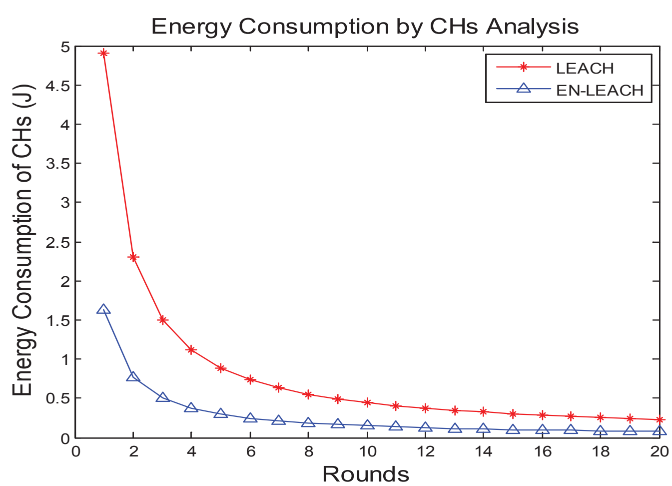

FIGURE 8: Energy Consumption by CHs

5.3 Throughput

Throughput is used to specify the rate of transfer of data packets from individual sensor nodes to the designated base station. In Fig. 9 we present a differentiation with respect to the volume of data packets obtained from BS over a given number of segments. The findings from the simulation experiment indicate the throughput for LEACH was far too low unlike the case with EN-LEACH. Base stations however, in our proposed situation do better in obtaining data packets. As shown in Fig. 8, throughput of EN-LEACH appears five times better than LEACH. A substantial change in throughput based on our proposal with LEACH owes it to the almost round-the-clock full coverage provided entirely to the network. In the case of simulation experiments, sensor nodes are allocated minimal amount of energy for the start. In any event CH classes of sensor nodes are out of power, it is deemed that death has taken place hence delivery of data ends automatically.

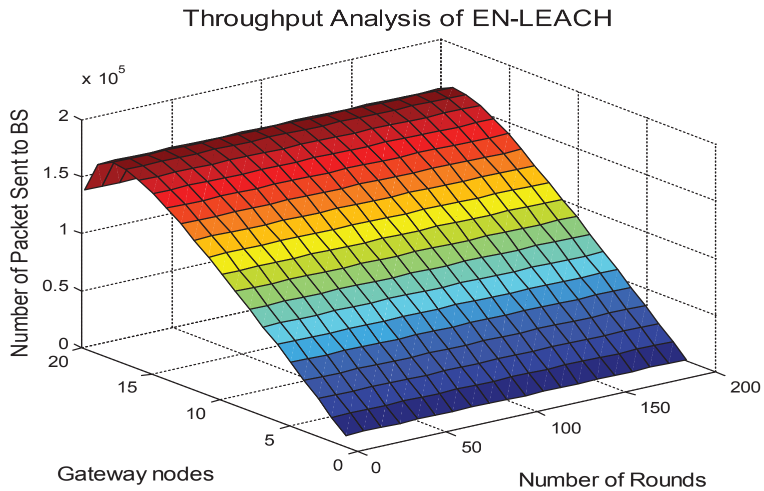

FIGURE 9. Throughput Analysis of EN-LEACH

From the simulation results obtained, the following observations are made:

i. When gateway nodes together with cluster heads are used, excessive energy requirements are kept very minimal throughout the entire network.
ii. Energy Neutral LEACH is able to attain double energy requirement reservation unlike the LEACH protocol.
iii. EN-LEACH outwits LEACH owing to a balance in energy emissions from each network node. Energy neutral state is therefore maintained.
iv. Emission of energy is kept at a balance between non-cluster head nodes and CH nodes in the EN-LEACH unlike the case with LEACH protocol.
v. The demise of any cluster head is usually caused by high energy intake, however, balancing this high-intake remedies this situation and further helps to curb the occurrence of an unstable situation that could be caused by a failure of any cluster head. Overall, energy neutrality is maintained throughout the network.

6. CONCLUSIONS

Implementing routing in sensor networks comes with a great challenge. This is owing to their peculiar characteristics which to a large extent differentiates them from other conventional wireless networks. Sensor networks will always remain sensitive to energy requirements. This however is not the case with the old-fashioned wireless network. In order to minimize the volume of messages that require transmission via the sink in the case of large scale wireless networks, the introduction of clustering in the network topology is considered necessary. In addition, "energy harvesting" technology which has also become available enables sensor node to attain an infinite quantity of energy. This in a way helps the sensor in the network to achieve neutral state of energy.

In this research work, we proposed a neutral energy LEACH (EN-LEACH) routing protocol for “harvesting of energy” in the case of wireless sensor networks. We further developed a network model that is based on “energy harvesting”. The MATLAB programming environment was used to simulate the model. The simulation results obtained showed that the energy requirement per cluster-heads for any given round in EN-LEACH was far lower compared to LEACH. In one instance, just about after 50 rounds, LEACH gulped about 42% of energy whereas EN-LEACH gulped about 15%. We further observed that failure of cluster was successfully prevented in EN-LEACH through ensuring a neutral energy state in the entire network. This however contributes to improved network data output coupled with consistency in delivery. We conclude this work by saying that the performance of energy neutral LEACH outsmarts LEACH.

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