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Average Energy Analysis in Wireless Sensor Networks using Multitier Architecture

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Abstract

The energy of sensor nodes plays a vital role in wireless sensor networks for different purposes such as sensing events, communicating among sensor nodes, and transmitting information from one node to another node. The average energy of the network is referred to as the ratio of the total energy of all sensor nodes in the network to the number of nodes. In this paper, multitier architecture is proposed for calculating the average energy and throughput of the network in terms of the number of packets reached at the base station (BS). The proposed approach has been compared with two existing approaches, the low energy adaptive clustering hierarchy and stable election protocol, in terms of average energy and throughput of the network. This paper presents the average energy of each node in the network in both 2D and 3D views for better interpretation of results. The proposed approach is 19.79% better in terms of average energy compared with the stable election protocol. The proposed approach is further compared with the low energy adaptive clustering hierarchy protocol and is found to be 34.20% better.

Keywords: average energy; wireless sensor networks; multitier architecture; throughput; network lifetime

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1. Introduction

Wireless sensor networks are composed of a number of sensor nodes, which send data to fusion centers. Fusion centers access the data or information from all sensor nodes, aggregate this information, and then forward it. To improve the quality of network information, there are some parameters such as the delay in the network and the packet reached at the base station. According to existing literature, there are mainly three cases for energy efficiency: circuit energy consumption, energy consumption reduced by dynamically sensor nodes, and power consumption by appropriate transmitting polices [1]. Generally sensing information in many application areas is useless and meaningless without real time and space knowledge. Application time is crucial for information extraction from the network. Numbers of protocols are available in literature for time specificity as per the requirement of application specificity in wireless sensor networks (centralized synchronization protocol and distributed synchronization protocol). The centralized synchronization protocol includes number of protocols like reference broadcast synchronization (RBT) and timing synchronization protocol for sensor networks (TPSN). Diffusion synchronization protocols include protocols like the time diffusion synchronization protocol (TDP) and average time synchronization protocol (ATS) [2]. The advantages of wireless sensor networks using sensor nodes are easy communication, low cost communication, and high flexibility. Periodic sensing of information is one of the most energy consumable phenomena in wireless sensor networks. To extend the network lifetime, it is expected to balance energy consumption among the networks [3].

In wireless sensor networks, there are three main tasks of each sensor node: communicating, sensing, and turning off nodes (sleep). These activities refer to specific terms; for example, sensing is used for monitoring, and sleep is used to save the energy of the networks. Three types of algorithms are considered to minimize the energy consumption: (i) multi-period and multi-mode scheduling, (ii) problem simplification of tractable analysis, and (iii) optimal design of the distributed algorithm [4]. Energy harvesting is an approach reported to minimize the energy. Energy harvesting nodes consume the

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energy from the environment (such as wind, solar, etc.) and convert it into electrical energy. A disadvantage of energy harvesting sensor nodes is that the sensor nodes require more circuitry energy, and that is why the cost of network increases. This type of network is only suitable for small area networks; otherwise, the cost of network will be high. The source of energy harvesting sensor nodes is the battery, so it is suggested that for better energy efficiency there is a need for dynamic power allocation in wireless sensor networks [5].

The remainder of this paper is organized into eight sections. The introduction is followed by related work in section 2. The proposed model of wireless sensor networks for average energy analysis using multitier architecture is presented in section 3. A mathematical model of the proposed approach is given in section 4. Section 5 presents the proposed algorithm. Performance parameters and simulation parameters are covered in section 6. Results and analysis with appropriate figures are shown in section 7. The conclusion is finally reported in section 8.

2. Related Work

Research papers for literature review are taken from different repositories including IEEE Xplore, Science Direct, ACM Digital Library, and Google Scholar Springer. Research papers related to the average energy are considered in this article. Here, a similar approach [6-8] is focused.

Criteria to adopted research paper:

Inclusion criteria: According to the literature survey, only the papers that include techniques to calculate the average energy of the wireless sensor networks are considered in this paper.

