Simulation and Analysis of LEACH for Wireless Sensor Networks in Agriculture

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Abstract: The challenges in deploying robust Wireless Sensor Networks (WSNs) in agricultural environments are limited power supply and variability of wireless propagation channel that restrict performance. Proposed protocols do not meet the challenges for realistic simulation and evaluation of WSN for agricultural applications. The design of LEACH protocol is, for the most part, efficient for many applications. It achieves energy efficiency through a clustering technique with TDMA based MAC layer algorithms and data aggregation method. Analysis performed shows that LEACH uses simple radio propagation and energy models that are unrealistic. This paper focuses on the performance analysis of LEACH protocol for agricultural environments.

Keywords: wireless sensor networks; LEACH; vegetation propagation model; clustering protocol; MAC layer protocol, internet of things

Reference to this paper should be made as follows:

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1. Introduction

Wireless Sensor Networks (WSNs) have emerged as the next wave of wireless technology particularly in internet of things (IoT), allowing unbounded physical environment to be monitored and control. A WSN consists of spatially distributed sensory devices that are small in size and able to sense, process data, and communicate with each other wirelessly. Networks of hundreds to thousands of the sensor nodes are envisioned to allow monitoring of a wide variety of phenomena with outstanding quality and scale. WSNs applications range from medical care

[1], environmental monitoring, such as early disaster warning [1-4], to precision agriculture [5-7]. Recently, there has been a significant expansion of land use for plantations such as oil palm [8], rubber and other commercially cultivated crops such as mangoes, which requires WSNs as the enabling technology to improve post harvest production, quality assessment, control crop growing conditions and automate agricultural process[9,10].

The technological challenges for developing and deploying WSNs in agriculture are daunting. Applications in agriculture usually involve wide area monitoring, in the absence of electrical power supply, harsh microclimate where degradable wireless links are unavoidable. Wireless signal propagating inagricultural environments such as in oil palm plantations are subject to many propagation losses due to blockage by trunks and/or shadowing in a hilly terrain, diffraction losses and scattering by trees which lead to reduced communication range and packet losses due to channel temporal variability.Thus, the application of WSN in agriculture needs to be carefully planned in terms of sensor nodes placements, network topology and communication protocols to ensure the system durable under a range of environmental stresses, including short and long term degradation due to weather conditions. WSNs systems are expected to provide continuous monitoring for long periods of time. Furthermore, network topology should be carefully designed to avoid data losses due to lost connectivity between nodes, since the typical propagation environment is characterized by the presence of trees, rocks and hills, which attenuates radio waves. Depending on the application, data from the sensor nodes are sent to the base station at seconds, minutes or hourly intervals or triggered by events [11,12]. To conserve energy for longer network lifetime, a suitable protocol is needed at MAC level to provide effective sleep and wake up patterns. The percentage of time each node is awake is known as the node’s duty cycle, and a variety of approaches are available for achieving low duty-cycle operation. The routing protocol implemented is another important consideration since the area is large with densely deployed nodes. Therefore, the routing protocol used must be energy efficient to deliver data from the nodes to the base station.

Several research studies in WSN have proposed various algorithms and protocols [13]. Their main aim is to optimize energy consumption and prolong network lifetime since in some applications battery replacement can be difficult and node failure can be costly. Clustering technique has been proven to be energy efficient and scalable [14]. Various cluster based routing protocols have been proposed for WSNs in the past few years. Although many of them produced results in some form of energy efficient clusters, only a few carefully considered the target applications scenarios such as the effects of different physical propagation mechanisms in the environment when forming clusters.

Low Energy Adaptive Clustering Hierarchy (LEACH) proposed by Heinzelman et al. [14] is a well-known clustering protocol for WSNs that has been used widely in the literatures. LEACH has attracted intensive attention because of its energy efficiency, simplicity and load balancing properties. LEACH combines the cluster-based routing and MAC-layer techniques along with application specific data aggregation to prolong network lifetime. In LEACH, cluster head role is rotated among the nodes to prevent energy draining of a single node. There is another variation of LEACH, which is named as LEACH-C. In this scheme, the cluster formation and the cluster head selection are centralized and implemented by the base station, after getting all the information of the sensor nodes in every round. LEACH assumes that all nodes are within reach of each other and all nodes are eligible to be a cluster head. This protocol shows a significant improvement in energy efficiency compared to non-clustered based routing technique [14].The design and performance of LEACH is proven to be efficient and this protocol is used as a benchmark for the evaluation of protocols in various research studies [15,16]. However, the routing and MAC-layer requirements for communications in WSN must be optimized depending on the target application. To the best of author's knowledge, there is no paper that discusses and simulates LEACH protocols for agriculture environment and analyzes the performance of the algorithm and the evaluation method. This paper shows how the unrealistic models and evaluation method affect the performance of the communication protocol.

In this paper, LEACH protocol is modeled and evaluated to study the performance of this protocol using OMNeT++ in agriculture. To model the agriculture environment in a simulation platform, vegetation propagation model is used as described in previous work [17,18]. The paper is organized as follows: Section 2 gives an overview of LEACH protocol and Section 3 describes the simulation and modeling processes carried out. Section 4 evaluates and discusses the benefits and limitations of LEACH protocol with respect to WSNs in agriculture and conclusions of the study are drawn in Section 5.

2. Overview of LEACH Protocol

The idea of LEACH [14] is to divide the system operation into fixed intervals called rounds as shown in Figure 1, with two phases in each round; setup and steady state phase. A round is defined as the period from one instance of clustering phase to the next cluster head selection. The number of rounds in LEACH is determined as N/K, where N is the number of nodes, and K is the expected number of clusters.

