# Design of an optimized energy-efficient routing protocol for reliable wireless body area networks

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**ABSTRACT**

Energy limitation is one of the essential parameters in the design of a Wireless body area networks (WBANs) as it is important to improve the lifetime of the network. WBAN routing is an effective approach for establishing energy efficiency sets and assign time slots for the network. Many algorithms that deal with interference model treats the whole WBAN as a minimum interference unit and increase their lifetime cycle. In this research, we report an effective low-energy adaptive clustering hierarchy (LEACH) routing protocol using MATLAB simulation and related C++ simulation codes to enhance the overall performance of the network by improving the energy efficiency and network lifetime cycles. Furthermore, the study sheds light up on the comparison of the protocol and proposes a modified protocol for WBAN. Based on the results obtained from conducting different configurations in the proposed design, the base station should be situated near the network to insure high network performance.



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## 1. INTRODUCTION

A wireless body area network (WBAN) is a network of sensor modules that can be placed on or around the human body to monitor the body's physiological status. The data collected by the sensor nodes is transmitted wirelessly to a coordinator, such as a smartphone or a tablet computer, which then forwards it to a remote control center, such as a hospital, using Wi-Fi or 4G communication technologies [1]. Due to the user's mobility, the network topology and location of the WBAN can vary frequently. WBANs have various applications, but their primary use is to monitor patients and collect physiological signals in healthcare. In recent years, there has been a growing interest in WBANs, and it has become an essential area of study due to its increasing demand in multiple disciplines. For example, the World Health Organization (WHO) [2], [3] reports more than 1.7 million new cases of coronary pneumonia worldwide. WBAN technology can provide remote and real-time health monitoring systems, which are essential for monitoring many patients. Wireless sensors detect physiological signals inside or on the body and transmit them to aggregation nodes and medical servers for further analysis [4]. IEEE 802.15.6 defines WBANs as short-range, low-power wireless networks [5]. In this research study, we aim to propose an efficient advanced routing protocol for energy harvesting and increasing the life cycle of the WBAN. Therefore, in this case, we propose enhanced direct, minimum-transmission-energy (MTE), and low-energy adaptive clustering hierarchy (LEACH) protocol to implement such an objective. However, the issue of direct and MTE protocols: both routing methods have some nodes draining their batteries much faster than another part of the network due to the distance or frequency of usage [6]–[15]. LEACH is a better protocol that balances energy consumption by localizing most data communication within clusters to reduce as much long-distance communication as possible while rotating the cluster head so that no node transmits data to sink too frequently. In this study, we will briefly put forward the enhanced LEACH protocol and then show our direct and LEACH protocol simulation results to see the performance of both protocols in different setups. Based on the mentioned contextual data, the problem of this study is to propose a solution that can help to increase the probability of obtaining more lifetime slots for nodes with higher data rate requirements, network lifetime cycle, and energy efficiency for the network. When nodes in WBAN have data to transmit, they can directly transmit to the sink until they run out of batteries. The main energy consumption factor is distance: nodes far away from the sink will drain their energy faster than the nodes nearer to the sink. As for minimum transmission energy, the basic idea behind this routing protocol is to choose another node closer to the sink as a router to route distant node data. This will reduce the energy consumption of nodes far away from the sink. In this proposed protocol, no node consumes high energy for transmission. However, the nodes near the sink will have to transmit data so frequently that their energy consumption needs lowered. Hence, they will instantly provide a better performance, i.e., enhanced network lifetime cycle, efficient energy harvesting in WBAN, and higher throughput with the least data loss [16]–[24].

## 2. METHOD

The proposed design and procedure depend on the modified LEACH protocol, which will fulfill the problem statement of this work. LEACH is very popular in the wireless body area network research community. It has inspired several variants and new algorithms because of its simplicity and proven effectiveness in improving the network energy efficiency [25]. However, the first embodiment of the protocol relied on some peculiar assumptions that prevented fully exploiting this communication scheme's true potential. The idea behind clustering is to leverage small transmit distances for most of the nodes in the network and limit long distances transmissions, the ones toward BS, to reduce the energy dissipated by sensors for communicating data over time and extend the network lifetime. LEACH outperforms classical clustering algorithms by using an adaptive cluster selection and rotating CHs over time to evenly distribute the energy spent for high-power transmission to all nodes in the network. LEACH differs from conventual static clustering because the cluster head (CH) and clusters are not fixed. The basic idea can be broken down into three steps and repeated every round: election of CH, formation of clusters, and data transfer to CH, then from CH to Sink.