Exclusion criteria: After searching the papers related to the average energy in wireless sensor networks, those that do not contain any technique for average energy are discarded.

Objective of the related work: The main objective of the literature survey is to find a technique to reduce energy consumption in wireless sensor networks.

Manjeshwar et al. [9] proposed using the TEEN protocol, which is also called the threshold sensitive energy efficient sensor network protocol, for reactive networks. There are two types of sensor networks: proactive networks and reactive networks. Proactive networks are suitable for periodic monitoring, and reactive networks are suitable for event based monitoring. In their model, the base station is situated away from the nodes, and the base station has no power constraints (reception, transmission, and processing). However, the sensor nodes have power constraints. This means that the base station is capable of transmitting data directly to the sensor nodes, but sensor nodes are not able to reply to BS directly or communicate in an asymmetric manner. This type of scenario is called event-based application. The TEEN protocol was found to be well-suited for event-based applications.

Yarinezhad et al. [10] discussed a novel approach for routing based on grid infrastructure. Sensor nodes that are close to the base station die early, and to overcome this problem, mobile sink is an appropriate idea. The main motto of their work is to reduce the energy consumption and delay in the networks. The network is divided into different numbers of cells, and then the four cells that are near the base station are actually the cells that have the minimum number of hops to the base station. Their approach prepared a virtual infrastructure time to time that helps identify the position of the base station. This model is suitable for small- to large-scale networks with single or multiple mobile sinks.

Rajeswari et al. [11] explained the genetic based algorithm for fault detection, message loss, average energy loss, and link failure for wireless sensor networks. Every bunch leader sets backup nodes for failure nodes in EEDC. The fitness function is measured with the help of residual energy and coverage of sensor nodes. Optimum numbers of sensor nodes are selected for backup nodes, and the nodes are responsible for monitoring the fault occurrence. If some of the nodes do not provide information, then it is assumed that the particular nodes are dead and need to be removed from the routing table. Zarifi et al. [12] analyzed a new technique for energy efficiency in WSNs using the distributed beam forming technique. Sensor nodes are the independent units in the networks. To achieve better communication, sensor nodes require a beam forming phase. Therefore, the selection of sensor nodes for beam forming is a crucial task for infrastructure design. Nodes that were closer to the ring inner side were used for beam forming selection. When distributed beam-forming nodes accessed noisy nodes, an optimal signal to noise ratio was achieved. Paschalidis et al. [13] focused on energy optimization in WSNs using optimized topology of the networks. They used a bidirectional spanning tree in their work. The selection of sensor nodes to optimize the problem formulation is an NP Complete problem. Their work was divided into two scenarios: large time horizon and small time horizon. Topologies were also categorized into two categories: static and dynamic. The shortest path and minimum spanning tree algorithm were run in static topology and were found with 0-8% optimal results. In the second scenario, the large time horizon network was used. Connected network was the pre-requisite for their proposed approach.

Chi et al. [14] reported on energy efficient technologies for nanosensor networks. Optimizing the energy consumption on links of nanosensors is more crucial than wireless sensor networks. They designed the on-off keying modulator for communication links in nanosensor networks. The total energy consumption is reduced through the reduction of the F-MCE and V-MCE at the transmitter and receiver end during communication. Saving energy depends on the quantity of power utilization per bit, and the consumption of energy may vary from a few bits to dozen bits. Hadzi-Velkov et al. [15] proposed a novel technique for the allocation of base stations for broadcasting the information simultaneously. They used the time division multiple access technique in their work to increase the throughput of the overall network. A generalized solution for power consumption in a fixed circuit was given. Zhou et al. [16] discussed the estimation problem using energy harvesting nodes in wireless sensor nodes. They used the Lyapunov optimization technique in their work (mean square error minimization). A model was formulated for limited horizon and infinite horizon for better interpretation of results. The model includes all sensor nodes connected with equal bandwidth in time division multiple access mode. Sensor nodes work for the amplifying and forward scenario. They designed two algorithms: optimal power allocation for Gaussian channel and the operational algorithm and compared the greedy algorithm with the simulated annealing methods.