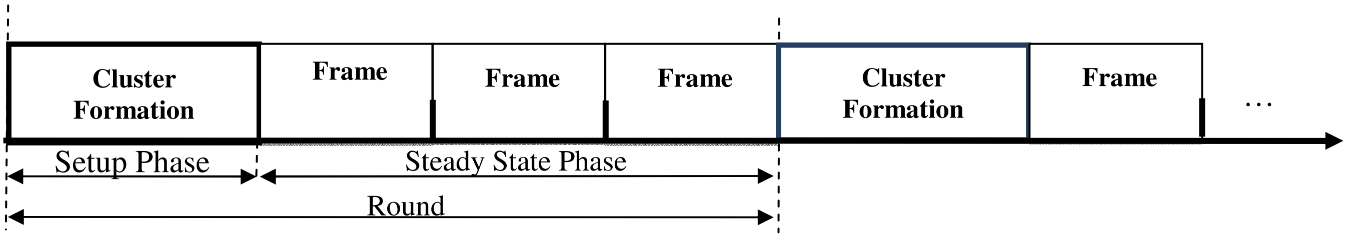


Figure 1Time Line showing LEACH protocol operation. Clusters are formed during the Setup phase and data transfers occur during the Steady State phase.

In the setup phase, LEACH activates an election process for identifying cluster heads within the network. The cluster formation algorithm is based on a probability that is chosen such that the expected number of clusters per round is k. To do this, each active node of the network generates a random number between 0 and 1; such a value is then compared with a time-varying threshold: the node is elected to be the cluster head when the generated value is below a threshold $T(n)$. At clustering round r, the threshold is described by:

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

where P is the desired percentage of cluster heads chosen so that the expected number of cluster head nodes for each round is k, and G is the set of nodes which did not become cluster head in the last ${}^{1}/_{P}$ iterations. When r is 0 (round 0), each node has probability P to become a cluster head. Nodes that have become cluster-heads in round 0, cannot be cluster heads for the next ${}^{1}/_{P}$ rounds. Therefore, the probability threshold increases since the eligible nodes to become cluster heads decreases. The probability threshold is 1 after ${}^{1}/_{P}$ rounds for any nodes that have not yet been a cluster head. All nodes are once again eligible to become cluster head after ${}^{1}/_{P}$ rounds.

Once elected, cluster heads broadcast an advertisement message based on a Carrier Sense Multiple Access (CSMA) protocol to all sensor nodes. Each node decides which cluster it will belong to for the current round based on the received signal strength and send joining packets to the closest cluster head. To calculate the received signal strength, LEACH uses the free space loss (FSL) and Plane Earth (PE) propagation models [17,18]. The transmit power is attenuated according to the FSL equation, if the distance between transmitter and receiver is less than a certain cross-over distance. If the distance is greater than a cross-over distance, the transmit power is attenuated according to the two-ray ground reflection propagation model [14]. The cross-over point is defined as:

$$d_{crossover} = \frac{4\pi\sqrt{L}h_{Tx}h_{Rx}}{\lambda} \tag{2}$$

where L is the system loss, h_{Tx} and h_{Rx} is the transmitting and receiving antenna heights, respectively, and λ is the wavelength.

The cluster head receives all join packets and creates a TDMA schedule to specify each node's time slot to send packets. The cluster creation is performed without taking into consideration bandwidth limitations. At the end of the setup phase and the network topology creation, steady state phase begins where nodes are ready to operate: data are acquired from sensors and forwarded to the cluster head according to the defined TDMA slot schedule.

As illustrated in Figure 1, the steady state operation is divided into several frames for intra-cluster communication and inter-cluster communication phases. Sensor nodes in each cluster send data to the cluster head at most once per frame during the allocated time slot. The duration of each slot is constant, thus the frame duration depends on the number of nodes in the cluster. If the cluster consists of a larger number of nodes, the frame duration will be longer. The cluster heads stay awake at all times while the sensor nodes may sleep until its allocated transmission slot and after transmission over.

In order to reduce energy, each non-cluster head node uses power control to set the transmit power level. The energy consumed by a transmitter over a short distance (below cross-over distance) is proportional to the square of the distance between the transceivers, d^2, whereas the energy consumed in a data transmission across longer distances (such as from a cluster head to the base station) is proportional to d^4.

3. Model Validation

To validate the model, various parameters have been studied and simulated results are compared with the result presented by Heinzelmanet al. [14]. A total of 100 nodes are placed in a grid topology in an area with dimensions of $100\ m \times 100\ m$ with $10\ m$ spacing between nodes. The node placement is based on the tree planting schemes widely used in the plantations where trees are planted in straight uniformly spaced rows, using a fixed distance between trees within a row [19]. Based on the tree species, the distance vary and for the purpose of this research, 10m is selected based on the distance suitable for oil palm and mango plantation [20]. An assumption is made that each trees in the area needs monitoring, and thus sensor nodes are placed at each tree.

The transmitter and receiver antenna height is set to 0.5m ($h_t = h_r = 0.5\ m$).Omni-directional antennas are used at the base station and sensor nodes; that is$G_t = G_r = 0\ dBi$ with no system loss $(L = 1)$. The wireless channel bit rate is set to 250 kbps at $2.4\ GHz$ radio frequency which has a wavelength of $0.125\ m$. The base station is located in the middle of network topology. All nodes are initially configured to have a maximum transmission power of 1mW and a receiver sensitivity value of -85dBm based on Chipcon CC2420 transceiver device specification [21].Initial battery capacities for all nodes are set to $250\ mAh$, while base station has unlimited power supply. Each scenario is evaluated based on the vegetation propagation models to represents agriculture environments as presented in previous work [17,18]. For each scenario, 10 different seeds are used to simulate the network based on Marsenne twister pseudo-random number generator.

