Low-Energy Adaptive Clustering Hierarchy (Leach) Algorithm For Selection Of Cluster Head In Wireless Sensor Nodes

Isaac A. Ezenugu
Department of Electrical/Electronic Engineering, Imo State University (IMSU), Owerri, Nigeria
isaac.ezenugu@yahoo.com

***Abstract*— In this paper, low-energy adaptive clustering hierarchy (LEACH) algorithm for selection of cluster heads in wireless sensor nodes is presented. Basically, LEACH algorithm is an energy–aware protocol whose main aim is to minimize the overall average energy used by the nodes in a wireless sensor network in transmission of their data to the base station. In this paper, the description of the LEACH algorithm is presented along with the key mathematical expressions and flowchart. Mathlab software was used to simulate the LEACH algorithm for a sample network that has 60 sensor nodes that are randomly distributed in a 600 m by 600 m region and the sink node is located at the center of the region at coordinate of 300 m by 300 m. In the simulation, the threshold signal transmission at which a node is selected to be a cluster head is if the node can run 150 transmissions and above. The results show that from the 60 sensor nodes studied, only 12 nodes had 150 transmissions and above, as such the sensor nodes are selected as cluster heads. Again, the result show that at the 23rd transmission, about 5.17 Joules of energy was consumed which is the maximum energy consumption by the nodes in the study. Furthermore, the permissible number of rounds by a node to be a cluster head is 200 rounds and 11 nodes had the accepted number of rounds and beyond. In essence, based on the number of signals transmitted and the number of rounds per node, the number of cluster heads selected by the LEACH algorithm was 11.**

Keywords*— *LEACH Algorithm, Sensor Node, Cluster Algorithm, Wireless Network, Cluster Head, Slave Nodes

I. INTRODUCTION

Over the years, wireless network has advanced and gained wider adoption in many areas [1,2,3,4,5]. Notably, the key concerns of the wireless network designers include among others, the propagation loss [6,7,8,9,10], the transmission range (or more appropriately, the network coverage are [11,12,13], fade mechanisms [14,15,17], efficient call admission and handoff mechanisms in the case of cellular networks [18,19], and transmission power demand. The challenges regarding management of transmission power have become prominent in wireless sensor networks (WSNs) [20,21,22,23,24,25,26,27] which in recent years have witnessed wide adoption in diverse applications.

Generally, WSN operates with very small, low-power but battery powered sensor devices with limited on-board processing and storage capacities [28,29,30,31,32]. The sensors devices (nodes) in the WSN are expected to work unattended while they capture relevant data and transmit same to the remote server location [33,34,35,36,37,38]. Due to the limited energy capacity, the design of the WSN has to be energy-aware and measures need to be put in place to minimize the energy required to transmit data from the various sensors in the network. Accordingly, in this paper, a Low-Energy Adaptive Clustering Hierarchy (LEACH) algorithm [39,40,41,42] is used in the management of the communication process in the WSN in such a way as to conserve the overall average energy consumption per transmission. The description of the LEACH algorithm is presented along with the key mathematical expressions and flowchart. Mathlab software was used to simulate the LEACH algorithm for a sample network.

II. THE LEACH ALGORITHM

A. Overview Of Leach Algorithm

Low-Energy Adaptive Clustering Hierarchy (LEACH) algorithm is use in a situation where different autonomous network nodes surrounding a base station (the sink node) collectively but stochastically select a number of cluster heads among the available nodes, each node that is not a cluster head transmits its signal to the cluster head to which it belongs and the cluster head in turn aggregates the data and forwards them to the base station (the sink node) [43,44,45,46,47,48]. The choice of cluster heads is repeated at certain interval and in such a way the role of cluster head is rotated among the participating nodes. The main idea behind LEACH is to minimize the energy used by the nodes in transmission of their data to the base station [49,50,51,52]. The theoretical bases of LEACH are that the amount of energy needed to transmit data from one point to another increases with the distance between the two devices. The shorter the distance the smaller the energy needed to transmit a given set of data. In this wise, a group of nodes transmits their data to a nearby cluster head which aggregate the data and transmits the aggregated data to the base station. In this case, the cluster slave nodes have conserved their transmission energy demand by transmitting to the cluster head that is closer to them.