Sunny et al. [17] explained multi-hop energy harvesting techniques for wireless sensor networks. They designed a framework to monitor the quality in long term resource allocation. Resource allocation refers to the energy capacity and energy constraints related to the networks. Finding the maximal independent set in terms of energy capacity and energy constraints is considered an NP-Hard problem. Energy constraints metrics were converted into clique to validate the correctness of this approach. Their model consists of a single antenna and limited power battery with data buffer. The time complexity of independent sets after converting into clique was $O(|N|3 + |L|3.5)$. Wang et al. [18] analyzed energy efficient clustering in WSNs based on correlation random update. Initially, the network was divided into numbers of clusters, and then the dynamic cluster head rotation scheme was applied. The chance to become a cluster head among nodes depends upon the residual energy of the node. Nodes with higher energy are able to become the bunch leader periodically. The sampling method was used for the transmission phase to balance the energy consumption in networks. The main disadvantages of their approach were message overhead and information exchange during cluster formation.

Yao et al. [19] focused on energy harvesting in wireless sensor networks based on cluster collaborative spectrum sensing. Cognitive nodes became the cluster for performing sensing information and improved the power level among them. Their main objective was to improve the throughput for energy harvesting cognitive wireless communication networks using suitable parameters (cognitive nodes, local threshold, spectrum sensing, etc.). It is hard to find the local threshold, so this may be identified in other terms like signal-to-noise ratio. The optimal solution was found using the bisection method and simplified linear model.

Yadav et al. [20] proposed a novel approach for communication among sensor nodes in an efficient way. Sensor nodes were deployed in a manner such that the error control took place in automatic request repeat (ARR) and the forward scenario. To reduce the energy consumption, the sampling approach was used before data transmission at the receiver end. Decoding took place at receiver end. Analysis was performed with limited power battery and considered the average packet drop. Their model consisted of point-to-point communication and rechargeable batteries of sensor nodes.

Flint et al. [21] studied the Boolean method combined with Poisson modeling for energy harvesting in wireless sensor networks. There are some assumptions in their work, including senor nodes are distributed in the form of Poisson distribution and have a sensing range in the form of a disc. Transmission takes place only in the single hop scenario. Results of their work were analyzed using both single hop communication and multi-hop communication. They also used star-shaped topology for better and more suitable interpretation of results.

More et al. [22] discussed energy efficient protocols for better coverage in wireless sensor networks. Clustering-based and distributed-based protocols are discussed in their work. These protocols have been further categorized into a number of subcategories based on node location information, the sensing model, and computational geometry. The main objective of their study was to focus on coverage protocols to remove the overlap area sensed by more than one node, so the energy efficiency in the networks could be improved. When a particular area is covered by more than one sensor node, we may turn off any of the nodes to save energy. Because only active nodes are considered to determine the network lifetime and throughput of the networks, reducing the number of active nodes by turning off the nodes in overlapping areas may further save energy.

After reviewing related works, it was found that multi-tier architecture may be used to increase the average energy in wireless sensor networks.

3. Proposed Model

The following assumptions are considered in the proposed model:

- All sensor nodes including the base station are stationary, meaning there is no movement in node location after deployment in the network.
- All sensor nodes have the same transmission power and reception power throughout all networks, meaning the network is homogenous.
- The changing of batteries of sensor nodes is almost impossible, meaning batteries are not rechargeable.
- The base station has no restriction in terms of energy.
- All sensor nodes communicate to each other in the multi-hop scenario.

Figure 1 shows the proposed model architecture, where mainly four types of sensor nodes are taken such as the normal nodes, gateway nodes, bunch leader, and base station. The network is divided into two parts: primary tier and secondary tier. Nodes are divided into these tiers based on received signal power (RSP) values. Nodes that have higher RSP values are considered as part of the primary tier and those that have smaller values are considered as part of the secondary tier.