Figure 2, retrieved from Heinzelman et al. [14], shows that the optimal numbers of clusters in a network of 100 nodes are between 3 and 5. For a verification of LEACH algorithm that has been implemented in OMNeT++, simulation studies have been performed to evaluate the behavior of the algorithm as the number of clusters varies. The simulated results from 15 seeds are summarized using box plot as shown in Figure 3. Despite taking the average energy consumption per round, result shown in Figure 3 illustrates the network lifetime until all the sensor nodes in the network are dead as the number of clusters is varied from 1 to 11.

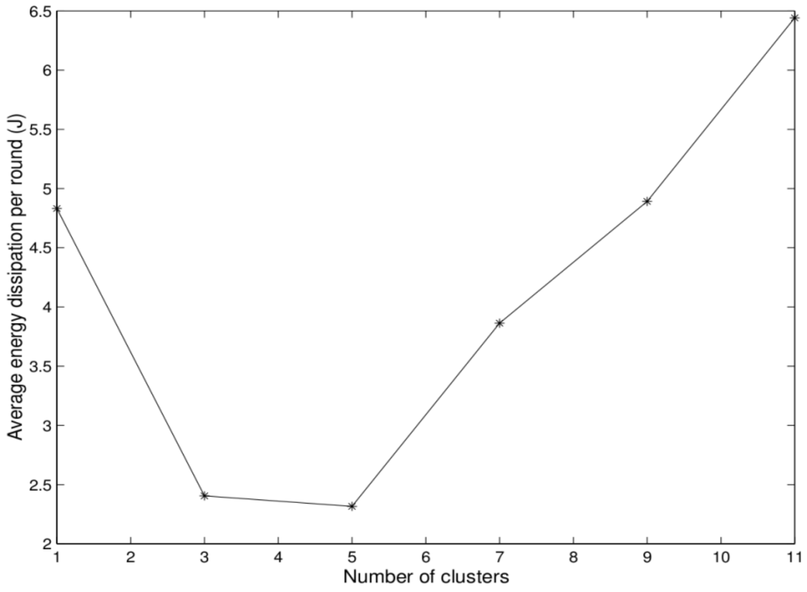


Figure 2 Average energy dissipated per round in conventional LEACH protocols retrieved from Heinzelman et al. [14] as the number of clusters is varied between 1 and 11.

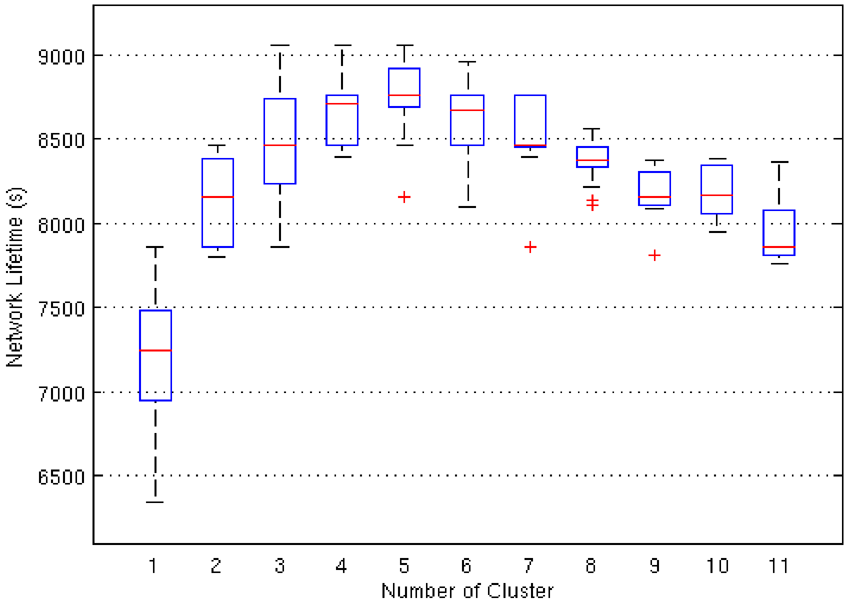


Figure 3 Network Lifetime of LEACH protocol simulated in OMNeT++ until all nodes in the network are dead as the Number of Cluster varied between 1 and 11

From Figure 3, it is clear that the highest network lifetime is achieved when the number of clusters is 5 which comply with the results of the original proposed LEACH protocol as shown in Figure 2. LEACH shows that energy dissipated per round is significantly increased when the number of clusters is 6 and above. Generated results from OMNeT++, as shown in Figure 3, illustrates a slower rate of decreasing network lifetime after the number of clusters is 6 when compared to LEACH. This is due to the fact that LEACH implemented in OMNeT++ is simulated on top of different underlying models such as the radio energy model and radio propagation model. Nevertheless, it can be observed from the figures that LEACH protocol implemented in OMNeT++ follows the same behavior as the original LEACH protocol presented by Heinzelmanet al [14].

Figure 4 shows the probability threshold, T(n) for the nodes to become cluster head in each round based on LEACH cluster head selection algorithm simulated in OMNeT++. The simulated results is based on P=0.05. The probability of each node to become a cluster head is 0.05 when the round is 0. As the number of round increases, the probability increases and becomes 1 at round 19. At round 19, all sensor nodes that have not yet become cluster head are selected as the cluster heads. After this round, the probability is once again 0.05.

