LEACH With Contention Window Adjustment for Optimum Performance in Energy Distribution and Efficient Utilization.

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ABSTRACT

Energy saving is an essential consideration when designing efficient wireless sensor networks. The overall energy consumption of the sensor nodes (SNs) in a network determines the lifespan of that network. This paper addressed issue of nodes competing for channel resource that leads to energy wasted through idle listening and overhearing. Contention window adjustment was utilized with Low Energy Adaptive Clustering Hierarchy (LEACH) to combat this challenge for energy efficient utilization and distribution. This technique is termed Contention Window Adjustment LEACH (*CW-*LEACH). This clustering technique extends a network's lifetime by minimizing energy wasted on idle listening and creating efficient energy distribution within the network. The simulation for this technique was done on MATLAB. The total round of successful transmission before the network collapse was 2929; the number of transmissions was 2400 and the average energy consumed for the full life cycle for 1000 nodes observed under simulation was 0.25J at peak of operation. This technique has a future in implementation on 5G with large number of connected devices.

1. INTRODUCTION

Wireless sensor network (WSN) is an interconnection of devices that house sensors that are capable of recognizing and reacting to physical or environmental influences such as pressure, temperature, light, sound, heat, etc. The outputs of these sensors are usually electrical signals that are transmitted wirelessly for further processing and use. These networks are widely distributed and self-organizing [1, 2]. The application of WSN technology is endless in areas such as health, transportation, IoT, environmental monitoring, security, etc. Wireless sensors are usually small, but they are equipped with sensors and computer circuitry, a radio transceiver, and a power element. [3]. The primary power source for WSN is a battery with finite life, so in order to use the nodes efficiently; the protocol utilized should ensure efficient use and distribution of power by the nodes in the network.

2. RELATED WORKS

Improvements to LEACH using radio frequency (RF) by incorporating active, standby, and sleep communication modes into the network were performed by [4]. Active mode was only used to collect data. Ready mode was used to collect and send data from the node to the sink, while sleep mode help nodes reduce energy consumption and balance the energy load on the CH. The term RFIDLEACH was coined as the name of the proposed method. They faced the challenge of clock synchronization, which is one of the hallmarks of RFID. This issue was addressed using the Contention Avoidance Algorithm (RTS/CTS). This technique describes a scenario in which a CH node sends a solicitation packet: Request to Send (RTS) containing a response feed to all cluster members (CMs). The CMs adjust their clock to the feed and responds with Clear to Send (CTS) for synchronization. The RFID LEACH scheme was simulated on NS2 and the graph results showed better performance than the LEACH and RFID protocols in terms of throughput, efficient energy use, reduced end-to-end latency, and network overhead.

A similar work on LEACH variant introduced two new techniques into the novel protocol. CH alternative scheme and dual transmission level to support efficient energy use [5]. MODLEACH as the protocol was termed does not take into account the effect of parameter *p*, which defines the probability of becoming CH. Instead, they ran a mathematical analysis and chose a nominal value for *p*. They also varied the estimated value of *p* and measured the effect by simulation in MATLAB. MODLEACH outperformed LEACH in terms of network life and packet switching with base stations.

Another work that hinted at network efficiency through the introduction of the Vice Cluster Head (VCH), this algorithm allows the nodes in the cluster to be selected as the VCH in case the CH goes down. When this happens, the data from the cluster nodes (CNs) would still get to the base station in an efficient way, eliminating the need to select a new CH in the current transmission round [6]. KLEACH used the Kmedoids clustering algorithm for uniform clustering and selected the CH using the Euclidean distance and maximum residual energy (MRE). This modification in CH selection reduced energy consumption by 33% compared to LEACH. This technique has advantages such as efficient transmission of data to the sink, improved network life, and reduced energy consumption [7].

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Most of the changes to LEACH focus on how to select cluster heads, inter-cluster head communication, and so on. IBLEACH, an improved work has directed efforts towards intra-cluster communication in hierarchical clustering networks. The legacy LEACH has two levels of operation. Setup and steady state. This research introduced a new state between setup and steady state called the pre-steady state to improve the performance of LEACH [8]. The main purpose of this new state was to calculate the workload of the CNs, select a CH that can aggregate the data collected from the CMs, send it to the sink in one frame and then handle the aggregated process in all frames of that round [9]. This allows the load overhead of the cluster to be distributed across the CMs. This technique has improved network life and balanced energy consumption.

