Wireless Sensor Networks and the LEACH Protocol: Analysis of Network using Certain Parameters for Clustering and Localization

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ABSTRACT
Wireless Sensor Networks (WSNs) represent a novel form of communication infrastructure comprising small sensor nodes distributed across an area, tasked with gathering environmental data. This information is relayed to a central base station, referred to as the Sink node. Within WSNs, optimizing energy usage and extending operational lifespan are paramount objectives. To achieve efficient and scalable performance, clustering is commonly employed, aiding in the decentralization of network control and facilitating localized communication. Additionally, localization plays a crucial role in pinpointing the geographical coordinates of sensor nodes within WSNs, enhancing their spatial awareness and overall functionality.

Keywords
WSN, Clustering, Localization, Leach Protocol.

1. INTRODUCTION
Wireless sensor networks (WSNs) represent a novel form of communication infrastructure, comprising small sensor nodes distributed throughout an area, tasked with collecting environmental data. These networks typically incorporate numerous resource-constrained sensors, which monitor their surroundings, gather data, and transmit it to remote servers for analysis. Despite their flexibility as ad-hoc networks, managing WSNs poses significant challenges, stemming from their large deployment size and the need to address quality concerns such as resource allocation, scalability, and reliability. Clustering involves the partitioning of the network into clusters, where each cluster comprises sensors in close proximity communicating with a designated cluster head. This cluster head is tasked with consolidating and transmitting data from its member sensors to the base station, thereby mitigating data transmission and con- serving energy within the network. The clustering algorithm may rely on different criteria, including energy levels, distances, and communication quality. Localization, conversely, focuses on determining the physical positions of individual sensor nodes within the network. Precise localization holds significance for diverse applications such as environmental monitoring, asset tracking, and security. Various methods exist for localizing nodes in WSNs, including GPS, triangulation, and signal strength-based techniques.[1] It is suggested to concentrate on hierarchical routing protocols, which are categorized based on the network's structure. These protocols rely on clustering algorithms to function effectively.[5]

Wireless sensor nodes do not necessarily need to communicate directly with the nearest control tower, which typically requires high power. They also may not need to communicate directly with the base station. Instead, they communicate only with local peer nodes. As a result, these connections form a peer-to-peer network, creating a mesh network. The mesh architecture enables a flexible networking structure with hopping branches. Additionally, the system is highly adaptive for substituting and compensating for node failures.[7]

2. RELATED WORK
Reviewing the literature on clustering and localization in WSN can give important insights into ongoing studies, new trends, and industry best practices. It enables a deeper comprehension of the issues, fixes, and developments related to WSN.

Wireless Sensor Networks (WSNs) comprise small sensor nodes distributed across an area, tasked with gathering environmental data. This collected information is transmitted to a central base station known as the Sink node. Minimizing energy consumption and maximizing lifespan are crucial objectives in WSNs. Clustering serves as a standard strategy for enhancing efficiency and scalability in such networks, enabling distributed network control and promoting localized communication. In this study, a clustering algorithm named CFL (Clustering for Localization) that integrates principles of clustering algorithm design while facilitating the development of localization algorithms based on clustering is introduced. The CFL algorithm employs a combined weight function to classify sensor nodes, aiming to minimize the number of clusters while maximizing the number of nodes within each cluster. Simulation results demonstrate the superior performance of the proposed CFL algorithm compared to existing approaches.[2]

Another approach towards clustering is using smart clustering algorithm (Smart-BEEM) to achieve energy efficiency and quality of end user experience. Balancing the energy consumption in per unit area instead of every single sensor can provide better-balanced power usage throughout the network.[4]

For understanding the concept of clustering and localization papers [2],[4] were referred. For studying various routing protocols and finalizing the most suitable protocol for proposed research papers[3],[5] were referred. For studying the importance of initial energy,

residual energy and other important terms related to WSN paper[1] was referred.

