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Ad hoc wireless network implementing BEE-LEACH

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ABSTRACT

Adaptations have been key to the development and advancement of the low energy adaptive clustering hierarchy (LEACH) protocol. Presented is an alteration to the traditional LEACH, low energy adaptive clustering hierarchy, algorithm. This algorithm focuses on the battery life optimization of sensors within a wireless sensor network (WSN). These sensors will be grouped into clusters with the aim of maximizing the battery life of the overall system by sorting each sensor by residual energy and assigning the highest residual energy the role of cluster head. The protocol will then assign sensors to cluster heads based on distance relative to the head. This algorithm achieves the goal of extending battery life and offers itself as a promising alternative to standard LEACH algorithms. The algorithm is tested by comparing sensor battery life, total sensors communicating at a given time, and sensors with residual energy. This paper addresses the strengths and vulnerabilities of the algorithm, as well as proposed work for further implementation for the following groups looking to create their own LEACH protocol.

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1. INTRODUCTION

Through the years, the development of internet of things (IoT) devices, has introduced the issue of routing amongst the devices that make up the wireless sensor network (WSN). These sensors communicate in a network in a near-infrastructure-less network, in which a base station (BS) communicates with the sensors and assigns connections and pathways between sensors in order to minimize power draw, as batteries in these IoTs may be difficult or impossible to change [1]. By maximizing the lifespan of these batteries through algorithm implementation, it ensures efficiency in terms of energy as well as efficiency in financial implementation as a new fleet of sensors would be needed to recreate the network. Low energy adaptive controlling hierarchy (LEACH) is the host algorithm, which has the base station designate sensors as cluster heads (CH) and assign sensors to those cluster heads to create a hierarchy of communication in which a steady flow of communication is established [2]. The sensors relay information, in this case, battery life, relative distance, and time since the sensor was last active to the cluster head, which then relays that information back to the base station. This streamlining of communication improves efficiency as it cuts down on the number of transmissions between sensors and the base station [3]. It also improves battery life as the base station could be located outside the network, and the power required to transmit a message from each sensor to the base station is inefficient. LEACH is a powerful tool as it takes advantage of ad hoc wireless network capabilities by creating a network in a near infrastructure-less environment. The sensors generate random signals and their relationship to each other is what determines their data connection from one sensor to another. This application is important in that it can be implemented to display temperature readings, moisture readings, or to detect movement in nature or places where network infrastructure may be sparse [4]. Ad hoc networks are self-sufficient networks that rely on the sensors themselves to transmit data back to the base station. This algorithm is unique in that the base station does not have to be centralized to the network. The distance between the BS and the relative CH can be adjusted to show the relationship between the distance a message must be transmitted and battery life [5]. This streamlining is the basis for the BEE-LEACH algorithm, the battery energy efficiency LEACH algorithm. The BEE-LEACH builds upon EE-LEACH, which is energy efficient LEACH. This algorithm achieves energy efficiency through Gaussian distribution, and the probability of getting assigned to be a cluster head is based on the function of spatial density. The proposed BEE-LEACH algorithm differs in that it takes advantage of calculating each sensor's unique distance between the sensor and the base station, as well as the battery level of the sensor itself. This information is sorted in ascending order and is when cluster heads are elected and then assigned subordinate sensors to make up the cluster. The parameters of the network regarding size, number of cluster heads, and sensors can be modified to exemplify their impact on the behavior of the system [6]. BEE-LEACH is directed towards maximizing battery potential and can be used in applications where the volume of messages relayed is important. As a result of this, BEE-LEACH is a perfect application for the agriculture industry, in which temperature sensors could be placed around a research facility and the information could be relayed back to the host as accurate, up-to-date information is key, as well as low-computational, easily deployable sensors are used to provide that information highway back to the base station [7]. As will be seen, sending and receiving messages consumes energy, and if nodes remain CHs and are not changed out, those nodes will die much faster because those nodes are tasked with sending and receiving messages to all subordinate nodes, which drains the battery. To combat this, in BEE-LEACH, nodes are considered exempt from becoming CHs if in the previous 10 rounds they were the cluster head [8]. This helps dissipate the concentration of cluster head power draw. The algorithm takes into account power level, distance, and rounds since the last designation of the cluster head. The IoT is the method of connecting several devices to the Internet. In the WSN framework, the devices are not connected to the internet. However, the WSN communicates the information to the internet through the cluster of sensors [9]. The contributions of the work are given below:

- The system was built using a 100 m by 100 m area, with a total of 100 nodes and 10 cluster heads for the system. These parameters will be adjusted, but for the initial setup for LEACH and BEE-LEACH, these were the values chosen as a baseline.
- The main issues that are being addressed by BEE-LEACH are the number of rounds the sensors are online for. If improvements can be made to the LEACH algorithm to extend the number of rounds the sensors can transmit data, then the capacity of total message rounds has been increased and the algorithm is a success.
- This protocol is implemented and set to apply to work in a WSN that takes up a 100 m by 100 m area. This area is filled with 100 nodes, and 10 of those nodes will be elected as cluster heads. The values output will show how many nodes are active per round, how many nodes are transmitting at once, the energy consumed per transmission, and the total number of rounds before all sensors are depleted of battery life.

2. LITERATURE REVIEW

Recent advancements in WSNs have focused on optimizing energy consumption and improving network longevity, reflecting a growing body of research dedicated to enhancing the efficiency and sustainability of these critical systems. For instance, the development of a cluster controller location method based on the bee colony optimization (BCO) algorithm demonstrates significant performance enhancements in node operation by facilitating energy optimization and smoother information flow [10]. Similarly, the implementation of an enhanced LEACH procedure, dubbed EE-LEACH, has shown to outperform conventional energy efficiency algorithms, markedly improving system throughput [11]. Further contributions include the design of an efficient wireless structure leveraging the time division multiple access (TDMA) process. This design has been mathematically analyzed, showing notable improvements in the network’s quality and lifespan compared to existing approaches [12]. Additionally, the introduction of a biogeography-based optimization (BBO) algorithm aimed at reducing WSN overhead has been proven to surpass existing methods in system performance, as validated through computer simulations [13]. Innovations continue with the novel application of bee algorithm (BEE) techniques for network energy consumption optimization. By selecting optimal routes for information transmission, these techniques have significantly enhanced the energy efficiency of networks [14], [15]. Moreover, genetic-based cluster algorithms have been developed to configure stable clustering, further improving the system’s energy efficiency [15]. Comparative studies on LEACH protocol variants have elucidated distinct approaches and their applicability based on network requirements. The BEE-LEACH variant, for example, maximizes battery life by optimizing the distance between sensors and cluster heads, addressing scalability and signal strength challenges [16]. On the other hand, EC-LEACH and EE-LEACH prioritize cluster head selection based on residual energy and signal strength, respectively, each with its own set of efficiencies and limitations tailored to specific network configurations [17]. This review underscores the dynamic and evolving landscape of WSN optimization research, highlighting the diverse methodologies and algorithms devised to tackle energy efficiency and network performance challenges. The collective findings from these studies provide a robust foundation for future research, aiming to further refine and innovate WSN technologies for enhanced durability and operational efficiency.

3. RESULTS AND DISCUSSION

Both EC-LEACH and EE-LEACH were derived from similar goals of EC-LEACH. Both algorithms address shortcomings of the traditional LEACH algorithm. EC-LEACH attacks this from the perspective of a centralized system, and EE-LEACH adapts the algorithm to assign CHs based on signal strength alone, which lowers energy costs from message transmission. However, it runs the risk of not having evenly distributed nodes, which could run batteries in those sensors very low very quickly compared to standard LEACH. BEE-LEACH aimed to combine the two approaches. Distances between the nodes and the base station, as well as residual energy left in the sensors themselves, are taken into account and sorted into ascending order. By assigning cluster heads based on equal distribution and energy level and assigning sensors to clusters based on overall system energy and not just shortest connections, improvements in the number of total rounds that nodes are active, as well as a more consistent amount of energy transmitted per message, can be seen after the implementation of BEE-LEACH. This system was tested in a mock network built in MATLAB 2021B and the coefficient is given in Table 1.

As shown in Figure 1, the network generates in a 100 m by 100 m space, with the BS represented by a red X at (50 m, 200 m). This shows the algorithms' capability to adjust to a base station that is stationary and a network that remains stationary but lacks infrastructure. The representation of the network shows that to communicate with the base station, each node without LEACH must communicate a minimum of 100 m and a maximum of 250 m, which is not energy efficient. Employing the use of BEE-LEACH, cluster heads are elected based on relative distance to the base station and other nodes, and the sensors' battery level. As more and more sensors become the CH, sensors further down in the network are elected, and the distance of message transmission is expected to decrease as the nodes appear closer together and the message travels across a shorter distance. As noted later, the energy required to transmit a message is a function of distance squared. As a result, cutting the distance messages must travel in half reduces energy costs by a factor of four. This is the problem with the formulation of BEE-LEACH.