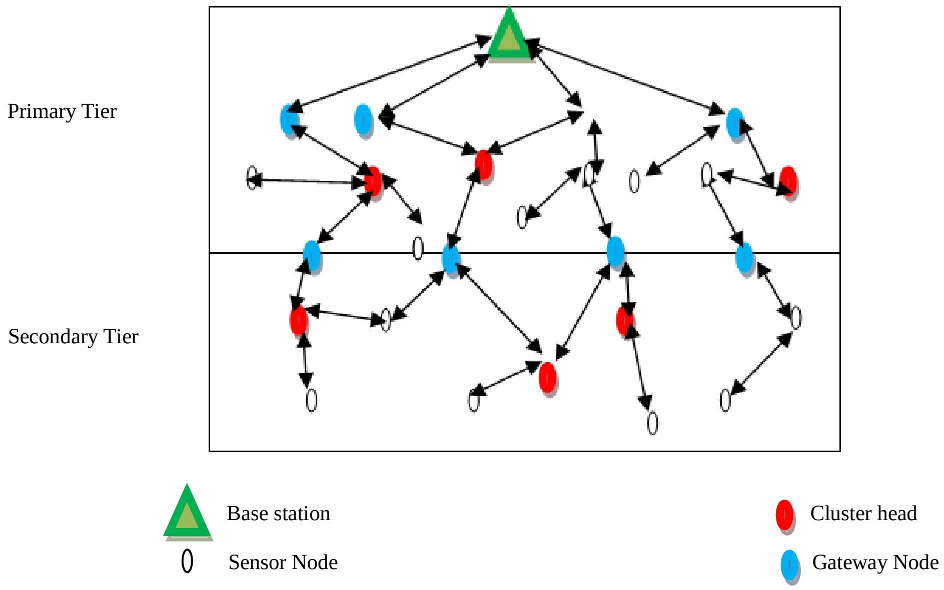

Figure 1. Proposed two tier architecture for WSN

Figure 2 shows the flow chart of the proposed model. The proposed model calculates the mean RSP values of all sensor nodes in the network. After that, if sensor nodes have RSP values greater than the mean RSP value, then nodes are put into the primary tier; otherwise, the nodes are put into the secondary tier. Among the tier nodes, nodes with higher RSP are selected for the gateway node.

4. Energy Model

In this section, energy consumption in different ways at different levels is shown. There are some assumptions in the proposed work; for example, the received signal power of nodes is the primary factor in this work. Gateway node and cluster head node selection is based on the RSP values of sensor nodes.

$$RSP(n) = \begin{cases} \dfrac{E_t}{1 - E_t\left(m.mod\left(\frac{1}{E_t}\right)\right)} \cdot \dfrac{E_r}{E_m}, n\epsilon N \\ 0 \qquad otherwise \end{cases} \tag{1}$$

Where $RSP(n)$ is the received signal power of the n^{th} node, E_t is the random probability, E_r is the remaining energy power, and E_m is the maximum energy power. Equation (1) is used to calculate the received signal power values for all the sensor nodes present in the network.

