NATIONAL UNIVERSITY OF SINGAPORE

Assignment Manual: Simulation Study of Variations to LEACH Protocol

EE5132 Wireless and Sensor Networks
EE5024 IoT Sensor Networks

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1. Objectives

- Understand and simulate the basic LEACH protocol
- Modify the LEACH protocol, analyse its performance and compare the performance of the modified scheme with that of the original LEACH protocol

2. Overview of LEACH

Low Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman, Chandrakasan, & Balakrishnan, 2000) is a TDMA-based MAC protocol which is integrated with clustering and a simple routing protocol in wireless sensor networks (WSNs). The goal of LEACH is to lower the energy consumption required to create and maintain clusters in order to improve the lifetime of a wireless sensor network.

Protocol explanation

LEACH is a hierarchical protocol in which most nodes transmit to cluster heads, and the cluster heads aggregate and compress the data and forward it to the base station. Each node uses a stochastic algorithm at each round to determine whether it will become a cluster head in this round. LEACH assumes that each node has a radio powerful enough to directly reach the base station or the nearest cluster head, but that using this radio at full power all the time would waste energy.

Nodes that have been cluster heads cannot become cluster heads again for $1/P$ rounds, where P is the desired percentage of cluster heads. Thereafter, each node has a P probability of becoming a cluster head in each round. At the end of each round, each node that is not a cluster head selects the closest cluster head and joins that cluster. The cluster head then creates a schedule for each node in its cluster to transmit its data.

All nodes that are not cluster heads only communicate with the cluster head in a TDMA fashion, according to the schedule created by the cluster head. They do so using the minimum energy needed to reach the cluster head, and only need to keep their radios on during their time slot.

LEACH also uses CDMA so that each cluster uses a different set of CDMA codes, to minimize interference between clusters.

Properties

Properties of this algorithm include:
- Cluster based
- Random cluster head selection each round with rotation
- Adaptive cluster membership
- Data aggregation at cluster head
- Cluster head communicate directly with sink or user
- Communication with cluster head using TDMA
- CDMA across clusters

3. Explanation of reference Matlab simulation program and graphical results

The reference Matlab program `LEACH.m` implements the original LEACH protocol (Heinzelman, Chandrakasan, & Balakrishnan, 2000).

This implementation of LEACH models a scenario with a deployment of 100 nodes spanning the area of 100m x 100m=10,000 m^2. Figure 1 shows the parameter settings for the protocol.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% PARAMETERS %%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Field Dimensions - x and y maximum (in meters)
xm=100;
ym=100;

%x and y Coordinates of the Sink
sink.x=0.5*xm;
sink.y=0.5*ym;

%Number of Nodes in the field
n=100;

%Optimal Election Probability of a node
%to become cluster head
p=0.1;

%Energy Model (all values in Joules)
%Initial Energy
Eo=0.5;

%Eelec=Etx=Erx
ETX=50*0.000000001;
ERX=50*0.000000001;

%Transmit Amplifier types (Epsilon_{amp})
Emp=100*0.000000000001;

% Data Aggregation Energy
EDA=50*0.000000001;
```

Figure 1. LEACH Parameters

The sink can be regarded as a base station (BS).

After random node deployment, the respective co-ordinates of the nodes remain static for the rest of the simulation.

Simulations are run for *rmax* rounds. In each round, cluster heads are chosen according to the LEACH protocol. Figures 2 and 3 depict the implementation of the Set-Up phase. In Figure 2, each node decides whether it wants to become a cluster head or not, while in Figure 3, non-cluster head nodes decide the cluster they want to be in. The evaluation of the energy dissipated is also shown.

The size of each packet is 2000 bits.

```
%Election of Cluster Heads
  if(temp_rand<=(p/(1-p*mod(r,round(1/p)))))
       countCHs=countCHs+1;
       packets_TO_BS=packets_TO_BS+1;
       PACKETS_TO_BS(r)=packets_TO_BS;

       S(i).type='C';
       S(i).G=round(1/p)-1;
       C(cluster).xd=S(i).xd;
       C(cluster).yd=S(i).yd;
       plot(S(i).xd,S(i).yd,'k*');

       distance=sqrt( (S(i).xd-(S(n+1).xd))^2 + (S(i).yd-(S(n+1).yd))^2 );
       C(cluster).distance=distance;
       C(cluster).id=i;
       cluster=cluster+1;

       % Calculation of Energy dissipated
       distance;
       S(i).E = S(i).E - ( ETX*2000 + Emp*2000*(distance*distance) );
  end
```

Figure 2. Cluster Head Election