Table 1. Values and coefficients used

Name	Symbol	Value
Base energy of Tx/Rx	E_{elec}	$50\ x\ 10^{9} J$
Unit energy of Tx/Rx	ε_{amp}	$100\ x\ 10^{-12} J$
Size of Tx messages	K_t	4,000 bits
Broadcast message data size	K_b	800 bits

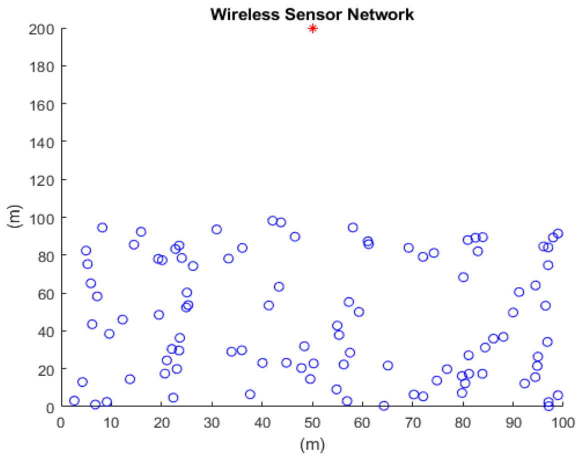

Figure 1. Representation of the network generated

4. BEE-LEACH SYSTEM MODEL

The first key equation that is used in BEE-LEACH implementation is the distance equation as shown in (1).

$$d = \sqrt{i^2 + j^2} \quad (1)$$

i and j in this case are referring to Figure 1, which shows the generated network used for this case. These i and j values will differ based on the node being surveyed. Distance will be calculated in two parts. Part one is the distance between the BS and the sensors, and part two is the distance between the sensors themselves [18]. These values will be defined using MATLAB code and stored in an array with indexing referring back to the generated network. In the code, each node will be indexed using i and n. i represents a source node, and j represents a destination node for data transmission. This is how distance and energy costs are calculated [18]. The source node i and destination node j differ based on the current node being surveyed. The algorithm checks each node for its updated distance vector value and energy transmission value. Using a nested for loop, this is accounted for and seamlessly incorporated to include up-to-date information for distance every round. For every (i, n) pairing, the distance will be calculated and indexed. The second equation that is implemented is the residual energy equation. As mentioned previously, to calculate energy in the sensors, energy transmitted, and energy received must be calculated. In (2), the energy transmitted is shown.

$$E_{tx}(k, d) = E_{elec} \text{ x } K + \varepsilon \text{ x } K \text{ x } d^2 \quad (2)$$

$$E_{rx}(k) = E_{elec} \text{ x } K \quad (3)$$

Equation (3) represents the energy consumed while receiving information from other sensors. It is the energy required to receive a message. K represents the number of bits being transmitted. As can be seen here, equation (2) has a factor of d^2 which as noted before, is the value that is aimed to be minimized after the implementation of the BEE-LEACH protocol. To obtain an accurate depiction of the total energy consumed per message transmission, for a predetermined message size, k, and a predetermined distance d, the values for (2) and (3) should be combined. Equation (4) shows the accurate value of energy consumed transmitting and receiving this message [19].

$$E_{tx}(k, d) + E_{rx}(k) = K\ x\ (2\ x\ E_{elec} + \varepsilon \text{ x } d^2) \quad (4)$$

This value is subtracted from the total battery level in the sensor and indexed appropriately in an array. This value is then sorted in ascending order using the onboard sorting algorithm within MATLAB. This arranges the values of residual energy in descending order, as the higher the residual energy left in the sensor, the higher priority that node will have when it comes to CH election in the next stage of the protocol [20].