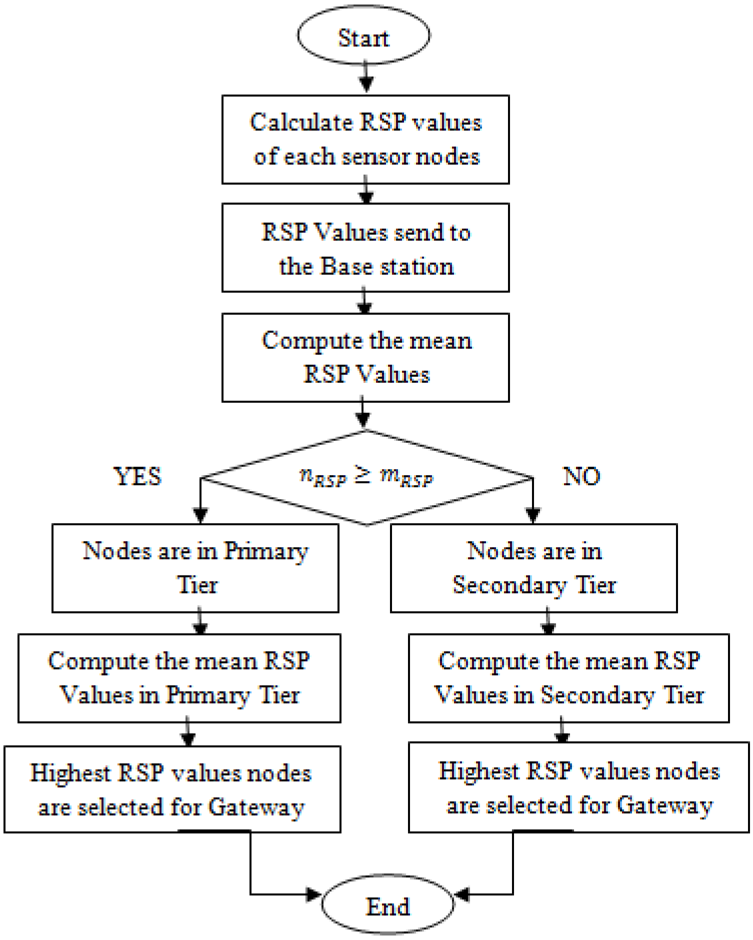

Figure 2. Flow chart of proposed model

$$T_n = \frac{t-r}{V_m} \tag{2}$$

Where V_m is the maximum sensing range of sensor node, $t-r$ is the time for node coverage, and T_n is the time of sensor node on (active). Equation (2) is used to calculate the active time duration of a sensor node.

$$T_f = min\left\{\frac{t+r}{V_m}, t_e\right\} \tag{3}$$

Where T_f is the time duration of sensor node off (sleep), $t+r$ is the time of sensor node coverage, and V_m is the minimum sensing range of sensor node. Equation (3) is used to calculate the duration of sleep time of a sensor node.

$$E_{Tx}(I,d)=\begin{cases} I \times E_{ele} + I \times \varepsilon_{fs} \times d^2, \text{ if } d < d_0 \\ I \times E_{ele} + I \times \varepsilon_{mp} \times d^4, \text{ if } d \geq d_0 \end{cases} \tag{4}$$

Where I is the number of bits in the message, E_{Tx} is the power utilization in message transmission, d is the distance, and ε_{fs} and ε_{mp} are the amplifier of the transmitter. Equation (4) is used to calculate the energy consumption in transmission of data in wireless sensor networks.

$$E_{Rx}(I) = E_{ele}I \quad (5)$$

Where E_{Rx} is the energy consumption in message reception by any sensor node. Equation (5) is used to calculate the energy consumption in data reception in wireless sensor networks.

$$E_T = E_t + E_r + E_i + E_s \quad (6)$$

Whole power utilization of a sensor node is calculated by using Equation (6), where E_t is the energy consumption in message transmission, E_r is the energy consumption in message reception, E_i is the energy consumption by nodes in the ideal situation, and E_s is the energy consumption in sensing the information.

5. Algorithm for Proposed Approach

N is the number of nodes in the network. *RSP*(*v*) is the received signal power value. *RSP*(*p*) is the *RSP* value in the primary tier. *RSP*(*s*) is the *RSP* value in the secondary tier. *RSP*(*m*) is the mean *RSP* value.

```
for (i = 1 to N)
RSP(i) ← RSP(v)
end for
RSP(m) ← RSP(N)/N
if (RSP(i) > RSP(m))
Primary tier ← i^th node
else
Secondary tier ← i^th node
Compute highest value of RSP(p)
Gateway node (p) ← highest value of RSP(p)
Compute highest value of RSP(s)
Gateway node (s) ← highest value of RSP(s)
```

5.1. Performance Parameters

There are following performance parameters taken in this paper; average energy of the network, throughput of the network and no. of bunch leader per round.

Average energy: Total energy of the network divided by total number of nodes.

Throughput: Packets reached at BSper iteration.

Cluster head: Bunch leader at any iteration number.