### 2.1. Election of CH

Each node in network selects randomly a number between zero and one. If that number is less than a set threshold, then this node becomes a cluster head.

$$T(n) = \begin{cases} \frac{P}{1-P*\left(\mathrm{r mod}\frac{1}{P}\right)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where, $P$ is percentage within network, $r$ is round per cluster, $G$ is set of nodes, and $n$ is node.

After electing cluster heads within the network, cluster formation takes place, wherein CH broadcast to all nodes using carrier-sense multiple access-medium access control (CSMA MAC) protocol with same transmitting energy. After the broadcast, non-cluster head nodes decide which CH they should get associated with as its cluster members for current round. After cluster formation, each CH in each cluster will inform its cluster members and provides time-division multiple access (TDMA) schedule for each node in cluster. When all messages (data) are received from the cluster member, CH perform signal processing which can be summation or any arithmetic processing to compress data and can send in one signal. To reduce overhearing between different clusters at the CH election, a random selection of CDMA codes from a list of spreading codes is used by each cluster to communicate. Figure 1 reveals the behavior of LEACH approach. It can be clearly seen that the dead nodes distributed at different part of the network, so the network can still sense the overall monitoring area. Flowchart shown in Figure 2 illustrates the structure of protocol being follow.

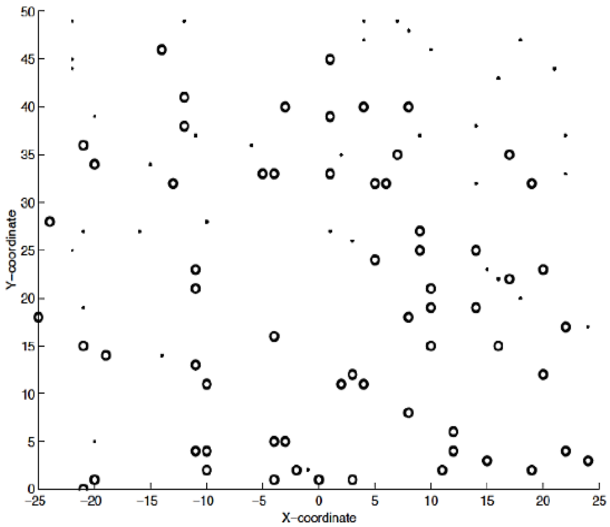


Figure 1. LEACH protocol after 180 rounds, where the circles represent the live nodes and the small dots represent the dead nodes. The sink is set at (x=0, y=0)