5. TESTING METHODOLOGY OF BEE-LEACH PROTOCOL

Figure 2 shows the implementation of the protocol in a system. The protocol surrounding the algorithm depicts the appropriate time to employ the algorithm and its implementation within a system. The protocol flowchart shows the network generation aspect of the system as the initial point, as that is what launches the first steps of the algorithm. The algorithm is then activated and begins calculating the energy within the battery. The initial energy in the battery has been predetermined to be 5 J for simulation's sake. As all batteries are at full capacity, the first step towards sorting into a hierarchy is distance calculation. Each node has its $d(i, j)$ calculated and sorted into a distance array. The protocol favours nodes that are closer to the base station. In Figure 1, this can be seen by the top layer of sensors closest to the BS. The protocol then enters the node check section. This section runs each sensor through the check of the highest residual battery energy and shortest distance, being the highest priority to the system. These values in the first round will go hand in hand, but the values for residual energy change as rounds progress. The residual energy is the value with the highest bias or priority. This value is then checked to see if the node it belongs to has been marked as the CH in the previous 10 turns. If the flag to check that value is low, then the node will be elected as a CH. If the value is high, then the node cannot be elected as a CH and must return to the node check phase. This must be repeated until ten successful cluster heads are elected, resulting in a 10% cluster head to sensor ratio [21]. Once all 10 cluster heads have been elected, the protocol then moves to the cluster assignment section. This non-CH hierarchy assigns sensors to CHs based on the distance between the furthest sensor and the cluster head. This is due to the fact that each cluster can hold a maximum of ten sensors each, and that the ten closest nodes may force a longer than desirable distance between a node and the cluster head. So, this distance value is sorted in descending order, with the distance calculation being sorted in reverse order of the previous [22].

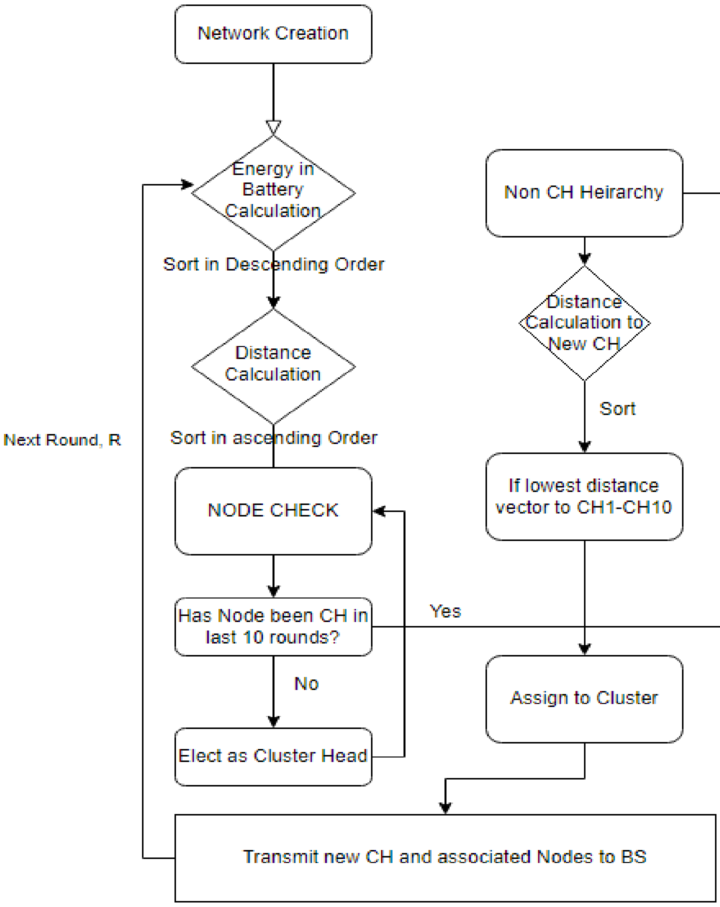

Figure 2. Protocol flowchart

As previously stated, the distance value is the one that should be kept as low as possible. If the value for the longest distance d_{max} can be kept to a minimum, then again, the value for d is squared in the energy formula. By decreasing this value, it is improving efficiency within the system as a whole. Once all 10 sensors have been assigned to the 10 cluster heads, the cluster heads and sensor data are sent to the base station. This has concluded a round for the system, and the sensors send their updated distance vectors, battery level, and cluster assignment info to the base station. This action costs energy, and the next round of transmission begins [23]. The parameters for message size, network area, and base station location will all be adjusted to acknowledge how each of those parameters affects the overall behavior of the graphs. Once again, the desired outcome over the original is to increase the number of rounds the batteries can transmit during. By focusing on battery level and assigning priority to those who meet criteria based on the recency of cluster head assignment, battery life should increase [24]. The number of rounds will fluctuate when compared to traditional LEACH. These values for BEE-LEACH will be compared to values for traditional LEACH to show emphasis on battery life extension. Both networks will be identical and will be constructed in MATLAB using a random generation model [25].