After simulation, it has been observed that the proposed approach has higher average energy and better throughput compared with the existing approaches (LEACH and SEP).

5.2. Simulation Parameters

In this section, parameters are shown with their respective values, which are considered in the proposed approach. The proposed work is implemented in Matlab 2013 with a core i3 processor and 4GB RAM. The system parameters are listed in Table 1.

Table 1. Simulation Parameters

S.No.	**Parameter**	**Value**
1	Network area	100M×100M
2	Nodes	200
3	Energy of node	.1 Joule
4	Coordinator node	50, 50
5	Rounds	10, 20, 50, 100
6	DA energy	5nJ

6. Results and Analysis

In this section, the results are shown. Performance parameters such as average energy in the network, number of packets reached at bunch leader, and number of packets reached at BS are presented in Figures 3-8.

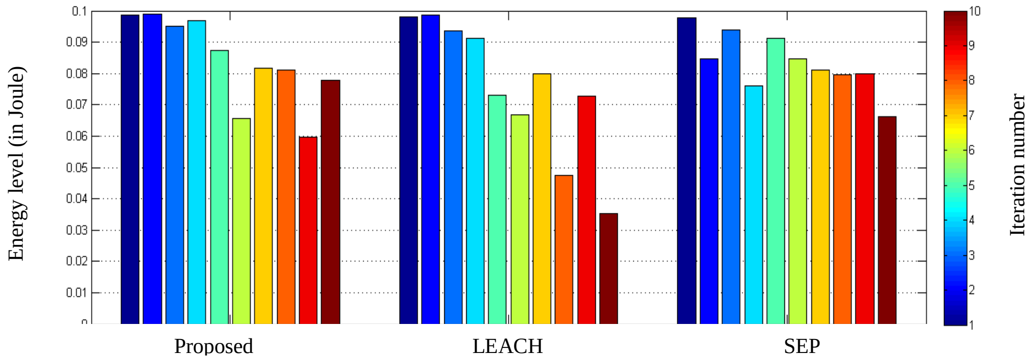

Figure 3. Average energy of each node for ten iterations

Figure 3 shows the average energy level in the network for LEACH, SEP, and the proposed approach. In this figure, the iteration number is ten and the energy level of the network at each iteration is shown. The initial energy of the network is the same for all approaches, but after simulation occurs, the changes in energy level in all approaches are different.

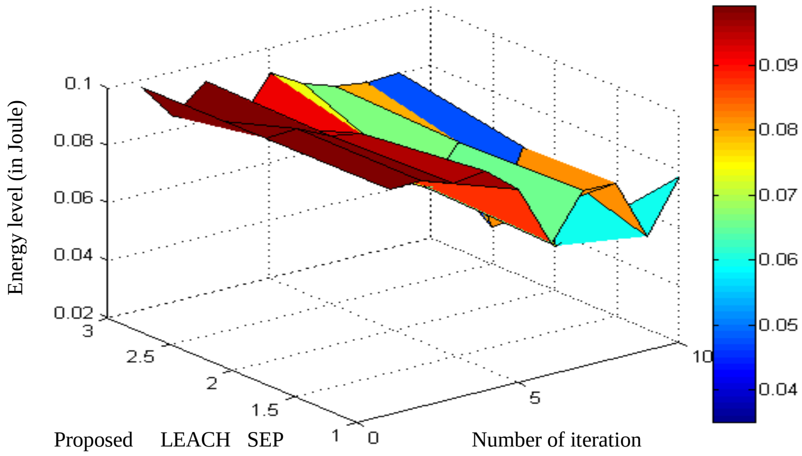

Figure 4. Average energy of each node for ten iterations in 3D

Figure 4 shows the 3D view of the average energy level in the network iteration for LEACH, SEP, and the proposed approach. The initial energy of the networks is .098, which is the same for all three approaches.