3. CLUSTERING AND LOCALIZATION
Clustering[3] is one of the important terms in WSN. It is a standard approach for achieving efficient and scalable performance in WSN. Clustering is a management method in WSNs, grouping nodes to manage them and executing various tasks in a distributed manner, such as resource management. Although clustering techniques are mainly known to improve energy consumption, there are various quality-driven objectives that can be realized through clustering. Localization[4], on the other hand, is extensively used to identify the current location of sensor nodes. The task of

determining physical coordinates of sensor nodes in WSNs is known as localization or positioning and is a key factor in today's communication systems to estimate the place of origin of events. As the requirement of the positioning accuracy for different applications varies, different localization methods are used in different applications and there are several challenges in some special scenarios such as forest fire detection.

4. METHODOLOGY

After scrutinizing various routing protocols for Localization and Clustering, it was decided to scale it down to LEACH (Low energy adaptive and clustering hierarchy) protocol [5] with due consultation with our project mentor. The LEACH protocol is enhances energy efficiency in wireless sensor networks by organizing nodes into clusters. The network periodically selects cluster heads, to achieve balanced energy consumption among the nodes. Each cluster head is responsible for aggregating data and transmitting it to a central sink, which conserves energy. LEACH protocol can be explained in the following steps:

1) Initialization: The LEACH protocol starts with the ini- tialization step. In this step, each sensor node is assigned a random value between 0 and 1, which is used to determine its probability of becoming a cluster head (CH). The sensor nodes that have a probability greater than a predetermined threshold value become CHs.

2) Cluster Formation: Once the CHs are selected, they broadcast an announcement message to the surrounding sensor nodes, inviting them to join their cluster. The nodes that receive the announcement message decide whether to join the CH's cluster or not based on the received signal strength. The nodes that do not join a CH's cluster remain idle to conserve energy.

3) Data Transmission: The sensor nodes in each cluster transmit data to their CHs. The CHs aggregate the data and compress it to reduce the transmission overhead. The CHs then transmit the aggregated data to the base station. The CHs also rotate their roles periodically to distribute the energy consumption among the nodes in the network.

4) Termination: The LEACH protocol operates in rounds, and each round is divided into the initialization and steady-state phases. At the end of each round, the CHs are reselected based on their remaining energy levels, and the cluster formation process is repeated. The termination condition is met when the network lifetime or the required level of data accuracy and reliability is reached.

To simulate the above protocol it is decided to use MATLAB as simulation platform. MATLAB is a programming language developed by MathWorks. It started out as a matrix programming language where linear algebra programming was simple. It can be run both under interactive sessions and as a batch job.

5. ALGORITHM AND PARAMETERS FOR EVALUATION

A. Algorithm

- Initialization:
  Set up the sensor network.
  Determine the number of clusters to create.
  Randomly assign each sensor node to a cluster.
  Calculate the centroid of each cluster.
- Cluster Formation:
  For each sensor node, calculate the distance to each centroid.
  Assign the node to the closest centroid.
  Update the centroids of each cluster based on the new assignments.
- Cluster Refinement:
  Repeat step 2 until the cluster assignments no longer change.

B. Parameters

Table I

Parameters	Values
Initial Energy (Eo)	0.5 - 2 Joules
Area	250 x 250 mtrs
No. of Nodes	25 - 200
Probability(P)	0.1
No. of rounds (rmax)	1000

Parameters are set with values as shown in Table1. Initial energy is varied from 0.5 Joules to 2 Joules. Area is kept fixed for varying number of nodes. For better results and understanding we preferred to run 1000 rounds.

6. SIMULATION RESULTS

For evaluating the network performance, we carried out multiple simulations on MATLAB by varying the parameters of network mentioned in Table 1. After carrying out multiple simulations we got the following results as shown in tables:

The observation tables(II to V), are for various parameters for different number of nodes with initial energy ranging from 0.5 joules to 2.0 Joules. The number of rounds is constant i.e 1000 and probability of getting selected as cluster head is 0.1 (p=0.1).