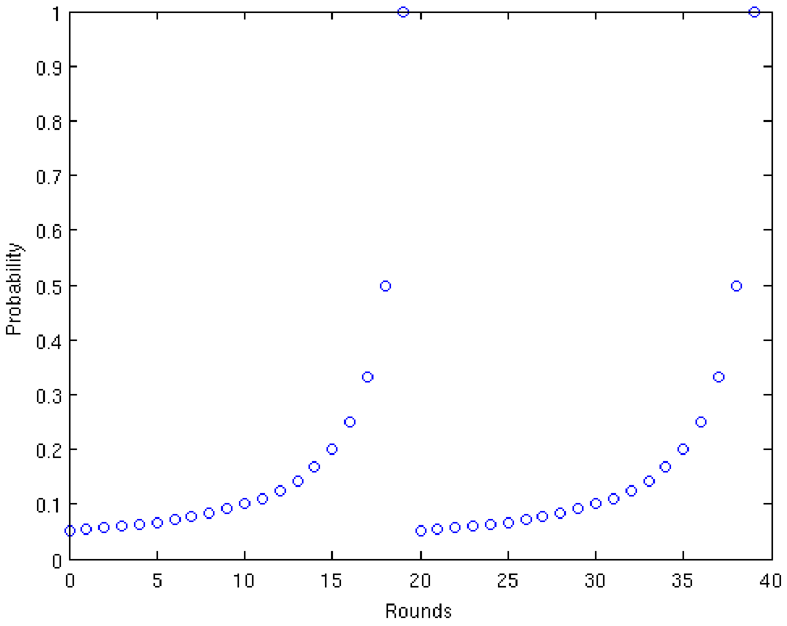


Figure 4The value of probability threshold, T(n) based on LEACH cluster head selection algorithm when the percentage of cluster head, P=0.05

4. Protocol Analysis and Discussion

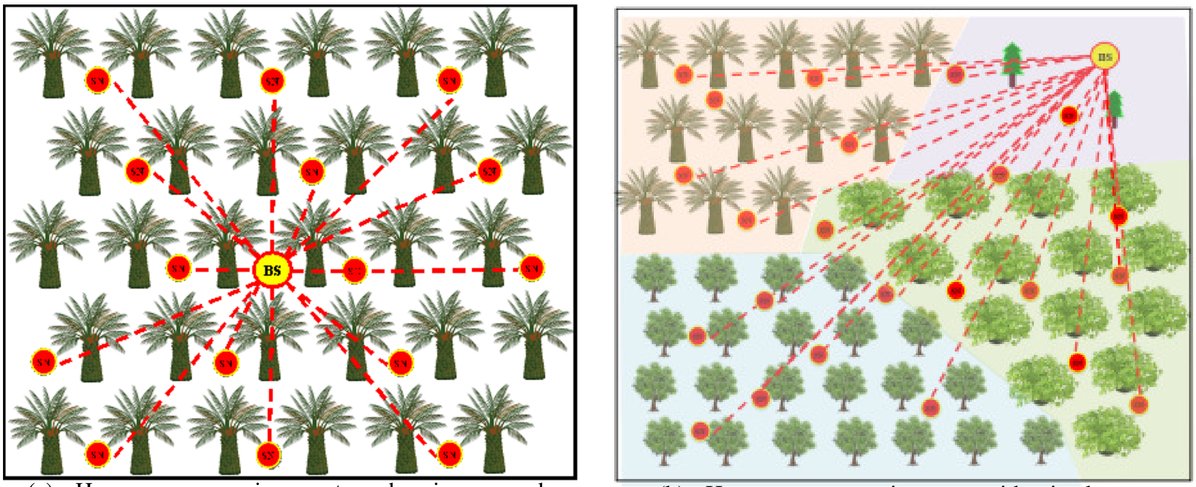
The design of LEACH protocol is, for the most part, efficient and valid and, has been used in various research works. However, some concerns are raised as to the validity of the evaluation techniques taken in Heinzelman et al. [14]. This section presents the analysis of LEACH protocol specifically targeted for agriculture applications.

4.1. Radio Propagation Model

The radio propagation model used in LEACH assumes no obstacles in the propagation path and the received signal power is only affected by the distance between the transmitter and receiver. All the simulations are based on the FSL and PE propagation models with no consideration of losses due to the existence of obstacles such as trees in the radio propagation channel. If the distance between the transmitter and receiver is less than $d_{crossover}$, the attenuation is based on FSL model, and if the distance is greater than $d_{crossover}$, the PE model is used. The calculation for $d_{crossover}$ is presented in Equation 2.As described in previous studies [17], FSL is suitable for predicting the signal strength at the receiving node when there is a clear Line of Sight (LOS) path between the transmitting and receiving nodes [22,23]. The received signal power decreases with increasing distance between the transceivers. On the other hand, the PE model assumes that the received signal strength is the sum of the direct LOS propagation path and one ground reflected component between the source and the destination nodes. However, for obstructed paths such as in the agriculture application, where there are trees it is not adequate to simply use FSL and PE propagation models to predict the signal strength. In the previous study reported in [17,18], it is observed that propagation model used significantly affect the network performance.