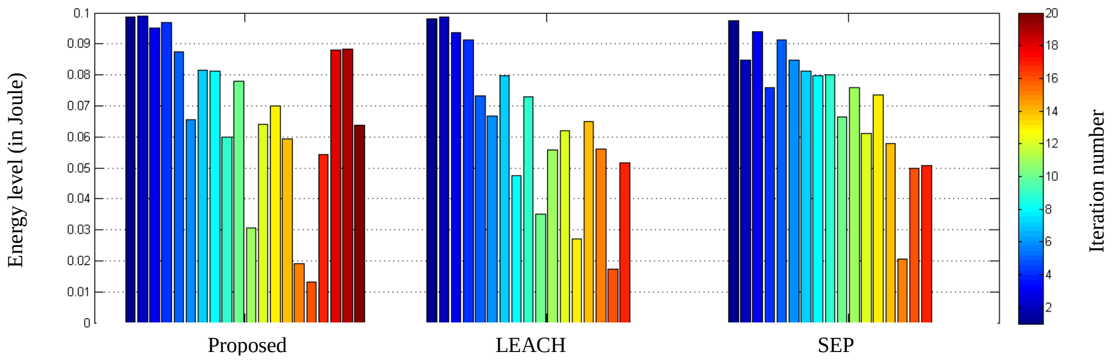

Figure 5. Average Energy of Each Node for 20 Iterations

Figure 5 shows the average energy level in the network for LEACH, SEP, and the proposed approach. In this figure, the iteration number is twenty and the energy level of the network at each iteration is shown. The initial energy of the network is the same for all approaches, but after simulation occurs, the changes in energy level in all approaches are different.

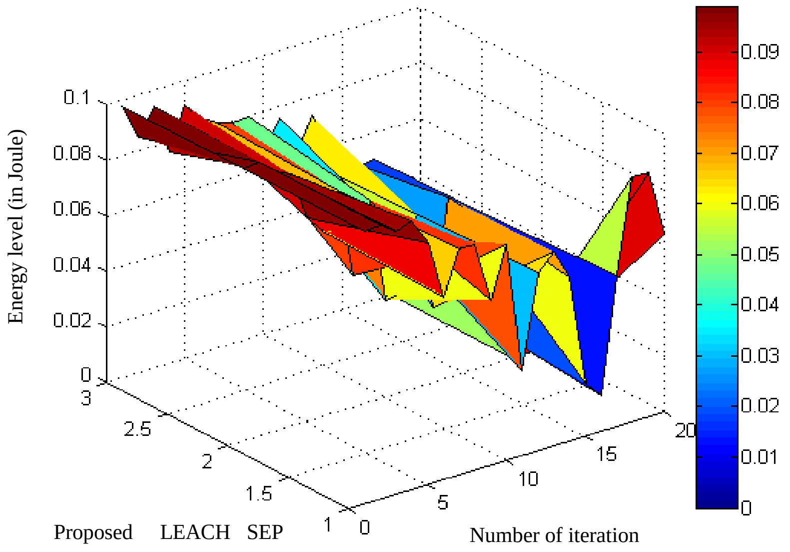

Figure 6. Average energy of each node for 20 iterations in 3D

Figure 6 shows the 3D view of the average energy level in the network iteration for LEACH, SEP, and the proposed approach. The initial energy of the networks is .098, which is the same for all three approaches). The proposed approach has higher average energy than LEACH and SEP, so the network lifetime is higher for the proposed approach than it is for the existing approaches.