Table I Values with Initial Energy 0.5J

Total Nodes	25	50	100	150	200
Avg Residual Energy	0.52	1.95	1.15	3.37	5.16
Count(CH)	0	6	3	7	7
Packet Transferred	14460	39831	78091	126661	177200
Packets to CH	5196	23276	60170	102880	150220
Packets to BS/Round	7	7	13	14	16
CHs to BS	9264	16555	17921	23781	26980
Live Nodes	7	25	28	63	90
Dead Nodes	18	25	72	87	110
For E0	0.5				

Table II Values with Initial Energy 1.0 J

Total Nodes	25	50	100	150	200
Avg Residual Energy	17.26	37.25	89.39	138.323	179.45
Count(CH)	2	2	13	10	22

Packet Transferred	23693	49428	99937	150150	199924
Packets to CH	10425	33320	78888	125014	168931
Packets to BS/Round	12	17	14	19	34
CHs to BS	13268	16108	21049	25136	30993
Live Nodes	21	47	99	150	197
Dead Nodes	4	3	1	0	3
For E0	1.5				

Experimental results were obtained using simulations for a wireless sensor network which has several parameters out of which a few critical parameters were chosen which had a huge impact on the overall performance of the network. These parameters were as follows:

1) Average Residual Energy is the total energy that is left after 'r' rounds for all nodes.
2) Live Node is a node which is functional, i.e. it has enough energy left to transmit data to the Base Station.
3) Dead Node is a node which is non-functional, i.e. it does not have enough energy left to transmit data to the Base Station.
4) Packets Transferred refers to the total amount of data that is transmitted from nodes to Base Station.
5) COUNTCHS is the number of cluster heads.
6) The data is transmitted from nodes to cluster heads (CH) which further transmit this data to the Base Station

These parameters are found to have different values when the initial energy (Eo) provided is varied. When the initial energy (Eo) was increased in sequential steps from 0.5 J to 2 J, the overall energy consumption of the nodes was reduced. The residual energy was increased, which translates to better network lifetime. The number of Live Nodes increased while the number of Dead Nodes was observed to be decreasing. A reduction in Dead Nodes and increase in throughput is a major breakthrough, which has several benefits, both in the process of transmission of data and in the financial sense.

a) : The research paper endeavors to offer an intricate comprehension of the correlation between node quantity and WSN efficiency utilizing the LEACH protocol through a thorough performance evaluation and analysis. This examination is conducted utilizing the parameters outlined in the tables above. Such analysis equips researchers and practitioners with the ability to ascertain the ideal node count for various regions, taking into account network performance metrics.

TABLE III Values with Initial Energy 1.5J

Total Nodes	25	50	100	150	200
Avg Residual Energy	9.0	14.83	37.18	59	85
Count(CH)	4	7	8	12	21
Packet Transferred	24296	46251	98183	147649	199631
Packets to CH	10867	31429	77071	122120	169766
Packets to BS/Round	10	7	12	24	32
CHs to BS	13429	14222	21112	25529	29704
Live Nodes	20	39	87	134	193
Dead Nodes	7	1	13	16	7
For E0	1.0				

TABLE IV Values with Initial Energy 2.0 J

Total Nodes	25	50	100	150	200
Avg Residual Energy	26.65	62	136.5	208.2	286.7
Count(CH)	3	3	9	12	22
Packet Transferred	24145	49875	100100	150150	200200
Packets to CH	11009	32601	80177	126353	168636
Packets to BS/Round	11	22	27	26	51
CHs to BS	13136	17274	19923	23797	30940
Live Nodes	23	48	100	150	200
Dead Nodes	2	2	0	0	0
For E0	2.0				

A. Graphical representation of results

Graphical representation of the observed parameters for the network performance is discussed below. The initial energy as mentioned was varied from 05J to 2.0 J.