6. SIMULATION RESULTS

Figure 3 shows the number of active nodes per round after implementing the BEE-LEACH protocol, and the number of active nodes per round for the original LEACH protocol and BEE LEACH. As seen by the behavior here, it is clear that BEE-LEACH unlocks more rounds per battery. It increases the value of rounds by a factor of this is a significant increase as this shows that BEE-LEACH can transmit a significant number of times more than a standard LEACH implementation. The increase in capacity is the behavior that was sought after. The behavior between LEACH and BEE-LEACH is relatively unchanged. The graph changes behavior. However, the general shape should remain the same from network to network. The increase in rounds is attributed to the prioritization of the node's energy level in the cluster hierarchy assignment. The drawback for BEE-LEACH comes from the lack of scalability. The structure can only handle up to a peak number of sensors before diminished returns are found.

The large number of sensors weighs down the sensors, in which other implementations of LEACH would be best suited for large scale use. Looking solely at the number of rounds, BEE-LEACH ended with a total number of 115,608 rounds before all nodes were depleted of battery. This is rivalled by the original values for LEACH, reaching 56,614 rounds. This seems like a large increase in rounds. However, as noted by the graph, between 90,000 and 10,000, the graph is hovering below 4 nodes. This is not optimal for networks. Useable node rounds, the behavior hovers around 85,000 rounds versus 56,000 rounds. The other factor considered can be seen in Figure 4. Figure 4 displays the energy spent per transmission between nodes. The value peaks at around 0.02 joules of energy. Remember that each battery started with 5 joules initially. The average energy expended by a message transmission lies between 0.005 joules and 0.01 joules.

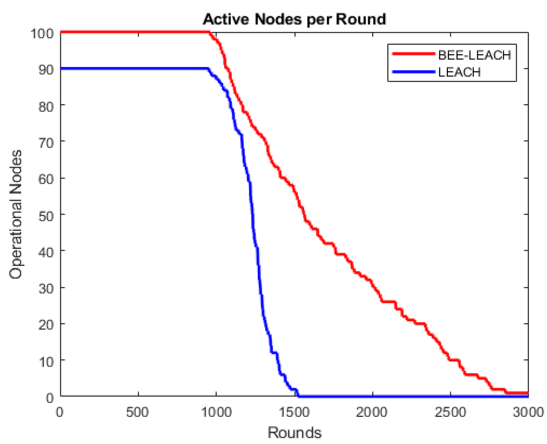

Figure 3. Active nodes per round for BEE-LEACH

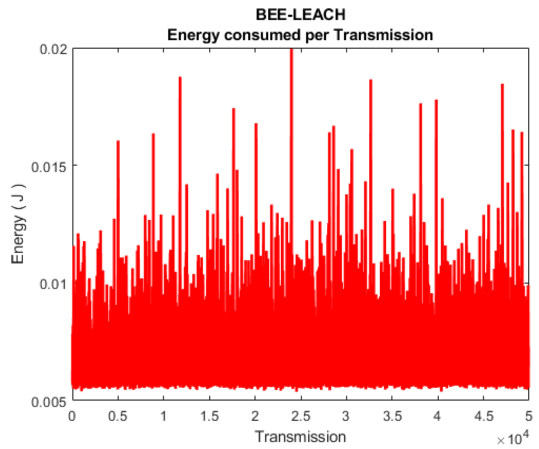

Figure 4. Energy per transmission for BEE-LEACH

Figure 5 shows the average energy per transmission for traditional LEACH. As can be seen, peak energy expended in traditional LEACH is 0.03 J, and average energy hovered between 0.02 J and 0.014 J. This shows the relationship between prioritizing distance between sensors when assigning clusters for the network. The last factor that was displayed was active nodes at a given time for transmission. This value is important as it shows possible interference and noise in the system for data transmission. As all nodes communicate between one another for updated information, active nodes at a given point in time shows a possible failure point within the system.