When there is vegetation in the radio waves propagation path, the signal undergoes scattering, absorption and blockage. The congruent effect is additional attenuation of the signal when compared to losses predicted using FSL or PE models. Based on the studies reported by Ndzi et al. [18], vegetation attenuation models can be used to model the behavior of radio waves in agriculture application such as in mango and oil palm plantation. Findings show that in the 2.4 GHz band, FITU-R gives good estimates for low density vegetative environments. For higher vegetation density environment in a mango plantation, the Non-Zero Gradient (NZG) model provides consistently low Root Mean Square Error (RMSE) values. Although the NZG model provides good estimates, it requires more input parameters and is computationally intensive. Thus, the second best fit model, COST235, can be used to represent this type of environment. In oil palm plantation, results show that the COST235 model provides consistently low RMSE values in very high density environments, where there are trees in the line-of-sight path. For measurements between two rows of palm trees, the path loss can be predicted using FSL model.

The applications of WSNs technology in agriculture includes monitoring various type of commercially cultivated crops in plantations such as oil palm and rubbers, and also monitoring high value crops such as medicinal plants and fruits cultivated in artificial conditions. Thus, the environmental sensors are deployed maybe homogeneously in a mono-crop plantation or heterogeneously in mixed crops farm area with multiple types of vegetation as shown in Figure 5. A realistic radio propagation model, especially model that can represent the target environment is important to accurately estimate the performance of algorithms and protocols. Inaccurate radio propagation models used in simulation to estimate the performance of WSNs protocols will result in inaccurate performance metrics such as network connectivity, energy consumptions and network lifetime.



(a) Homogeneous environments such as in managed plantation

(b) Heterogeneous environment with mixed crops

Figure 5 Examples of WSNs node placement in agriculture monitoring

4.2. Radio Energy Model and Transmit Power Control

The aim of the transceiver modeling and simulation is to allow accurate evaluation of different parameters that influence energy consumption in WSNs nodes. An accurate radio energy model would enable precise performance measurements and more energy efficient protocols to be designed and evaluated. In power computation performed to determine the power consumed from the energy source, LEACH protocols models the energy loss based on the distance. The algorithm assumes that, as the distance increases, energy consumption increases exponentially and there are no maximum limits as shown in Figure 6.

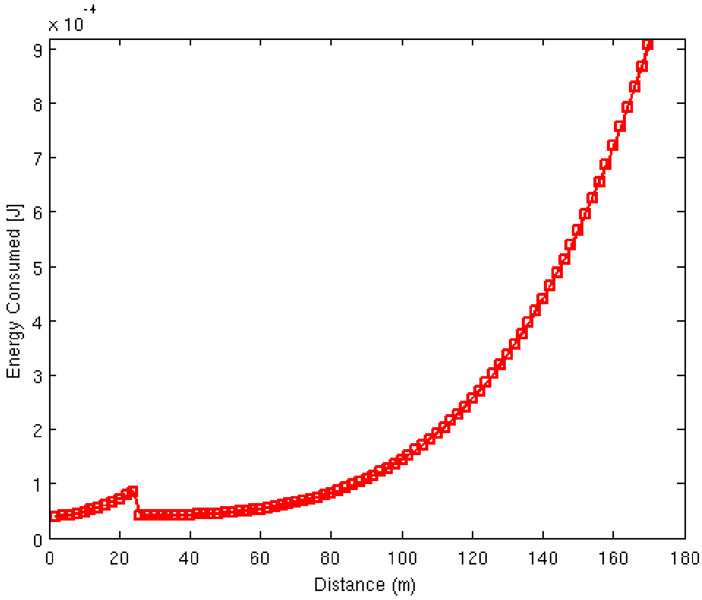


Figure 6 Energy Consumption during transmission based on LEACH Energy Model

Thus, to transmit an l-bit message at distance d, the energy that the radio expends can be calculated using equation (3).

$$E_{Tx} = \begin{cases} lE_{elec} + l\epsilon_{fs}d^2 & d < d_{crossover} \\ lE_{elec} + l\epsilon_{PE}d^4 & d \geq d_{crossover} \end{cases} \tag{3}$$

where the parameters ϵ_{fs} is based on FSL equations meanwhile, ϵ_{PE} is calculated based on PE model.To transmit over a short distance (below cross-over distance), the energy consumption is proportional to the square distance between the transceivers, d^2, and based on FSL model. On the other hand, the energy consumed in a data transmission across longer distances (such as from a cluster head to the base station) is proportional to d^4 and calculated based on PE model. Based on Equation 2, the crossover distance for the experiments described in this research (assuming no system loss (L=1), transmitting and receiving antenna height of 0.5m and 2.4 GHz radio frequency) is 21.5m. The power level needed to transmit for a successful reception of data packets is adjusted based on the distance as given by equation (4).

$$P_{Tx} = \begin{cases} \alpha_1 P_{sensitivity} d^2 & d < d_{crossover} \\ \alpha_2 P_{sensitivity} d^4 & d \geq d_{crossover} \end{cases} \tag{4}$$

Where $\alpha_1 = \frac{(4\pi)^2}{G_{Tx}G_{Rx}\lambda^2}$, $\alpha_2 = \frac{1}{G_{Tx}G_{Rx}h_{Tx}h_{Rx}}$ and $P_{sensitivity}$is the receiver sensitivity level.