```
% Election of Associated Cluster Head for Normal Nodes
for i=1:1:n
   if ( S(i).type=='N' && S(i).E>0 )
     if(cluster-1>=1)
       min_dis=sqrt( (S(i).xd-S(n+1).xd)^2 + (S(i).yd-S(n+1).yd)^2 );
       min_dis_cluster=1;
       for c=1:1:cluster-1
           temp=min(min_dis,sqrt( (S(i).xd-C(c).xd)^2 + (S(i).yd-C(c).yd)^2 ) );
           if ( temp<min_dis )
               min_dis=temp;
               min_dis_cluster=c;
           end
       end

       % Energy dissipated to associated Cluster Head
       min_dis;
       S(i).E = S(i).E - (ETX*(2000)+Emp*2000*(min_dis*min_dis));

       % Energy dissipated at associated Cluster Head
       if(min_dis>0)
           S(C(min_dis_cluster).id).E = S(C(min_dis_cluster).id).E - (ERX+EDA)*2000;
           PACKETS_TO_CH(r)=n-dead-cluster+1;
       end
       S(i).min_dis=min_dis;
       S(i).min_dis_cluster=min_dis_cluster;
     end
   end
end
```

Figure 3. Cluster Selection

The implementation assumes ideal channel conditions and perfect data fusion. Therefore, data fusion at the cluster head results in one aggregated data packet which is always received by the sink node. Figure 4 depicts the performance of the LEACH protocol. Figure 4a shows the number of data packets received by the sink node throughout the simulation time, whereas Figure 4b shows the energy expended to send data packets to the sink node.

Figure 4c shows the number of nodes alive over time. Figure 4d represents the number of nodes alive per amount of data sent to the sink node.

Figures 4 a-b and 4 c-d can be found in (Heinzelman, Chandrakasan, & Balakrishnan, 2002) as Figures 7 and 8, respectively.

Figures 4 e and f show the effect on total system energy dissipation if certain parameters are varied. Figure 4e depicts how the normalized total system energy dissipation changes by varying the percent of nodes that are cluster heads, whereas Figure 4f shows the effect of varying network size on total system energy dissipation. These two figures can be found in (Heinzelman, Chandrakasan, & Balakrishnan, 2000) as Figures 8 and 9, respectively.

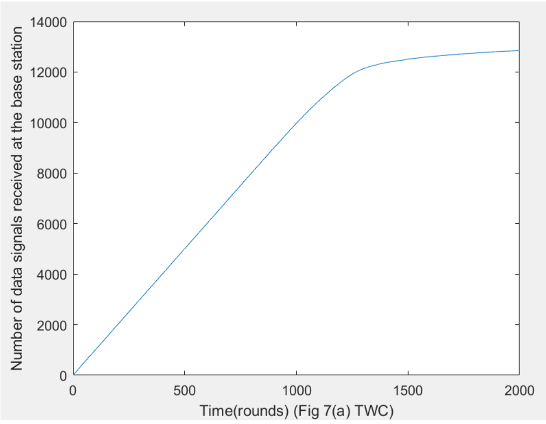

Figure 4a. Data packets received over time

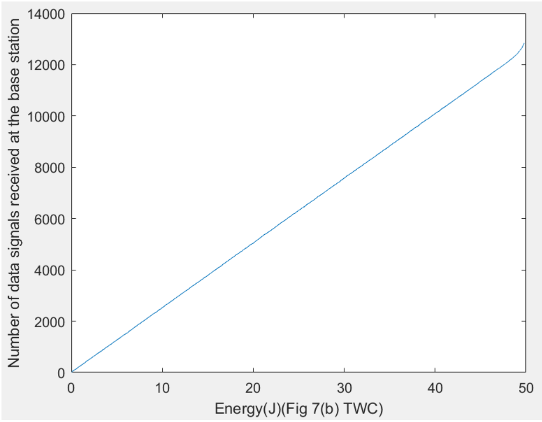

Figure 4b. Energy expended to transmit data packets

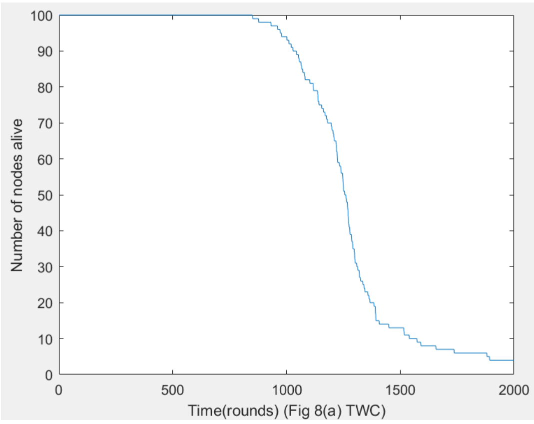

Figure 4c. Number of nodes alive per unit time

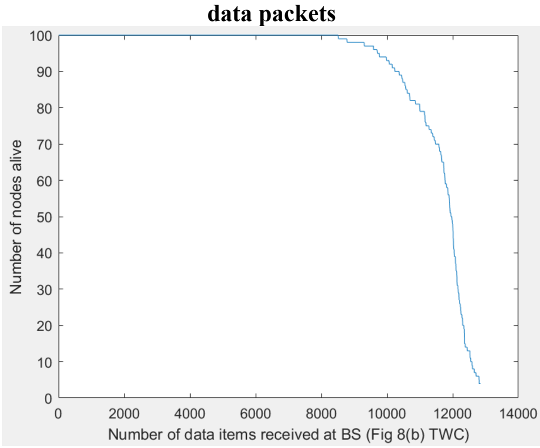

Figure 4d. Number of nodes alive per amount of data sent to sink node (BS)

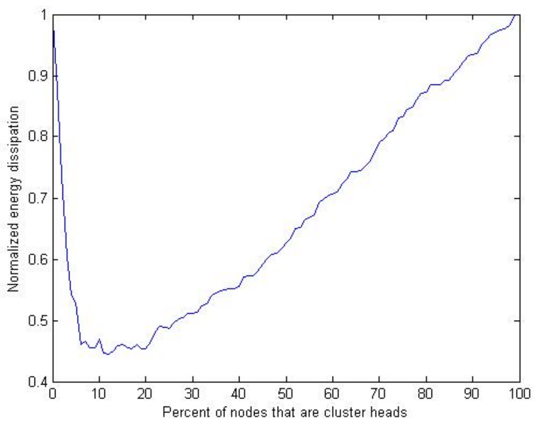

Figure 4e. Energy dissipation vs % of cluster heads

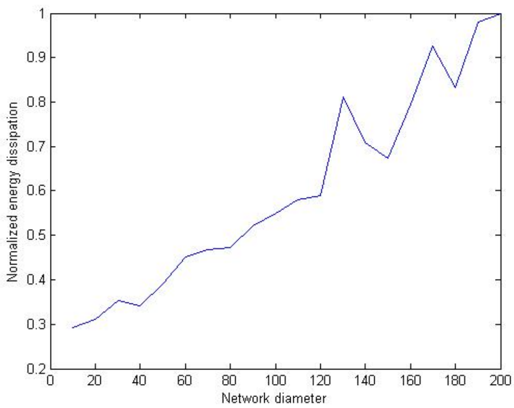

Figure 4f. Energy dissipation vs network diameter

Figure 4. Performance of the LEACH protocol

4. Modifications to the LEACH Protocol

Although LEACH performs sufficiently well for resource-constrained wireless sensor networks, it has several shortcomings. The aim of this assignment is to study the performance of variations to the original LEACH protocol implementation.

Let us consider two variations to the original LEACH protocol that have been proposed by researchers.

A. Centralized Cluster Formation