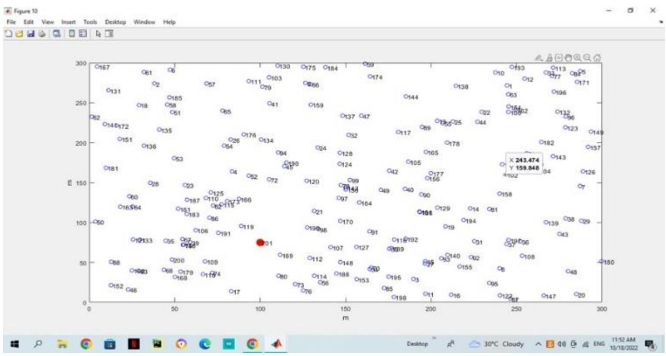

Fig. 1. Simulation setup for nodes

Figure above (Fig.1) shows the initial setup of nodes in an environment. Here 200 nodes were depicted to monitor the performance of the network.

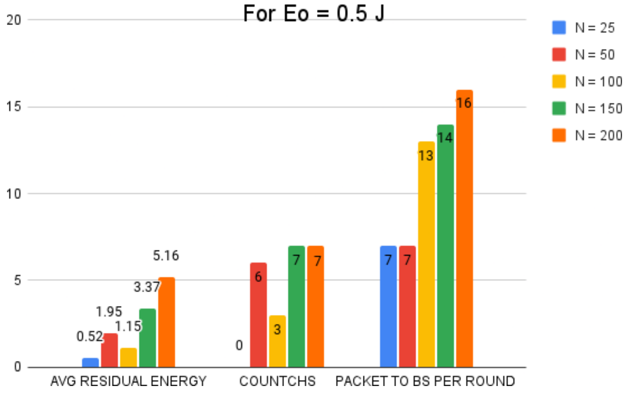

Fig. 2. Energy(0.5), CH count and Packets

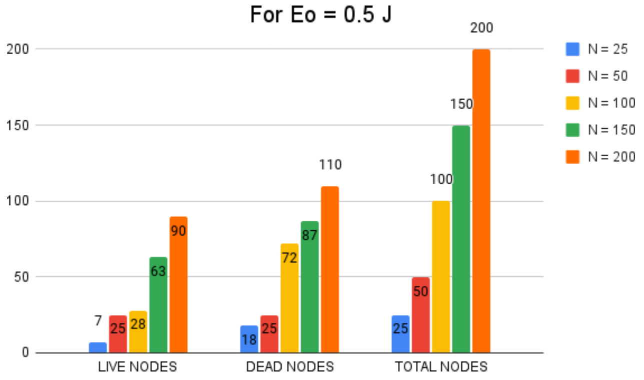

Fig. 3. E=0.5, Live and Dead Nodes

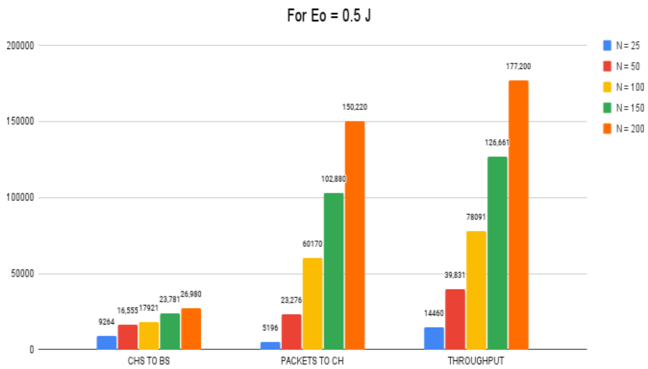

Fig. 4. E=0.5, Packets handling

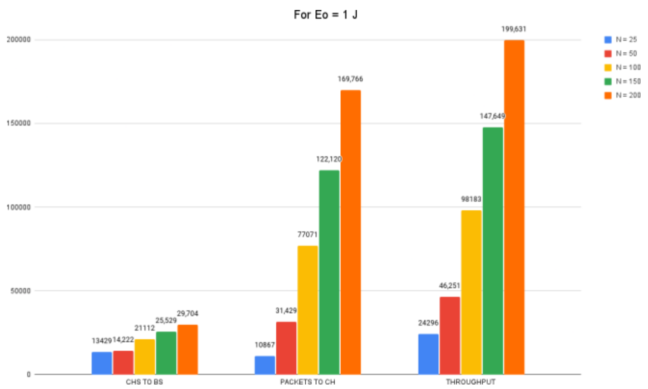

Fig. 5. Energy(1.0), CH count and Packets

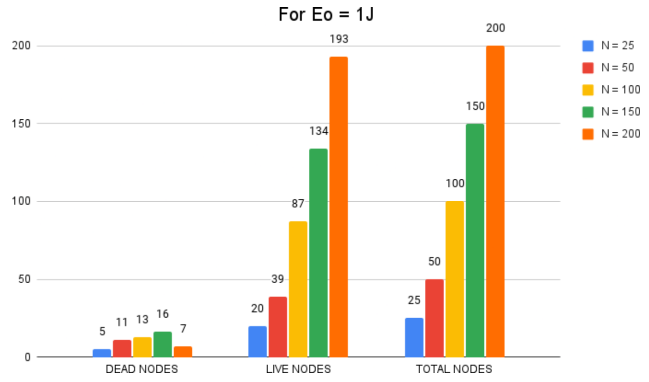

Fig. 6. E=1.0, Live and Dead Nodes

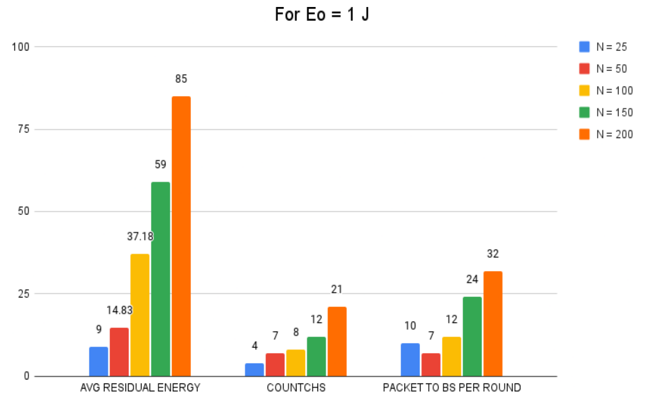

Fig. 7. E=1.0, Packets handling

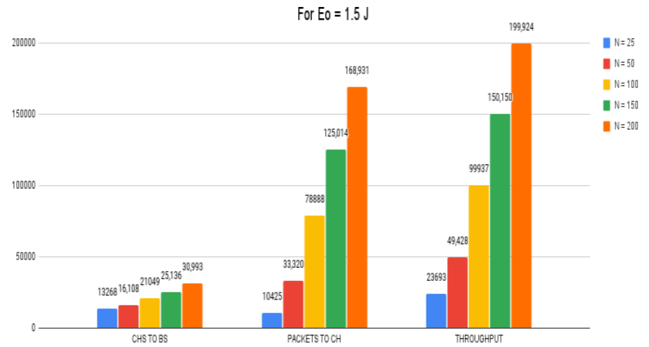

Fig. 8. Energy(1.5), CH count and Packets

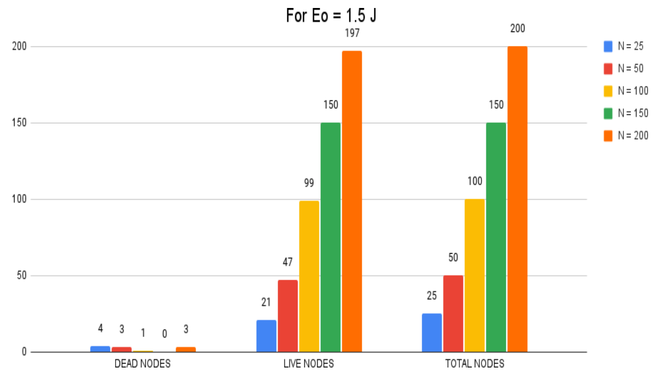

Fig. 9. E=1.5, Live and Dead Nodes

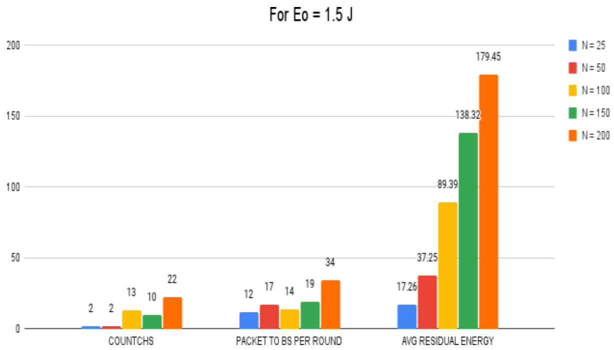

Fig. 10. E=1.5, Packets handling

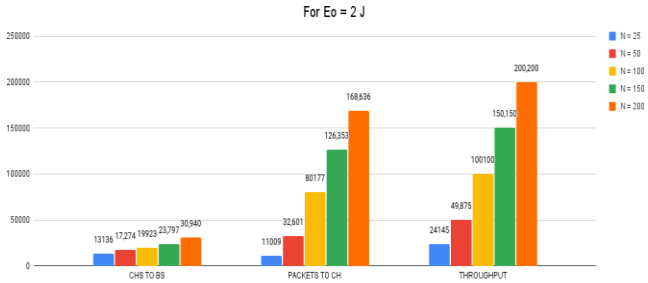

Fig. 11. Energy(2.0), CH count and Packets