It is worth noting that in the conventional LEACH model, energy consumption increases exponentially with distance and there are no maximum limits. In reality, the transmit power level of a sensor node can only be adjusted to discrete values that may result in one transmit power level for multiple distances. Therefore, the resulting energy consumption for two links of different distances can be equivalent. As discussed in previous study in [24], power consumption in WSN nodes can be divided into two parts: energy consumed by the on-board electronics (sensors, display, CPU, etc) and energy consumed by the communication unit. Research has identified the radio communication unit (in all its modes: transmitting, receiving, idle, listening, and sleeping) as the main energy consumer [25-27]. The energy required for data transmission is the orders of magnitude higher than the power spent on data processing. According to Pottie and Kaiser [25], the amount of energy spent to transmit 1 kb of data to a node located 100 meters away is equivalent to the energy expended executing 3 million instructions on a general purpose 100 MIPS/W processor. Energy consumption in most devices is non-linear, as part is dissipated as heat, thermal noise and a fraction is channeled to accomplish the task [27,28]. The former two energy consumptions are difficult to standardize and they are assumed to be constant.

The total energy, E_{SN_i} consumed by i^{th} sensor node in Joules is:

$$E_{SN_i} = \sum_{state} E_{state} = \sum_{state}(P_{state} \times t_{state}) \tag{5}$$

where the index state refers to the operational state of the mote: Sleep, Transmit (T_x), Receive(R_x) or Idle. P_{state} is the power consumed (in Watt) in each state based on the transceiver specification which can be computed using:

$$P_{state} = V \times I_{state} \tag{6}$$

The term I_{state} denotes the current used by the node in Amperes (A) and V represents the supply voltage. $t_{state}$is the time spent in the corresponding state, which depends on the amount of information being transmitted or received. This can be calculated using:

$$t_{state} = \frac{L_{Packet}}{R_{Bit}} \tag{7}$$

whereL_{Packet} is the packet length in bits, and R_{Bit} is the data rate in bps. Table 1 shows the example of power consumption value and energy consumed by the nodes when transmitting 100 bytes packet based on Chipcon CC2420 radio transceiver [21]. Since the radio communication unit is the main consumer of the battery power, the energy consumptions of the device's circuitry (sensors, CPU and display) can reasonably be assumed to be a non-variant constant.

Table 1Power consumption in each state based on Chipcon CC2420 radio transceiver. Example of energy consumption, E_{Tx}calculated by setting V=1.8V and L=100 bytes

State	P_{level}(dBm)	I_{level}(mA)	P_{Tx}(mW)	E_{Tx}(mJ)
Transmit	-25	8.53	15.3	0.049
	-15	9.64	17.35	0.056
	-10	10.68	19.22	0.062
	-7	11.86	21.35	0.068
	-5	13.11	23.60	0.075
	-3	14.09	25.36	0.081
	-1	15.07	27.13	0.087
	0	16.22	29.20	0.093
Receive	-	19.7	35.46	0.113
Sleep	-	0.08	0.144	-

4.3. Optimum Number of Cluster

Cluster heads normally spend more energy than cluster member. Therefore, LEACH proposes to select cluster heads periodically in which each sensor node takes its turn to be a cluster head. If the probability to become, a cluster head is set high, more nodes will become cluster heads and the rate of energy consumption also becomes high. However, if the probability is too low, the size of each cluster becomes large and the average distance between members and their respective cluster heads increases, which then increases energy consumption. Therefore, there is a trade-off between the number of clusters and the energy consumption in LEACH. Figure 2 shows that the optimum number of clusters is between 3 and 5. The network lifetime is shorter when the number of clusters is below 3. When the number of clusters is less than 3, the size of each cluster is large, and consequently, the non-cluster head nodes expend more energy to communicate with the cluster head. LEACH shows that the maximum network lifetime is achieved when the number of cluster is 5.On the other hand, when the number of clusters is larger than 6, the number of members in each cluster is small thus, increasing the frequency of packets transmission from the nodes to the cluster head. As a consequence, the sensor nodes consume more energy to transmit more data which reduces the sleeping time and the cluster heads consume more energy to receive more data. Therefore, the network lifetime is reduced significantly as the number of clusters increases.

4.4. Cluster number variability

The cluster head selection algorithm proposed by LEACH was created to ensure that the expected number of clusters per round is k. The parameter k was pre-determined to ensure minimum energy dissipation in the network as shown in Figure 2. However, the number of clusters generated by LEACH in each round varies in a large range around the optimal value, which shortens the lifetime of the network.

Considering a network of 100 nodes and assuming that the desired number of cluster heads is 5; the desired percentage of cluster head, P, is set to 0.05. Figure 7 shows the distribution of the number of cluster heads. It can be seen that the number of cluster heads varies in a large range between 0 and 11. The percentage of rounds that the number of cluster heads is equal to the target value, 5, is approximately 18% which is less than 25%. In worst cases, there is no cluster head selected.

Figure 8 shows the simulated results when the desired percentage of cluster head, P is 0.05 in 50 nodes topology. Based on the probability, the expected number of clusters is 2. However, the figure illustrates that the number of cluster heads produced in every round ranged from 0 to 7. Number of clusters equal to 2 is achieved in 29% of the rounds. Thus, the number of clusters generated in LEACH does not converge to optimal value.