LEACH is a decentralized clustering algorithm. Cluster formation during the set up phase may result in a non-uniform distribution of the cluster heads which adversely affects the quality of clusters. Incorporating a centralized approach such as LEACH-C can ensure uniform distribution of the cluster heads throughout the surveillance region. LEACH-C, unlike LEACH, also takes into account the remaining energy levels of the nodes. The decision for nodes to become cluster heads is based on the remaining energy and the current location of the nodes, as described in (Heinzelman, Chandrakasan, & Balakrishnan, 2002). Several variants of the centralized scheme have been proposed, e.g. BCDCP (Muruganathan, 2005).

B. Hierarchical LEACH

Hierarchical clustering was proposed as a future work in (Heinzelman, Chandrakasan, & Balakrishnan, 2000). The implications of such a scheme were not known then, but several articles, for instance (Loscri, Morabito, & Marano, 2005), claim that the latter approach outperforms LEACH in terms of energy computation and lifetime of the nodes. The notion of hierarchical clustering is to use several levels of clustering. In this setting, the cluster head nodes would communicate with the super cluster heads and so on until the top level of the hierarchy is reached. An enhancement of the scheme is described in (Manzoor; K., Jokhio; S. H., *et al*, 2019).

5. Assignment Details

The provided Matlab program `LEACH.m` implements the basic LEACH algorithm described in (Heinzelman, Chandrakasan, & Balakrishnan, 2000) and generates the graphs shown in Figures 4a, b, c and d.

You will work in groups of 6 students for this assignment. Members of each group will be randomly assigned. Some groups will study LEACH variation A described above and other groups will study LEACH variation B. Divide the technical aspects of the workload evenly amongst all 6 students. Each student is expected to write the part of the report that corresponds to his/her contribution as well as present his/her contributions using a few slides during the final presentation session in Week 12. You will also jointly prepare a statement of contributions by each student (see Appendix).

Part I

Extend the `LEACH.m` program to compute the performance of LEACH when
(i) the percentage of cluster heads among all the nodes is varied from 0 to 100%, **OR**
(ii) the network diameter is varied from 10 to 200 meters
and hence, generate the graph shown in Figure 4e or 4f corresponding to your choice.

Comment on the similarity or differences between your graph and Figure 4e or 4f as the case may be.

Part II

Read the reference papers for this assignment and the LEACH variation assigned to your group described in Section 3, i.e. variation A or variation B.

Design a scheme that modifies the original LEACH protocol to achieve the variation.

Analyse the theoretical performance of the scheme in one or more aspects.

Implement this modified LEACH scheme in the Matlab program.

Generate five graphs (i.e. similar to Figures 4a-d and 4e or 4f depending on your choice in Part I) to show the simulation results of your modified LEACH scheme.

Compare the performance of your modified LEACH scheme vs the original LEACH scheme in each of the five aspects of the graphs and explain the differences in performance that are observed.

In addition, compare the simulation results with the theoretical results for the aspect(s) for which you have obtained analytical result(s) above.

Discuss the similarities and/or differences between your approach and results compared to those in the relevant stated reference paper(s).