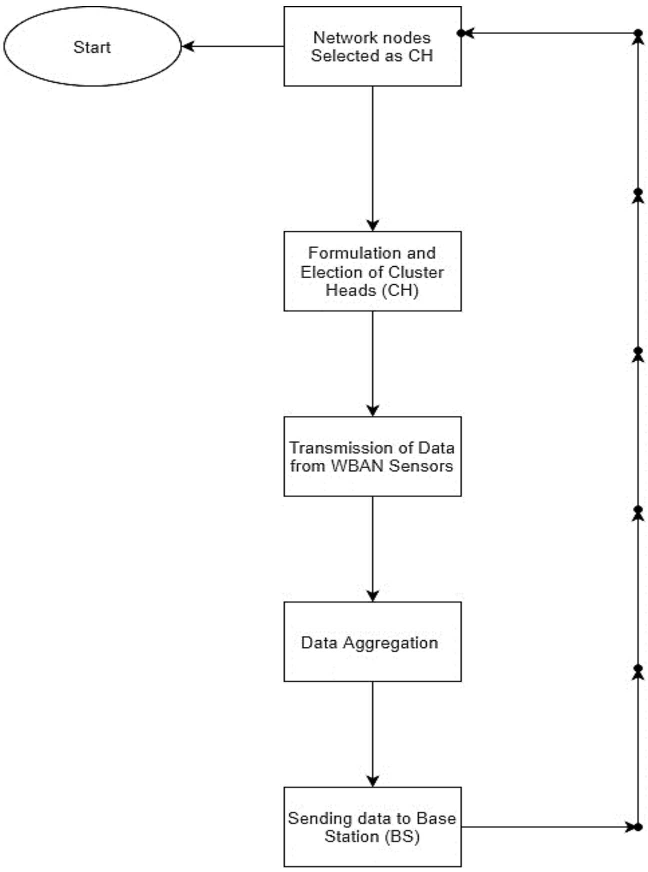


Figure 2. Illustration of the LEACH protocol and the overall network behavior

### 2.2. Simulation procedure

In the proposed simulation, the initial conditions are set to provide a realistic and manageable environment. The number of nodes is 50, and the monitoring area is 100×100 meters, with nodes randomly distributed. Each node has a 0.05 J battery, which is set low to make plotting and managing the raw data easier. Furthermore, each node will send an 8-bit size data message each round. By setting these initial conditions, we can ensure that our simulation will be as accurate as possible while still being easy to manage. The simulation runs by rounds, a program to finish the 3-step procedures in the LEACH network. The simulation will then stop at either the defined total number of rounds (*TOTAL_ROUNDS*) or the average energy of the network that is below 10% of the initial energy. We propose an improved version of LEACH, LEACH+. The communications between the cluster heads and the sink consume much energy [26]. To overcome this limitation, the node current energy was treated as a factor for threshold calculation. Then the threshold would vary depending on the node's current energy. The higher the energy they have, the larger the chance they became. Based on this idea, when LEACH+ is running, each round will find the max energy node and use this max energy as a factor to multiply with the cluster head percentage constant to rescale the percentage. Therefore, the node with half of the max node energy only has half the chance to be a cluster head.

$$Rescale\,factor = \frac{Node\ current\ energy}{Max\ node\ energy\ in\ the\ network} \quad (2)$$

### 2.3. Simulation code

The research created an existing LEACH and direct transmission protocol simulation. To improve the parameters of the proposed system, such as index errors/overflow, formula typo, and wrong logic, and added functions and data structures for monitoring and storing the whole simulation process, including most of the data generated from the individual sensor and whole WBAN network performance. Formatted text files were generated to visualize the raw data in MATLAB. Through this process, we learned the details of each step in the LEACH protocol and how the data transferred between nodes to cluster heads and sink. The data plots from the raw data provided a good perspective of what was happening in the network. In order to understand the layout strategy of the work, as is it more effective than others, Figure 3 depicts the design of each step in LEACH protocol and how the data is transferred between nodes to cluster heads and then to sink. Now let us compare the energy levels of sensor nodes over time for each proposed CH selection strategy for the same simulation configuration.

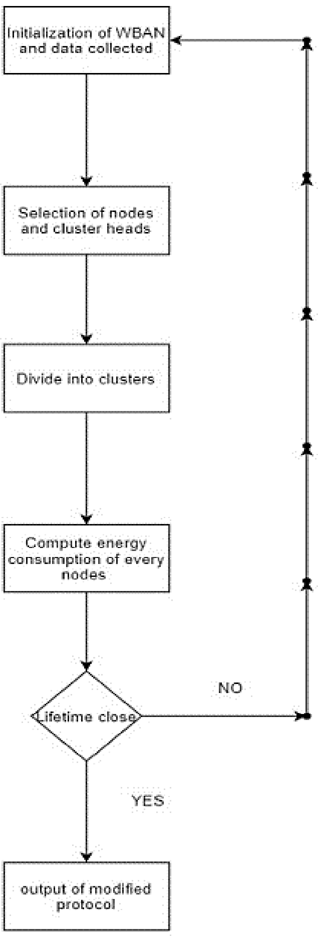


Figure 3. Steps of the proposed modified LEACH+ protocol in each round of clustering for WBAN

## 3. RESULTS AND DISCUSSION

This study simulated three protocols at different configurations for WBAN efficient energy harvesting and network lifetime. First one is by changing the base station distance to the network. Second is by changing the cluster head percentage. Table 1 indicates that two LEACH protocols perform much better than the direct transmission. The overall lifetime is two to three times longer than the direct transmission protocol. However, at long distance, such as 500-1,000 m, we can observe that even the live time is much longer than the direct transmission, the actual data that reach the sink are not significantly larger than the direct method. Our LEACH+ does not perform significantly better than the original LEACH method over the Base station distances. The abbreviations for the performance metrics are as: Num of nodes@50, cluster head percentage@0.05, executed rounds=E.R, first dead node=FDN, and bits transmission=B/T.

Table 2 shows that both LEACH protocols perform better than direct transmission. But the best cluster head percentage is at 20%, which means one cluster has around five nodes. Combining Table 3 and 4, the base station at (100 m, 100 m) and percentage at 20% will give us a good result in Table 5.