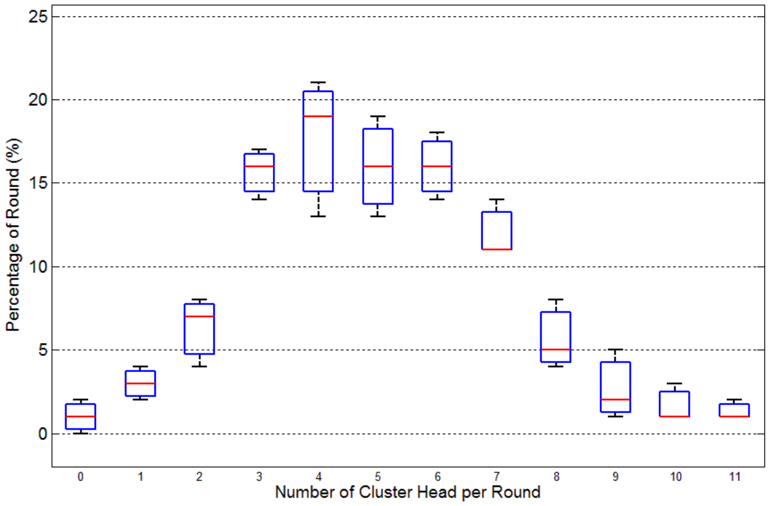


Figure 7 Cluster head variability Issue when p is 0.05 and N is 100

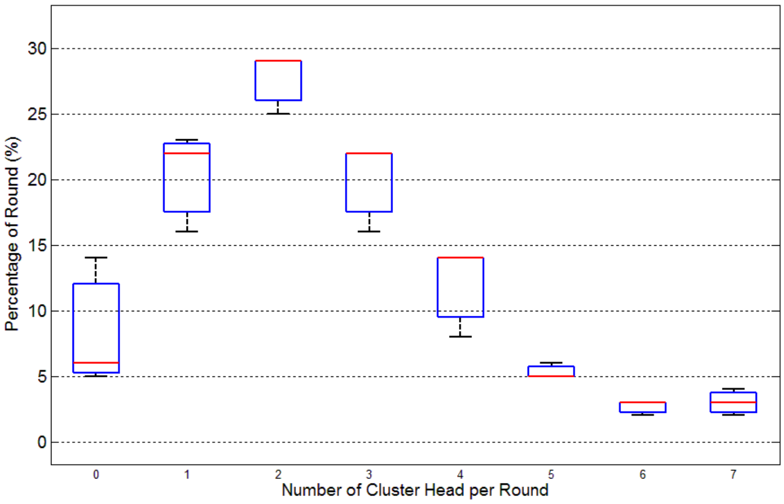
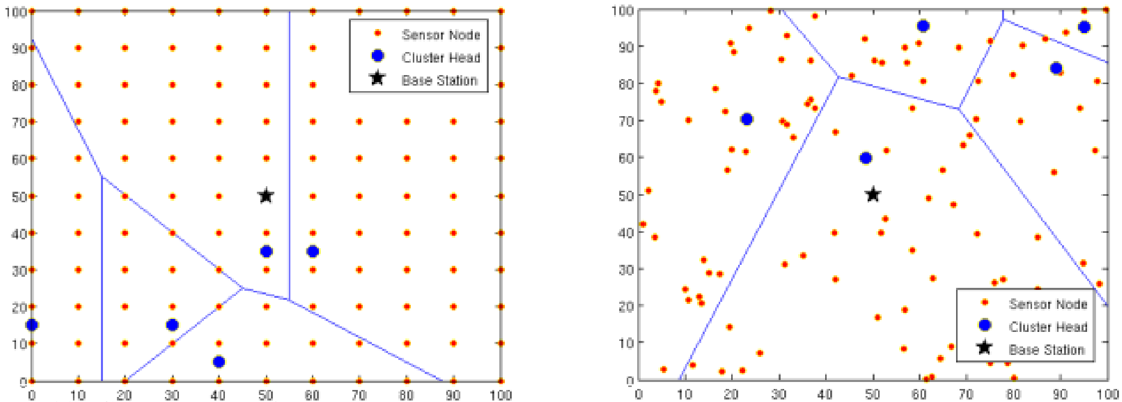


Figure 8 Cluster head variability Issue when p is 0.05 and N is 50

4.5. Cluster Distribution

Based on LEACH cluster head selection algorithm, it could be assumed that a selection of favorable cluster heads in earlier round may result in an unfavorable cluster heads selection in later rounds since LEACH tries to distribute energy consumption among all nodes. For example, consider the simulated grid and random topology as shown in Figure 9.



(a) Grid Topology with 100 nodes

(b) Random Topology with 100 nodes

Figure 9 Cluster head distribution issue where cluster heads are located in proximity to each other and near the edge. This leads to high energy consumption to transmit over long distance.

It can be observed that LEACH produces an uneven distribution of cluster heads throughout the sensor field, where in worst case scenario, may result in cluster heads become concentrated in one part of the network. The reason behind this is because LEACH cluster heads selection mechanism does not guarantee that the location of cluster heads are optimized. All cluster-heads can be located near the edges of the network or adjacent nodes can become cluster heads. Thus, there could be a number of sensor nodes which are located far from the cluster heads, and as a result, these nodes will deplete their energy more rapidly as they need higher power to transmit successfully to their cluster heads. Furthermore, as shown in Figure 9, LEACH protocol does not also guarantee that nodes are evenly distributed amongst the cluster head nodes [14]. Thus, the number of member nodes in each cluster is highly variable in LEACH.

4.6. LEACH MAC Layer Protocol

LEACH MAC layer scheme is based on TDMA scheduling where each node in a cluster is allocated one time slot per frame as shown inFigure 10. Each time slot is constant, thus, the time for a frame of data transfer depends on the number of nodes in the cluster [14]. As discussed in Section4.5, the number of members in each cluster is highly variable with some cluster heads coordinating a very large number of nodes whereas others may have very small numbers. Thus, the amount of data each node can send to the cluster head varies depending on the number of nodes in the cluster [14].