According to the LEACH algorithm, once a node becomes a cluster head, that node cannot become cluster heads again until after a certain number of rounds, say, P rounds. As such, each of the participating node in the network has a 1/P probability of becoming the cluster head in each given round. After the cluster heads are identified in a given round, the nodes that are not cluster heads are referred to as cluster slave and the cluster slaves select cluster heads closest to them and transmit their data to the cluster heads.

The cluster head on the other hand creates a Time Division Multiple Access (TDMA) scheduling framework that enable the cluster slaves to transmit in turn to avoid collision of data. The cluster slave nodes transmits in such a way that minimum energy needed to reach the cluster head is utilized.

B. Operation of leach algorithm

The entire LEACH operation is defined in two phases, namely, the as-set up phase and the steady phase. In the setup phase, the cluster heads are selected and the clusters are formed. In the steady state phase the normal data transmission between the cluster heads and the cluster slave nodes and to the base station takes place. The flowchart for the setup phase of the LEACH algorithm is shown in Figure 1.

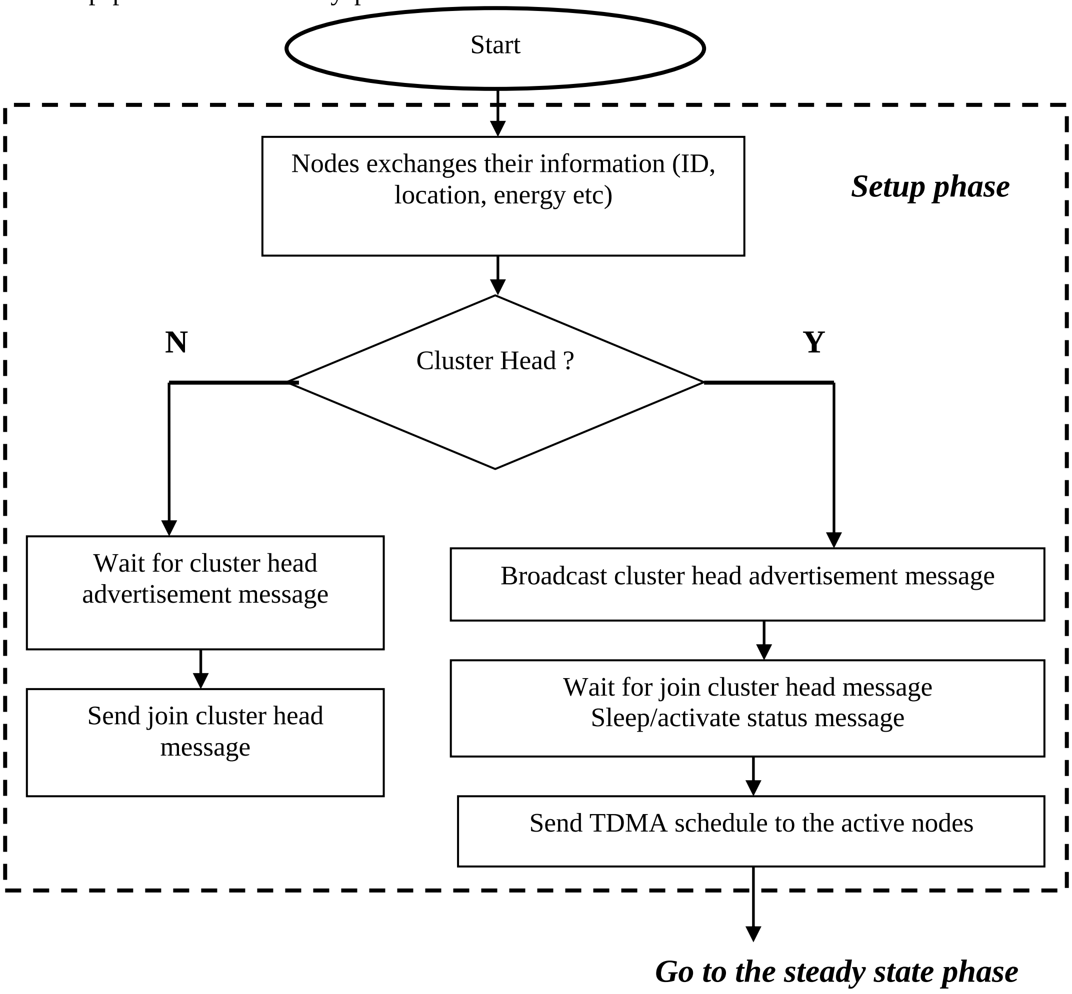

Figure 1. The flowchart for the setup phase of the LEACH algorithm

In LEACH algorithm, the operations are classified into rounds or cycles. At the beginning of each round r+1 which starts at time t, each sensor node elects itself as the cluster head with probability, $P_i(t)$. In a network with N nodes, the probability $P_i(t)$ is selected such that the total number of cluster heads in the round is not more than K; hence:

$$\sum_i^N P_i(t) = K \qquad (1)$$

Where k is the number of clusters formed during each round

N is the number of sensor nodes in the network.

Each node in the LEACH algorithm will become one of the cluster heads (CH) once in every N/k rounds. Hence, each sensor node has equal probability, $P_i(t)$ to become a CH. In round r, the probability is give as:

$$P_i(t) \begin{cases} \frac{K}{N-K\left(r \bmod\left(\frac{N}{K}\right)\right)} & : C_i(t) = 1 \\ 0 & : C_i(t) = 0 \end{cases} \qquad (2)$$