Table 1. Three protocols performance/B.S

| | LEACH | LEACH+ | Direct |
|---|---|---|---|
| | Base@[100,100] | | |
| E.R | 12,063 | 12,085 | 3,574 |
| FDN | 2,725 | 2,636 | 3,396 |
| B/T | 2,359,658 | 2,356,351 | 1,539,825 |
| | Base@[200,200] | | |
| E.R | 2,047 | 2,063 | 878 |
| FDN | 852 | 785 | 820 |
| B/T | 523,985 | 523,745 | 363,820 |
| | Base@[500,500] | | |
| E.R | 260 | 255 | 137 |
| FDN | 80 | 79 | 135 |
| B/T | 60,065 | 60,060 | 50,784 |
| | Base@[1000,1000] | | |
| E.R | 467 | 468 | 32 |
| FDN | 30 | 28 | 37 |
| B/T | 13,571 | 13,598 | 12,748 |

Table 2. Three protocols performance over cluster head percentage

| | LEACH | LEACH+ | Direct |
|---|---|---|---|
| | C.H Percentage@0.05 | | |
| E.R | 2,288 | 2,301 | 816 |
| FDN | 765 | 770 | 795 |
| B/T | 495,544 | 495,528 | 352,792 |
| | C.H Percentage@0.10 | | |
| E.R | 2,151 | 2,159 | 892 |
| FDN | 853 | 835 | 891 |
| B/T | 497,485 | 499,632 | 357,452 |
| | C.H Percentage@0.20 | | |
| E.R | 2,006 | 2,006 | 852 |
| FDN | 795 | 795 | 820 |
| B/T | 514,504 | 514,504 | 355,592 |
| | C.H Percentage@0.50 | | |
| E.R | 2,136 | 2,136 | 846 |
| FDN | 806 | 806 | 845 |
| B/T | 472,659 | 472,364 | 324,748 |

As we can see from Table 3, even though the second case has first dead notes happening earlier than the first case, due to the randomness of the simulation, the overall executed rounds and data transmission is better than the first case. After careful observation and running simulations on multiple ideas, the study observed that if we decrease the cluster head percent, there is slight space for improvement with rounds. Simply put, a node can become a cluster head with a certain threshold of battery power. To get that threshold battery power, a profile run of LEACH at 0.05 cluster head percentage was used with a node energy of 0.75 j. The maximum cluster head energy required to transmit the packet to the sink and noted in vector data structure was collected during each round. From that data structure, it can be found that the minimum value among collected maximum value and made a hypothesis that to become cluster head, a node should require this threshold of energy. In the original LEACH idea, a node was chosen as cluster head depending on round and fixed cluster head percentage without taking care of the node's current battery power in WBAN. Nevertheless, this value is fixed. In future studies, a formula can be derived to determine this value based on the node's distance to sink. Below simulation had sink placed at x=500 m, y=500 m, and cluster head percentage set to 0.05 with 50 nodes distributed randomly within x=0 m to x=100 m and y=0 m to y=100 m.

Table 3. Comparison between cluster head percentage at 5% and 20%

| | LEACH | LEACH+ | Direct |
|---|---|---|---|
| | C.H Percentage@0.05 | | |
| E.R | 12,655 | 12,655 | 3,598 |
| FDN | 2,756 | 2,678 | 3,398 |
| B/T | 2,398,745 | 2,354,782 | 1,537,495 |
| | C.H Percentage@0.20 | | |
| E.R | 12,204 | 12,204 | 3,471 |
| FDN | 2,629 | 2,628 | 3,233 |
| B/T | 2,557,368 | 2,557,392 | 1,386,488 |

## 4. CONCLUSION

This paper presented an energy-efficient protocol to improve the energy consumption and lifetime of the WBAN network. The proposed modified protocol offers less energy consumption and provides an enhanced lifetime cycle of the network. The routing protocol's operation was thoroughly investigated using MATLAB simulation and related C++ simulation codes to attain effective energy harvesting and network lifetime cycles. The review reveals insight into the correlation of the convention and proposes a changed convention for WBAN. Through simulations of various configurations, the base station should be close to the network, within 100~300 meters, to get a remarkable performance. A 20% cluster head percentage would be an optimized ratio for this range for routing communication. The experimental results assured that the proposed routing protocol attained higher outcomes than the existing routing communication protocol.

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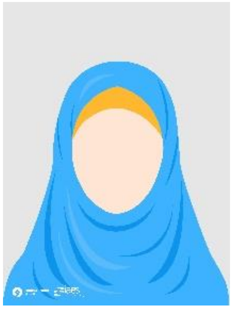

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