EEE LEACH Energy Efficient Extended LEACH is an energy-efficient protocol that increases energy utilization by forming multi-level clusters and shortening wireless communication distances. In addition to two-layer clustering, this multi-level clustering protocol involves the formation of similar layers between nodes and sinks. [10] Cluster formation and CH selection are done in the first tier. The CMs then send the recorded data to their CHs. CH uses a backup mechanism to aggregate the data received from the cluster members. In the next shift, the master cluster head (MCH) is selected. CHs find the closest MCH by calculating the distance between them and send their aggregated data to each MCH. [11]. Similarly, the MCH receives data from the nearest CH, aggregates all the received data, converts it to a compressed format and transfers it to the sink.

DDLEACH (LEACH with Distributed Diffusion) was developed as an improved LEACH protocol. This technique uses multi-hop routing of data from the sensor node to the sink. Nodes and CHs act as relay nodes for forwarding packets from other nodes to the sink. In the DDLEACH protocol, data is accumulated at several levels [12]. First, the data is aggregated at the CH level. CH collects data from member nodes. All median CHs also perform data aggregation at various levels while the data is being transferred to the sink. DDLEACH reduces the energy consumed by multi-hop routing communications.

LEACH-A (Advanced Low Energy Adaptive Clustering Hierarchy); in the novel LEACH protocol, CH is responsible for sending data directly to sink which expends high amount of energy than other member nodes in the network [13]. In advanced LEACH, a technique called mobile agent is used to process data. This LEACH variant protocol is defined as a heterogeneous energy inclined protocol developed for the purpose of energy conservation, efficient data transfer, reducing the probability of node failure and for improving the time interval before demise of the first node. Hence, both the energy conservation and data transfer reliability is improved in LEACH-A. This scheme also use synchronized clock, through which each sensor node gets the beginning of each transmission round. [14].

There is an improved LEACH protocol referred to as MG-LEACH. This modified protocol divides the deployed nodes into sub-groups (G1….Gk) based on locations of the nodes; where k is a real number. The numbers of groups in this modification are mainly dependent on node density. The groups' formation is coordinated by the sink at the time of deployment and after every "*r*" rounds. [15]. This is an extra step employed in their algorithm before setup phase and steady state phase called Set building phase. MG-LEACH has three steps. The build phase is utilized during time of deployment after each "*r*" rounds per sink, and the remaining two are the same as those applied in LEACH such as the set up phase and steady state phase. This protocol offered better performance than LEACH in terms of energy conservation and efficient utilization [16].

In the same vein of attempt to further reduce the energy consumed in an IoT related environment, this variant of LEACH modified the protocol by initiating a strict threshold for CH selection and retaining the CH position to serve for multiple rounds provided the node has enough residual energy to match up with the task [17]. The proposed protocol also switches the power between the CNs. This protocol focused on the growing demand for IoT devices which the novel LEACH is unable to cater for in terms of energy because of the frequent rotational duties of the CH. This rotation consumes energy. I-LEACH (short for IoT LEACH) maintains a node that has serve as CH in the previous round if the energy threshold value still meets the set criteria [18]. This way the energy wasted during routing information to the new CH in each round can be minimized. The extra energy consumed for the formation of new cluster due to new CH selection can also be minimized. I-LEACH protocol outperforms LEACH by 67% increase in throughput and extending the lifespan of the network through successful 1750 rounds of communication.

3. PROPOSED WORK

Contention Window LEACH (*CW*-LEACH) clustering protocol divides the deployed nodes into multiple clusters which become sub groups of the main area of coverage. These divided nodes collate data and forward to selected CHs that will in turn send to the upper parent nodes in the upper hierarchy and so on till the packet gets to the sink. Inter CHs communication is handled by border nodes which act as relay. The intra cluster communication occurs between nodes in a cluster and CHs. Cluster members compete for channel access to forward their individual packets to the CHs. Optimum contention window adjustment is deployed to manage channel resource to ensure efficient utilization through assigning of slots to active nodes only. The contention window varies proportionally with the number of active nodes. The different levels of hierarchy in *CW*-LEACH is shown in figure 1.0