Essentially, $C_i(t) = 1$ is like a flag that is used to check if node i can be a cluster head or not.

III. NETWORK MODEL, SIMULATION AND RESULTS

The LEACH simulation procedure adopted in this paper involved setting up of different network topologies and the average of the results obtained were taken so as to minimize the effect of network distribution. The LEACH algorithm was simulated using a MALTAB software version 2015a. The network simulated has 60 sensor nodes in a 600 m by 600 m region. The minimum probability for any node to become a cluster head is set at 0.1 and the initially energy for each of the nodes is set at 0.5. Some of the key parameters used in the simulation are shown in Table 1.

Table 1. Some of the key parameters used in the simulation

Parameter	Value
Number of sensor nodes	60
Network Size	600 m by 600 m
Base station location	300 m by 300 m
Initial nodal energy	0.5 Joule
Data size	500 Bytes with packet header of 25 bytes
Radio propagation speed	$3x10^8$ m/s
Bandwidth of the channel	1 Mbps
Processing speed	50 μs
Node Distribution	Random
The number of rounds	10000

Some salient network model assumptions adopted for the simulation are as follows:

- There is one sink node (base station) in the network and it has a fixed (static) location which in this case, is at the centre of the area considered in the study
- The sensor nodes are all homogeneous and they are all energy constrained with uniform energy.
- The sensor nodes are static in their position and all the sensor nodes are able to reach sink node which is the base station.
- All the sensor nodes have the same initial energy;
- The nodes that are not cluster heads transmit directly to their respective cluster heads within a particular cluster to which they belong.
- Both the clusters and nodes within the clusters are static.

The x-y coordinate location of the 60 sensor nodes considered as randomly generated around 600 m by 600 m region is shown in Table 2. The positions of the sensor nodes expresses in x-y coordinate format are presented in Figure 2. The sink node is located at 300 m by 300 m of the region, as shown in Figure 2.