The group should divide the work fairly among group members and each student should write his/her contributions in the Statement of Contributions (see Appendix). The various aspects of work are, but limited to, Part I extension; Part II algorithm development; mathematical analysis; programming; results generation, performance evaluation; comparison, critical discussion (e.g. computational complexity) etc.
More than one student can contribute towards a particular aspect.

Report, Presentation, Submission

Write a report of about 12 pages long (about 2 pages per group member; write the name of the author(s) after the section heading, e.g. "Section 3: Description of Method (Student 3)") that includes:

(a) the method of implementation for Part I, the graphs obtained and comments

(b) detailed description of the proposed scheme that modifies the original LEACH protocol, theoretical analysis of one or more aspects, the method of implementation and programming aspects for Part II, together with the supporting graphs, explanations and discussions in separate logical sections

(c) discussion of the similarities and/or differences between your approach and results compared with those found in the relevant reference paper(s), and

(d) signed Statement of Contributions (see Word document) (this is not counted in the 12-page limit).

The group will make a 25-minute presentation (short introduction, each student: 3 minutes, short conclusion) in Week 12 on **Thursday 7 April 2022**, between 6-9pm.

Upload the report (filename: GroupxxX_Report.docx/pdf) and presentations slides (filename: GroupxxX_Slides.pptx/pdf) by 2pm on that day to LumiNUS EE5132/EE5024 "Assignment 2 Submission" folder, where xx is your group no. 01 to 12, and X is variation A or B.

After the session, the final version of the report, Matlab file(s), slides and references (typically, PDF files) should be zipped in a single zip file with group number in the file name, e.g. GroupxxX_Submission.zip, and uploaded to the LumiNUS EE5132/EE5024 “Assignment 2 Submission” folder by **Friday 8 April 2022**.

Each student and the group will be assessed according to the following criteria:
1. Contributions (based on the Statement of Contributions of each student) (25%)
2. Technical mastery and understanding (25%).
- Quality and correctness of work (analysis, diagrams, results, programming, critical evaluation etc.) and conclusions drawn.
3. Report Writing (25%)
- Quality of explanation, diagrams, results, discussion
4. Quality of Presentation, i.e. quality of slides and quality of verbal explanations and ability to answer questions (25%)

References

Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000). Energy-efficient communication protocol for wireless microsensor networks. *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences.* IEEE.

Heinzelman, W. B., Chandrakasan, A., & Balakrishnan, H. (2002). An Application-Specific Protocol Architecture for Wireless Microsensor Networks. *IEEE Transactions on Wireless Communications.* IEEE.

Muruganathan, S. D. (2005). A Centralized Energy-Efficient Routing Protocol for Wireless Sensor Networks. *IEEE Radio Communications.* IEEE.

Loscri, V., Morabito , G., & Marano, S. (2005). A two-level hierarchy for low-energy adaptive clustering hierarchy (TL-LEACH). *Vehicular Technology Conference.* IEEE.

Manzoor; K., Jokhio; S. H., *et al* (2019), Enhanced TL-LEACH routing protocol for large-scale WSN applications, *2019 Cybersecurity and Cyberforensics Conference* (CCC), IEEE.