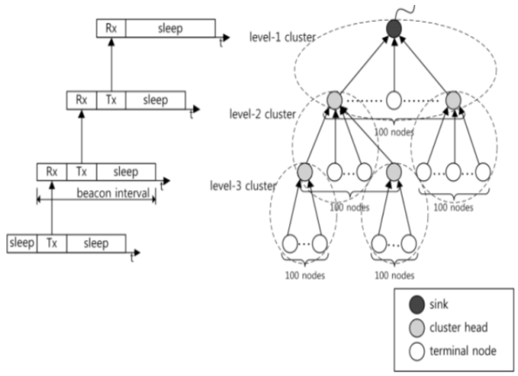

Figure 1. Level Cluster Network for CW-LEACH [19]

3.1 Set-Up Phase

The set-up phase is subdivided into little tasks. It is responsible for organizing SNs in the deployment area, cluster formation and electing CH. Then it initiates time division multiple access (TDMA) schedule for generating time instances for sink and SNs communication. Each SN in a cluster picks a number randomly between 0 and 1. The node that selects a random number that is less than the threshold for *n* becomes the CH for that round. The threshold value T(*n*) of node can be calculated using the expression:

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

where; *P* = the desired percentage of the CH node.

r = the number indication the current round of communication.

G = set of nodes that have not been selected as CH node in the previous *1/P* rounds.

When CH has been selected successfully, the CH broadcasts a message to other nodes. Based on the received signal strength of the advertisement, other nodes decide to which cluster it will join for this round and send a membership message to its CH. After the exchange, the cluster formation is completed. When the number of cluster is too few, energy consumption of cluster heads will increase and cause early death of those cluster heads; when the number of cluster heads is enormous, it will cause transmission data overload of the sink node, which will affect the entire network energy consumption, thus shortening the life cycle of the WSN. The optimum number of clusters formed based on the number of nodes and coverage area is given by:

$$K = \sqrt{\frac{N}{2\pi}} \sqrt{\frac{\in_{fs}}{\in_{mp} - d^4{}_{to}BS}} M \tag{2}$$

where N is the number of SNs and M is the area of the network.

$\in_{fs}$ is the amplifier energy of the free space radio model and $\in_{mp}$ is the amplifier energy of the multi-path radio model.

$d_{to}BS$ Indicate the average distance from CHs to the sink.

The last task executed in the set up phase is calculating the number of neighbors each node has through calculation of the neighborhood radius. This information helps each node effectively utilize the *CW* adjustment and optimum *CW* selection for energy distribution and channel utilization. The expression for calculating the neighborhood radius is given by:

$$R_{ch} = \sqrt{\frac{M \times M}{\pi \times K}} \tag{3}$$

where R_{ch} is the neighborhood radius.

$M * M$ is the area of nodes deployed and

K is the number of clusters.

3.2 Steady State Phase

The steady-state phase starts with computing the mobility of the sink node. The sink compiles data from the SNs of each cluster. The sink waits for the definite amount of time specified by (TDMA) scheduling. Once the waiting time is over then TDMA enables time-out session which redirects the sink to move to the next cluster. After completion of data compilation from all clusters the sink returns to ready mode. That is, waiting for CHs to aggregate and forward data of their cluster members.

3.3 Energy Model

The transceiver consumes more of the dissipated energy in the sensors [11]. It is made up of transmitting and receiving circuits embedded in the nodes and the sink. The transmitter circuit uses more energy compared to the receiver circuit. The different power dissipated by the receiver and transmitter is calculated by the following formulas:

3.3.1 *Transmitting Circuit Equations*:

$$E_{TX\_}(k, d) = E_{TX\_}\{(E_{elec} \times k) + (\in_{mp} \times k \times d)\} \tag{4}$$

$$E_{TX\_}(k, d) = E_{TX\_}\{(E_{elec} \times k) + (\in_{fs} \times k \times d)\} \tag{5}$$

$$E_{TX\_}(k, d) = \in_{fs} \times d^2 \times k \; if \; d < d0 \tag{6}$$

$$\in_{fs} \times d^4 \times k \; if \; d \geq d0$$

$$d_O = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \quad (7)$$

3.3.2 Receiving Circuit Equation:

$$E_{RX\_}(k) = E_{RX\_}(E_{elec} + EDA) \times k \quad (8)$$

where,

E_{elec} = denotes quantity of Energy consumption per bit in the transmitter or receiver circuitry.

ϵ_{mp} = quantity of energy consumption for multipath fading.