Table 2 Position of the nodes at the region under study

Node numbering	x-coordinate	y-coordinate
1	395.623411414484	272.236471082002
2	22.5633677100883	261.013602256770
3	444.739584848391	563.418399121202
4	236.660449919215	147.482669577549
5	95.6137210233174	460.710847391008
6	424.443482550914	348.748203442065
7	564.173745073049	202.910540329206
8	441.584464587774	597.262043634996
9	274.714432026853	451.309592636458
10	85.0138878949086	76.9807315986144
11	575.603174577428	173.338945364358
12	518.885015306157	377.151604879374
13	443.903922849694	94.8922069471646
14	109.888617883052	72.3233289370822
15	129.388725654910	166.873840785184
16	240.532061804569	182.168685066825
17	159.255709578343	250.451481561633
18	488.761377090082	259.397281342524
19	366.575063825284	110.303582744810
20	596.095427279242	49.8613510110866
21	505.573187364784	590.404910924135

22	9.43905004351988	20.5515043605086
23	72.6593568732431	279.996976843546
24	569.625473535295	150.225817453163
25	555.409129693795	191.212924206653
26	225.676696598587	16.4265583050186
27	265.924547765962	512.539307781449
28	217.686304221005	283.853785509235
29	523.018171655150	498.202188001396
30	494.651282813441	584.815369490664
31	117.538632364521	565.846878304039
32	265.179549846121	52.4673250159419
33	568.328898454136	481.575791529507
34	454.882269850279	229.274413599909
35	476.058199721402	227.173086253292
36	340.337061195762	71.4616764861290
37	240.171997717467	346.225836256358
38	60.2915403233083	527.598027269239
39	42.7453958181770	436.536605337184
40	202.124291568880	296.963933901822
41	414.581359657787	452.105172889176
42	450.654077151718	202.750289099294
43	3.12523397382001	149.352618842922
44	245.043938521900	313.513946275121
45	21.7973928505964	419.010553935934
46	313.524096735854	70.0569477835574
47	380.829151262555	407.128966239328
48	320.416894608998	458.181249641505
49	467.759945197943	55.2917616278195
50	450.529114790159	83.1602690606891
51	433.030689464629	356.144986796309
52	5.52778622752985	521.387839731397
53	14.9838661508934	443.212123739622
54	586.580969132977	393.976573764805
55	43.8308753889839	385.358529915707
56	267.454915504436	209.232050325045
57	304.766684705657	343.028917664702
58	338.446008800783	238.474120783131
59	271.280704428373	361.849293896619
60	238.519013958431	273.094955068585