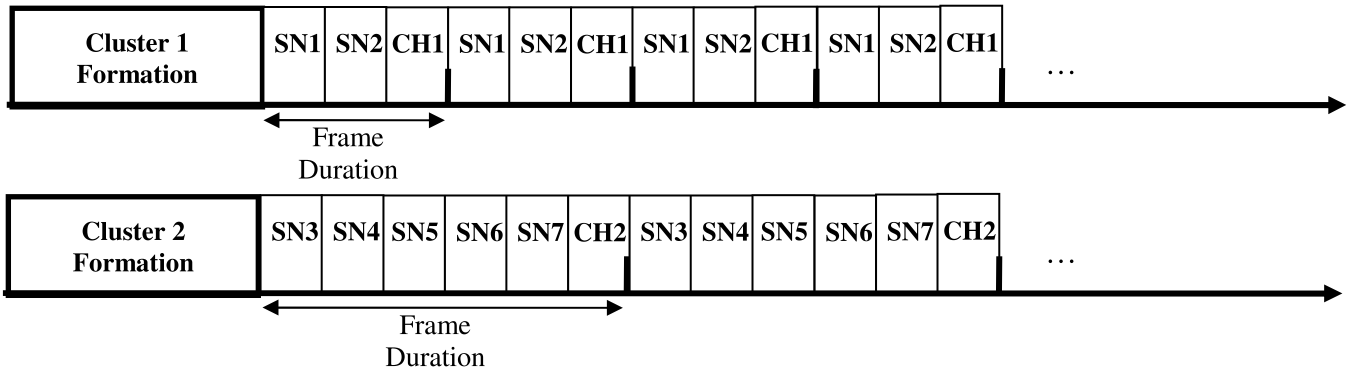


Figure 10 Slot allocation for each node in the cluster based on LEACH MAC layer protocol.

Figure 11 shows an example of LEACH network topology with uneven number of members in two clusters. There are 5 members in cluster 1 and only 2 members in cluster 2. Figure 10shows the LEACH MAC layer algorithm in this case where there are 4 frames in cluster 1 and only 2 frames in cluster 2. Nodes in cluster 1 transmit four times per round whilst members of cluster 2 only transmit twice per round. The nodes with high frequency of data transmission will, therefore, deplete their energy faster than the nodes with lower data transmission rate.

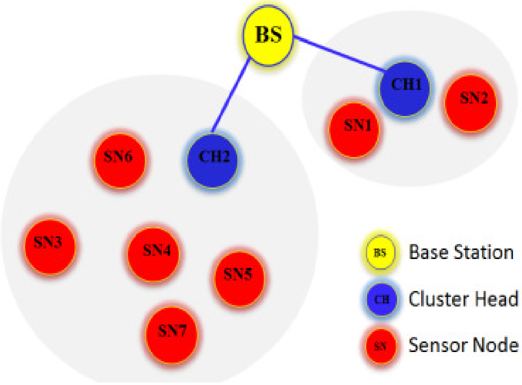


Figure 11 Example of network clustering with uneven number of nodes in each cluster

Additionally, cluster heads consume a large amount of energy since it needs to be awake at all times, even when it is not receiving packets from the member.

5. Conclusions

This paper has presented the modeling and evaluation of LEACH protocols in agriculture. LEACH is a cluster based routing protocol which is widely used in WSNs. The protocol achieves energy efficiency through clustering technique with TDMA based MAC layer algorithms and data aggregation method. However, analysis and simulation studies performed on LEACH protocol shows that it uses very simple and unrealistic models, such as simple radio propagation model that do not consider obstacles such as trees in radio propagation channel, simple radio energy models and unlimited transmit power level for protocols evaluation.

A realistic radio propagation model, especially model that can represent the target environment is important to accurately estimate the performance of algorithms and protocols. Inaccurate radio propagation models used in simulation to estimate the performance of WSNs protocols will result in inaccurate performance metrics such as network connectivity, energy consumptions and network lifetime. The radio propagation model used must depend on the target applications. To simulate protocols in agriculture application, vegetation attenuation models can be used to model the behavior of radio waves.

In the conventional LEACH model, energy consumption increases exponentially with distance and there are no maximum limits. In reality, the transmit power level of a sensor node can only be adjusted to discrete values that may result in one transmit power level for multiple distances. Therefore, the resulting energy consumption for two links of different distances can be equivalent. In order to realistically simulate protocol, radio energy model based on hardware specifications such as CC2420 can be used to estimate the power consumptions during transmission, reception, idle listening and sleeping. The radio energy model specifies the maximum transmit power level and hence limit the sensor node range based on the propagation environment.

Even though LEACH protocols stated that the optimum number of cluster to prolong network lifetime is between 3 and 5 in 100 nodes network, the cluster head selection algorithm shows that the number of cluster heads in each round varies between 0 and 11. In worst case scenarios, there is no cluster head elected in the round. This indicates that the number of clusters generated in LEACH does not converge to an optimal value which shortens the lifespan of the network. Additionally, in agriculture various types of crops exist in the same plantation area. Each crop needs different types of parameters to be observed and control at different time intervals. Some of the crops need to be monitored at minute(s) intervals whilst data from other type of crops are needed only twice a day. This leads to the necessity for a large number of clusters that are specific to different systems for better farm management.

In some cases, LEACH cluster head selection algorithm produced uneven distribution of clusters within the network area. All clusterheads can be located near the edges of the network or adjacent nodes can become cluster heads. In addition, the node scheduling pattern in the LEACH MAC layer algorithm is not optimized resulting in nodes in different cluster having different data transmission rates to the cluster head. Therefore, the nodes that have to transmit data to cluster heads at shorter time intervals deplete their energy faster than the nodes with lower data transmission rate.

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