ϵ_{fs} = quantity of energy consumption for free space.

EDA = Data aggregation energy.

where k is the message size and d is the distance.

3.3.3 Average Energy

The Average energy of the network is given by:

$$E_{avg} = \frac{\sum_{i=1}^{N} E_i}{N} \quad (9)$$

where E_i is residual energy of i^{th} node and

N denotes the number of SNs in the network.

4. SIMULATION AND RESULTS

A network scenario of 1000 nodes and area of 100m x100m was considered, the position of the sink is at 50m by 200m. The coverage area has 10 clusters which results to 100 nodes per cluster and 10 cluster heads. We assumed equal distribution of nodes in the clusters and area. Three layers of child parent relationship for effective data forwarding. For the purpose of simulation a constant packet of 4000 bits was used as data to be transferred between nodes. The total energy consumed is the aggregate of the energy utilized in the individual clusters.

CWmin = 2

CWmax = 1023

$CWopt \approx 8.5N - 5$ (10)

The minimum contention window size is 2 and the maximum is 1023 according to 802.11 standard and 20μs per slot. The contention window size starts from the minimum but exceed the optimum (*CWopt*) by one step after calculating the number of active neighbors using equation 10. This optimum selection increases the chance of successful transmission and reduces the number of packets dropped when the nodes are unable to send.

During the set up phase information on cluster size, members and number of neighbors are exchanged in the network while the steady state phase, all interaction between nodes in a cluster and their CHs, the CHs and the sink are handled. The nodes that have data in their buffer to send pick the limit of the minimum required contention widow size to send their packets then double their slots each time the channel is busy but won't exceed the calculated value for *CWopt* by more than one step and reset to minimum when transmission is completed. This is replicated over other clusters.

Table 1.0 shows the other parameters that were utilized for the purpose of simulation and achieving the objective of achieving successful transmissions between the nodes in the network and minimizing energy loss through idle listening and overhearing.

TABLE 1. Simulation Parameters

S/N	Parameters	Value
1	M×M	100m × 100m
2	N	1000 nodes
3	Sink Node	50m × 200m
4	E_o	2 J
5	E_{elec}	50×10^-9 J/bit
6	E_{Tx}	50×10^-9 J/bit
7	E_{Rx}	40×10^-9 J/bit
8	EDA	5×10^-9 J/bit
9	E_{amp}	100×10^-12 J/bit/m²
10	P	0.05
11	Packet size	4000 bits
12	E_{fs}	20×10^-12 J/bit/m²
13	Number of rounds	100-4000

Figure 2.0 showed the random deployment of the nodes in a coverage area. The sink has receiving power to accommodate aggregated packets from all nodes serving as CHs. Another assumption made is that the nodes all have transmission capability to reach the sink from any location within the specified coverage area. Parent node of one cluster acts as child node in another cluster in the upper level.

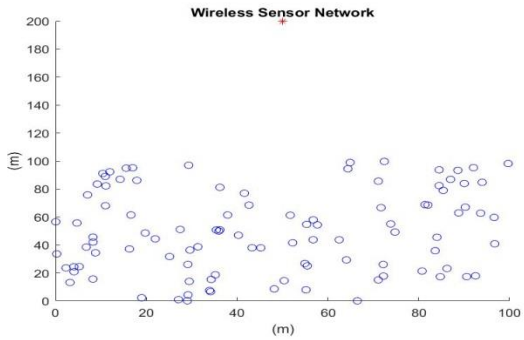

Figure 2. Random Deploment of Nodes.

Figure 3.0 showed the progress of rounds of communication and the number of operational nodes. As the number of rounds increased the number of operational nodes reduced because some nodes died out after serving as CH for number of rounds. LEACH without contention window adjustment in this area went a total of 2301 rounds before all the nodes in the network died out while *CW*-LEACH went on for 2929 rounds. The technique showed better performance when compared with the novel LEACH using the same parameters.