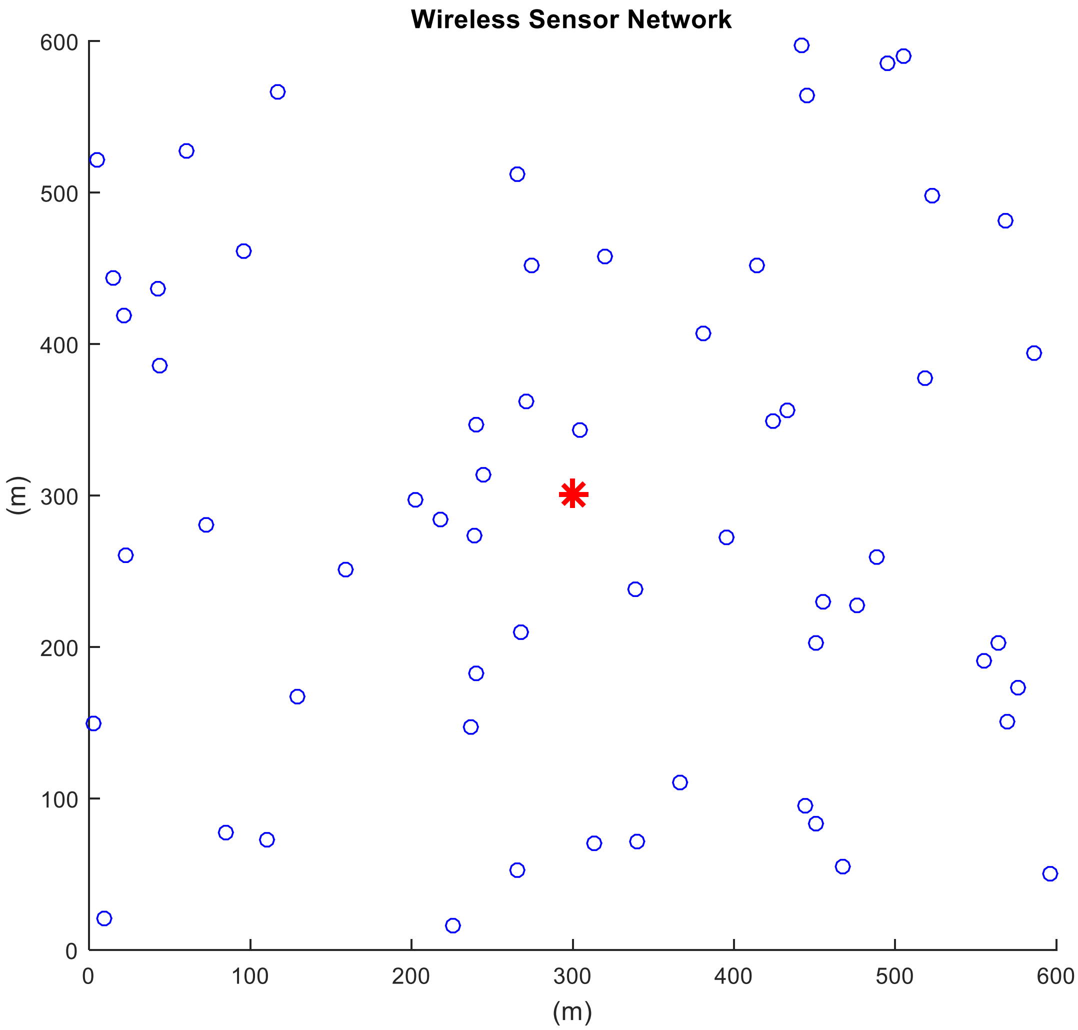

Figure 2 The position of the sensor nodes in the region considered in the study

The result on the amount of energy consumed per transmission by the entire nodes is shown in Figure 3. The energy consumption of the nodes with respect to the number of signal transmission for 35 transmissions is shown in Figure 3. It is observed that at the 23rd transmission, 5.17 joules of energy was consumed which is the maximum energy consumption by the nodes in the study. The number of operational nodes during signal transmission is shown in Figure 4.

The threshold signal transmission at which a node is selected to be a cluster head is if the node can run 150 transmissions and above. As such, from Figure 4, it can be seen that from the 60 nodes studied, only 12 nodes had 150 transmissions and above as such are selected as cluster head.