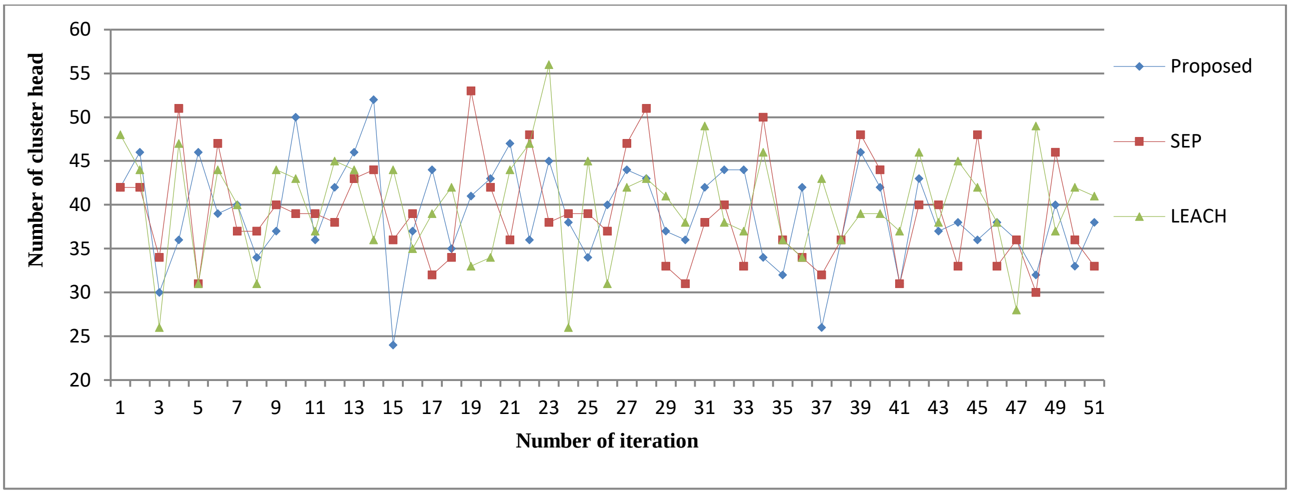

Figure 7. Number of cluster heads in the network

Figure 7 shows the number of cluster heads in the networks in different approaches, where the horizontal axis represents the number of iterations and the vertical axis represents the number of cluster heads. The minimum number of cluster heads is 24 in the proposed approach, which is also the minimum among all three approaches. The maximum number of cluster heads is 56 among all three approaches, formed in the LEACH approach.

Figure 8 shows the number of packets reaching the cluster head as well as the number of packets reaching BS. The horizontal axis represents the approaches used for calculating the number of packets. The vertical axis represents the number of packets. The proposed approach has a higher number of packets at BS and the cluster head compared with the existing LEACH and SEP approaches. The overall network throughput in the proposed technique is better than that of the existing approaches.

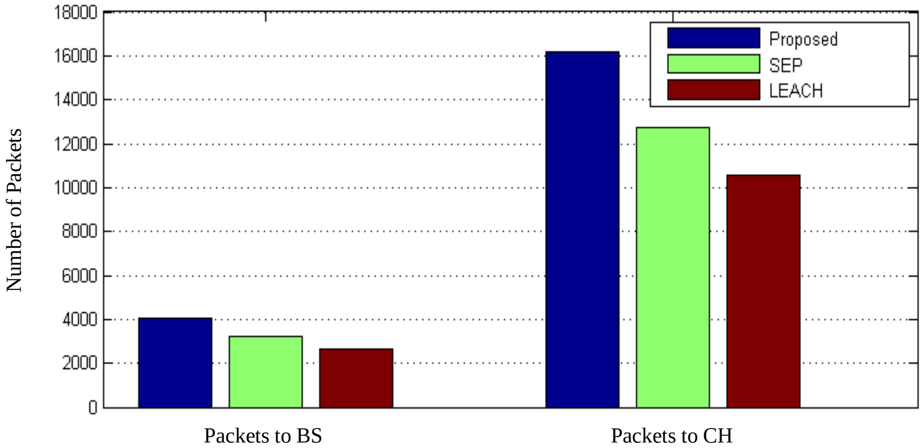

Figure 8. Packets at BS and cluster head

7. Conclusions and Future Directions

Energy play a vital role in many terms, such as processing information, communicating among sensor nodes, and transmitting information from one node to another node. The proposed approach is 19.79% better than the stable election protocol and 34.20% better than the low energy adaptive clustering hierarchy protocol. In this paper, two tier architecture is used to calculate the number of packets reached at the base station and the average energy of each node in the network. The primary tier and secondary tier architecture-based model is able to improve the average energy of each node in the network and the throughput of the network. In the future, the same work will be applied to multitier architecture.

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