Figure 6 shows active nodes for BEE-LEACH and for traditional LEACH. the base station, or in number of sensors. These factors will be addressed by modifying the parameters in MATLAB and running the tests with half as many sensors as well as halving the size of the network area. Both are done independently.

The number of nodes transmitting at once in traditional LEACH is half that of BEE-LEACH. This brings about a huge possibility for failure in real world scenarios. This is a key point of contention when modelling systems in MATLAB. Since systems are ideal and interference is not accounted for directly, implementation of this algorithm could present an issue with constant updating and interference between nodes. This needs to be quantified and adjusted for real-world implementation. These three values, as well as the round total, show the key points that BEE-LEACH aimed to address over the traditional LEACH algorithm. The BEE-LEACH simulation took around five minutes to run. The algorithm was run using MATLAB 2021a with a 3090 and an Intel i9-9900k. The simulation runs through 110,000 trials and the processing power required is immense. This can be alleviated by reducing the scope of the network, whether that be in terms of size, relative distance to Figure 7 will show a 50 m by 50 m area with 100 sensors. The 50 m by 50 m area network had 40,000 rounds total when compared to the BEE-LEACH algorithm with a 100 m by 100 m area. When decreasing the area by half, the number of "active" nodes rounds halves as well.

The only caveat being that, again, the nodes do not all die in BEE-LEACH until much after the total number of nodes is below five. The behavior and shape of the 50-sensor BEE-LEACH is given in Figure 8, have much harsher corners. This harsh adjustment to halving the number of total sensors reduced the number of rounds to 49,278.