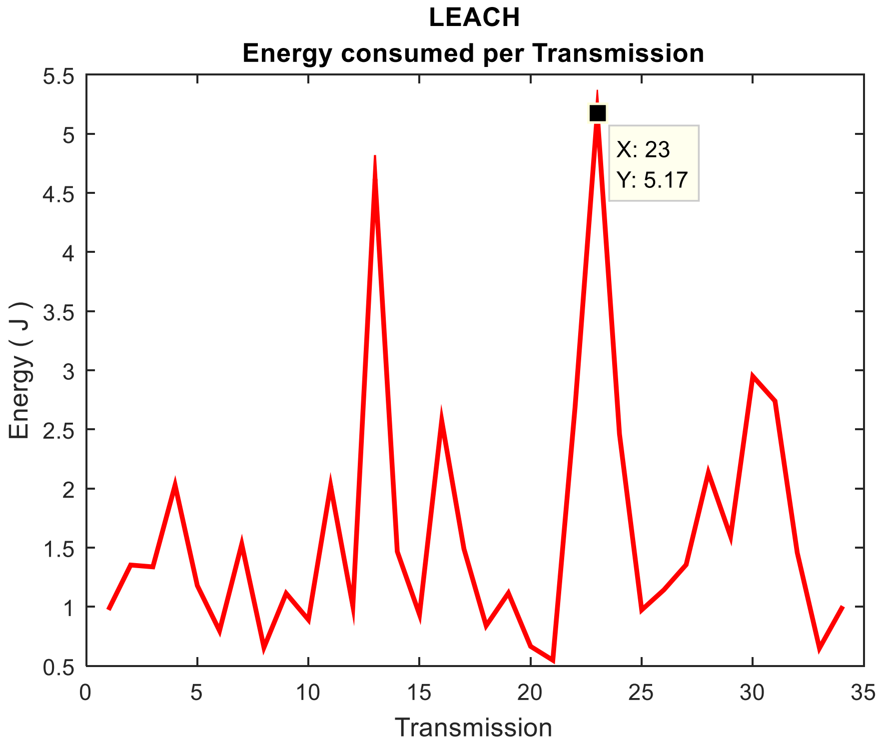

Figure 3; Energy consumed per transmission by the nodes

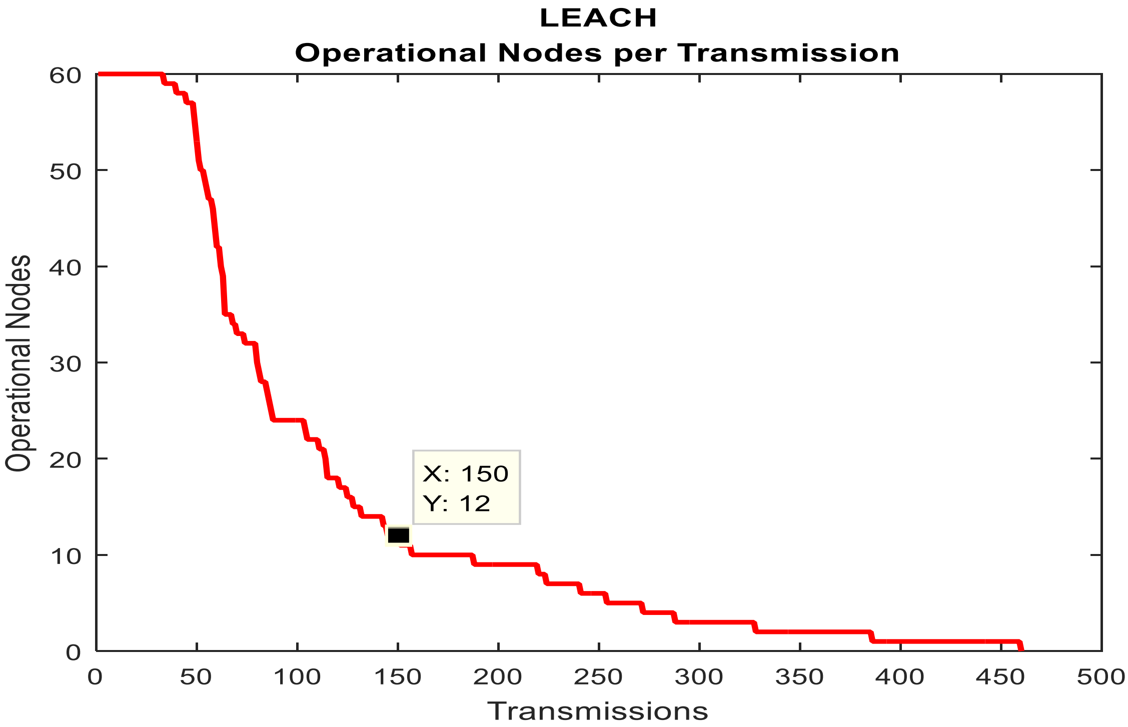

Figure 4 The number of operational nodes during signal transmission

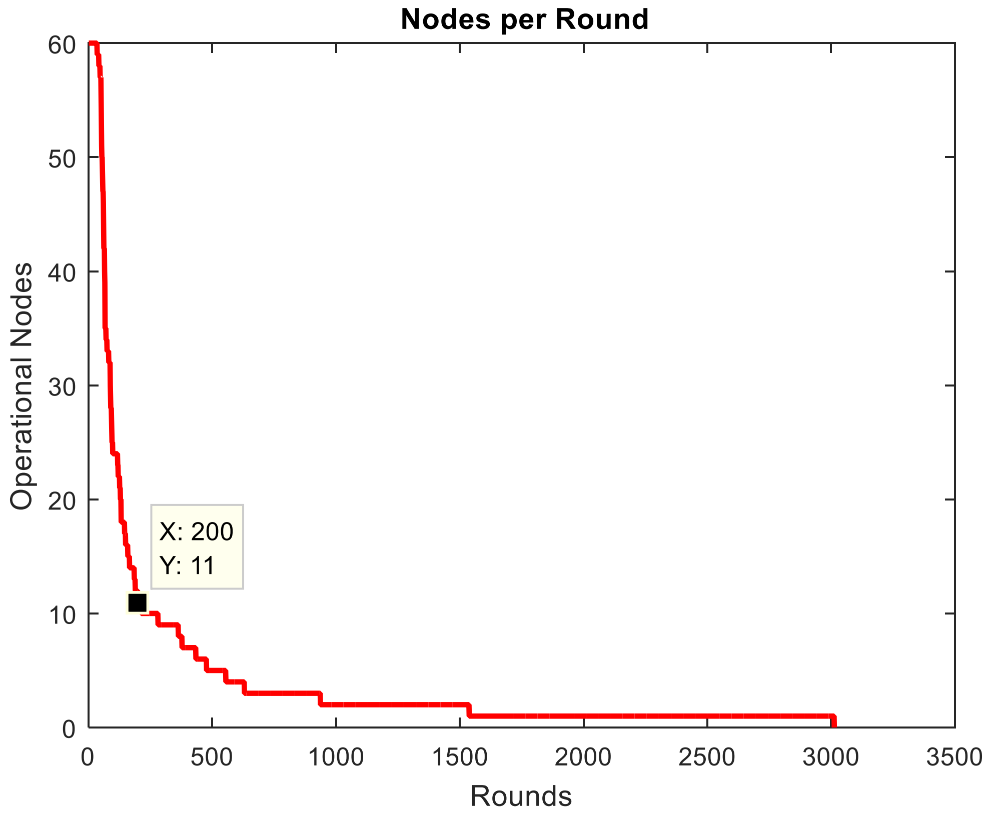

Figure 5; Number of transmission rounds at different operational nodes.

From Figure 5, it was observed that 12 nodes had at least 150 signal transmissions. This is proportional to the number of rounds by each of the nodes as shown in Figure 5. The permissible number of rounds by a node to be a cluster head is 200 rounds and 11 nodes had the accepted number of rounds and beyond. In essence, based on the number of signals transmitted and the number of rounds per node, the number of cluster heads selected by the LEACH algorithm was 11.

IV CONCLUSION

A Low-Energy Adaptive Clustering Hierarchy (LEACH) algorithm for selecting cluster head in a wireless sensor network was studied. The LEACH algorithm seeks to minimize the energy used by the network nodes in the transmission of signal. This is accomplished by the use of device-to-device communication through appropriate choice of cluster heads and formation of node clusters within the network coverage area. In this paper, sample wireless sensor network was used to demonstrate the application of LEACH clustering algorithm in the cluster head selection. Some key parameters were used to evaluate the performance of the algorithm. Such parameters are the number of cluster heads selected in a given set of nodes as well as the number of operational nodes during signal transmission. In all, the LEACH algorithm studied was able to select a good number of cluster head which enabled the network to transmit data at a minimal energy demand.