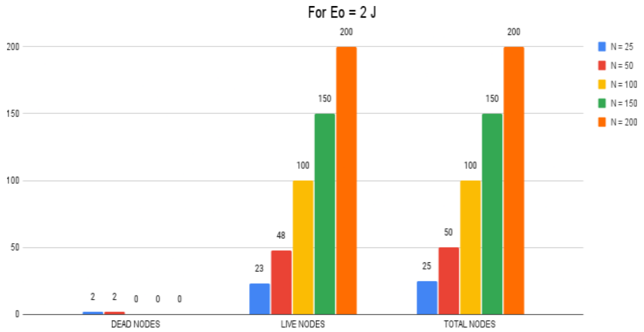

Fig. 12. E=2.0, Live and Dead Nodes

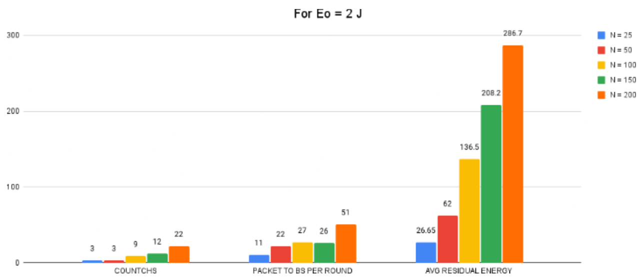

Fig. 13. E=2.0, Packets handling

The figures (Fig.2 to Fig. 13) depicts the average residual energy, number of cluster heads , and number of packets that are sent from cluster heads to Base Station per round. For a larger number of nodes, the residual energy was found to be more. Moreover, it shows the effect of initial energy on number of live nodes and dead nodes. Total number of packets delivered from nodes to cluster head(CH), CH to Base Station(BS) and overall packets handled by the network is also shown.

Network with initial energy 1.5J and above shows comparatively better performance than network with low initial energy.

7. CONCLUSION

This paper provide a brief summary about the results which were derived after running the simulation on MATLAB. The description of these results provides an insight into understanding the parameters and theories taken into consideration and why they were considered over other records for varying initial energy and total nodes. After the successful implementation, following conclusions were drawn based on above results.

1) Before Clustering, the efficiency of the network was substandard. Cluster-based protocols can prolong the network lifetime by reducing the energy consumption of the sensor nodes.

2) As it has been observed from the Graphs, the average residual energy gradually increases and the number of dead nodes become more than 50

3) After varying the initial energies from 0.5J to 1J, 1.5J, 2J, it can be concluded that the networks with initial energy 1.5J and 2J gives better performance compared to other values of initial energies.

4) After simulating multiple rounds in MATLAB for Clustering of nodes, it has been figured that the most optimal performance of the network would suffice at 1.5J as anything above the same would not be economically feasible.

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