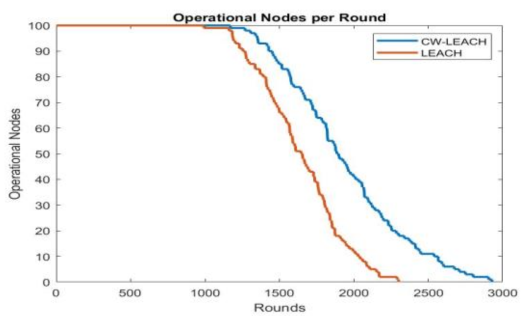

Figure 3. Operational Nodes per Round of Communication

Analysis of figure 4.0 showed the performance of the nodes according to the number of transmissions. This communication between nodes and CH then CH to sink was accounted for on the area. This covered the communication when the CH was rotated among the nodes in the cluster. When the number of transmissions increases the number of operational nodes reduces. Some nodes die out after going through multiple transmission and contention window adjustment aid the total number of nodes to service more transmissions. The results of figure 4.0 also depict transmissions performance of the nodes before all the nodes reach the end of life. The novel LEACH protocol without CW adjustment went a total of 1978 transmissions successfully while the number of successful transmissions with contention window adjustment for *CW*-LEACH stood at 2400 before total collapse of the network.

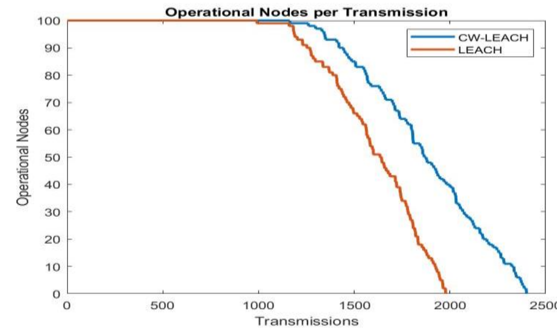

Figure 4. Operational Nodes per Transmission of Communication

Measurement of the energy consumed per transmission of the nodes, the period of peak and lowest point were taken during simulation. The energy performance tracks the highs and lows of the energy consumed during rounds of transmissions which traced the useful lifetime of operational nodes, the energy distribution and efficiency. The well balanced energy distribution ensured deployed nodes are efficiently utilized. In Fig 5.0 it was observed the energy consumed per transmission in a LEACH algorithm without contention window adjustment peaked at 0.33J and was least at 0.10J. For *CW*-LEACH the peak energy was 0.25J and the least was 0.09J as shown in figure 6.0.

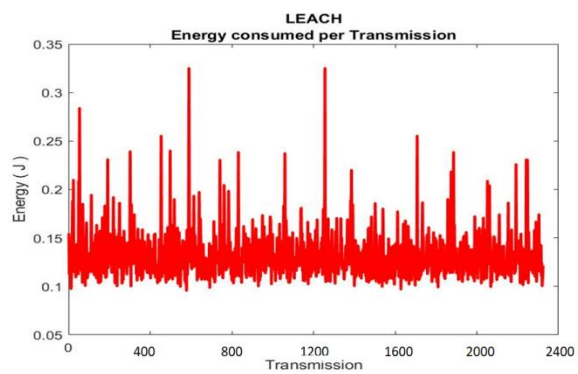

Figure 5. Energy Consumption per Transmission for LEACH

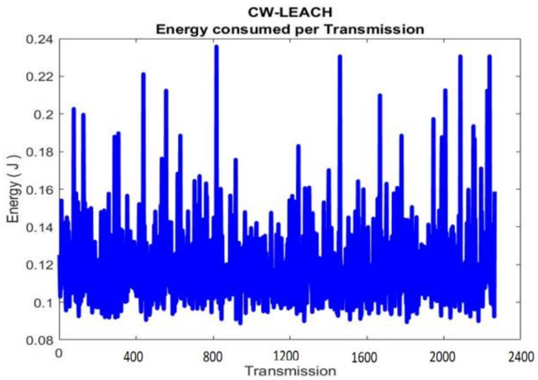

Figure 6. Energy Consumption per Transmission for CW-LEACH

5. CONCLUSION

Energy efficiency has been the target improvement of LEACH protocol from the onset but growth of demand for more information in the different fields of application has limited the solution provided by this novel protocol. *CW*-LEACH has potential to cater for growing demands for machine to machine interaction in WSN and the need to keep energy consumption at efficient level reducing energy wasted on idle listening and efficient channel utilization. It improved the total number of rounds the nodes could go before dying out, this number stood at 2929 as against 2301 rounds on the novel LEACH. This signifies an improvement of 16%. The total number of transmissions carried out by operating node increased from 1978 to 2400. Average energy consumed was less than 0.25J at the peak of operation.

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