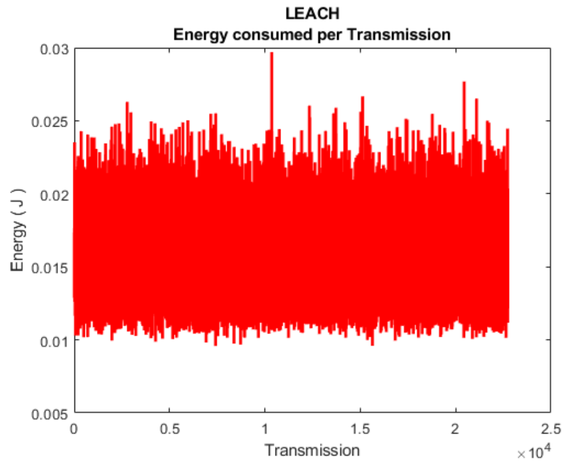

Figure 5. Energy consumed in message transmission for LEACH

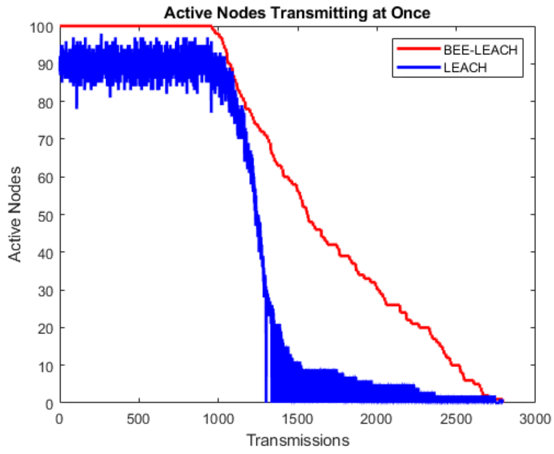

Figure 6. Active nodes transmitting

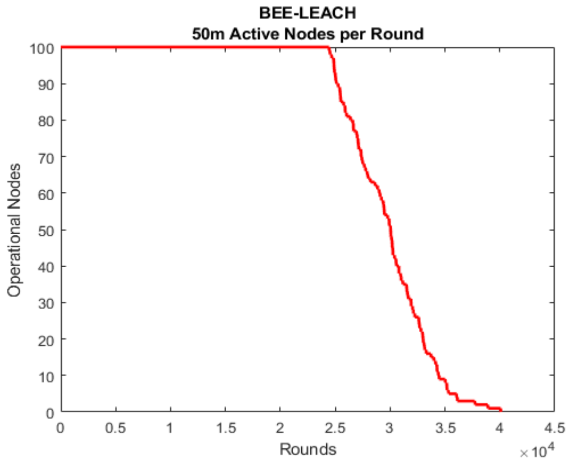

Figure 7. 50 m by 50 m BEE-LEACH network

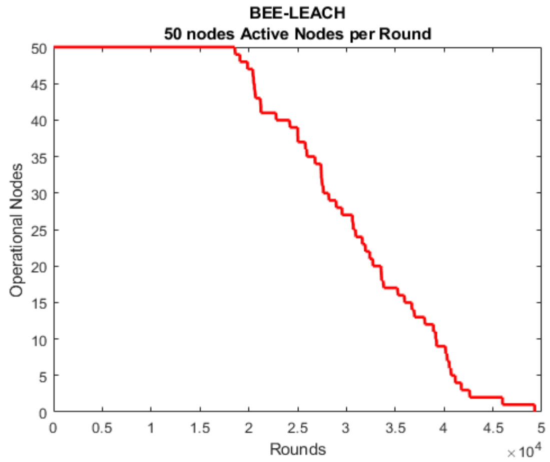

Figure 8. 50 sensor BEE-LEACH

7. ANALYSIS OF LEACH PROTOCOL

Drastic improvements were made in the number of totals rounds the simulation was able to transmit data over. However, the peak number of nodes transmitting is nearly doubled per transmission segment. This has the possibility of introducing a tremendous amount of noise into the system. This is especially a problem in IoT implementation, as the low computational power of IoT devices could prove to be an issue when handling noise. This is an effective way to simulate and implement this algorithm in MATLAB where interference is not modelled within the system. With noise introduced, distance values transmitted to the base station, and the advertisement of CH to sensors could become distorted and encounter noise and rogue sensors in the system. It does not, however, address the security or optimization issues that other LEACH algorithms do. This algorithm should be deployed in a low-noise environment with low interference and a goal of high battery efficiency. This algorithm is also designed with a static base station and sensors. The algorithm is based on a static network but changes the hierarchy based on the randomized nodes. Another algorithm would need to be developed to implement this into a hotspot network or just a mobile network where the base station's location changes. Overall, improvements were seen that were to be expected and they were repeatable. These improvements were seen across network area adjustments and adjusting the number of sensors across the network. Shortcomings of limited scope of application and the issue of noise can be an issue if not addressed properly in real world implementation. The average energy per transmission is nearly an order of magnitude lower than in the traditional LEACH protocol, allowing the network to support nearly 60% more rounds. This shows where the improvements in the shorter distance between sensors influence the overall energy cost. As noted, with the algorithm boiling down to the distance being calculated twice in the algorithm, minimizing the overall aggregate distance is where huge potential for energy saving is possible. If implemented properly with sufficiently powered IoT devices, the system could theoretically run almost twice as long, about 1.6 times as long. This is massive in terms of potential energy savings, as, again, the implemented sensors could be difficult to address, or even impossible to switch batteries. This increase in efficiency could be a possible selling point for people on a system of temperature monitoring IoT sensors. Table 2 indicates the implementation differences of the LEACH protocols.

Table 2. Comparing BEE-LEACH to LEACH protocol implementation

Type of LEACH	Total rounds	Total node transmitting at once	Average energy expended per transmission
LEACH	56,614	46	0.017 J
BEE-LEACH	120,210 (87,045)	91	0.007 J

8. CONCLUSION

By manipulating the distance value to be the lowest it possibly can be, overall energy saving is worth the tradeoff over the traditional LEACH algorithm. This lower energy cost is a direct result of manipulating the hierarchies to accommodate the furthest sensors first and building the clusters in reverse order. This has the tradeoff of an increased number of nodes transmitting at once, which can introduce noise. However, it is unclear what would occur in a real-world situation. The BEE-LEACH algorithm addresses LEACH in a new and unique way that does improve battery energy efficiency at the cost of increased node transmission. Each node communicates with their cluster head, and the cluster heads then communicate with the base station. Previously, each node was not communicating nearly all of the time. Creating LEACH algorithms is a challenge that allows the user to address whatever aspect of networking interests them. Battery optimization is relevant to the open market as decreasing energy requirements is a pillar of wireless communications. to take advantage of a mathematical relationship between distance and the energy cost of transmitting a message. Since all other parts of the equation remain the same, and the distance is the only variable that changes, the algorithm seeks to decrease the factor of distance as greatly as possible. The implementation of the sort algorithm and the battery level calculation in tandem with one another is the crux of the operation. The novelty of the BEE-LEACH algorithm lies in the coexistence of those parts.

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