REFERENCES

1. Clarke, R. N. (2014). Expanding mobile wireless capacity: The challenges presented by technology and economics. *Telecommunications Policy*, *38*(8-9), 693-708.
2. Wekhande, V. (2006). Wi-Fi Technology: Security Issues. *Rivier Academic Journal*, *2*(2), 1-16.
3. Sato, T., Saito, T., Kunimatsu, F., Hayakawa, Y., Kawamura, A., & Muraki, K. (2013). Flexible Communication Infrastructure Using Existing Systems and Terminals. *Hitachi Review*, *62*(3), 174.
4. Liu, Y., Kashef, M., Lee, K. B., Benmohamed, L., & Candell, R. (2019). Wireless network design for emerging IIoT applications: reference framework and use cases. *Proceedings of the IEEE*, *107*(6), 1166-1192.
5. Ezema, M. E., Okoye, F. A., & Okwori, A. O. (2019). A framework of 5G networks as the foundation for IoTs technology for improved future network. *International Journal of Physical Sciences*, *14*(10), 97-107.
6. Akaninyene B. Obot , Ozuomba Simeon and Kingsley M. Udofia (2011); *"Determination Of Mobile Radio Link Parameters Using The Path Loss Models"* NSE Technical Transactions , A Technical Journal of The Nigerian Society Of Engineers, Vol. 46, No. 2 , April - June 2011 , PP 56 – 66.
7. Akaninyene B. Obot , Ozuomba Simeon and Afolanya J. Jimoh (2011); "*Comparative Analysis Of Pathloss Prediction Models For Urban Macrocellular" Nigerian Journal of Technology (NIJOTECH)* Vol. 30, No. 3 , October 2011 , PP 50 – 59

8. Ozuomba Simeon ., Enyenihi, J., & Rosemary, N. C. (2018). Characterisation of Propagation Loss for a 3G Cellular Network in a Crowded Market Area Using CCIR Model. *Review of Computer Engineering Research*, *5*(2), 49-56.
9. Njoku Chukwudi Aloziem, Ozuomba Simeon, Afolayan J. Jimoh (2017) Tuning and Cross Validation of Blomquist-Ladell Model for Pathloss Prediction in the GSM 900 Mhz Frequency Band , *International Journal of Theoretical and Applied Mathematics, Journal*: Environmental and Energy Economics
10. Ozuomba Simeon ., Johnson, E. H., & Udoiwod, E. N. (2018). Application of Weissberger Model for Characterizing the Propagation Loss in a Gliricidia sepium Arboretum
11. Johnson, E. H., Ozuomba Simeon ., & Asuquo, I. O. (2019). Determination of Wireless Communication Links Optimal Transmission Range Using Improved Bisection Algorithm.
12. Ozuomba Simeon imeon (2019) ANALYSIS OF EFFECTIVE TRANSMISSION RANGE BASED ON HATA MODEL FOR WIRELESS SENSOR NETWORKS IN THE C-BAND AND KU-BAND, Journal of Multidisciplinary Engineering Science and Technology (JMEST
13. Ozuomba Simeon imeon (2019) EVALUATION OF OPTIMAL TRANSMISSION RANGE OF WIRELESS SIGNAL ON DIFFERENT TERRAINS BASED ON ERICSSON PATH LOSS MODEL
14. Ononiwu, G., Ozuomba, S., & Kalu, C. (2015). Determination of the dominant fading and the effective fading for the rain zones in the ITU-R P. 838-3 recommendation. *European Journal of Mathematics and Computer Science Vol*, *2*(2).
15. Ozuomba, Simeon, Constance Kalu, and Akaninyene B. Obot. (2016) "Comparative Analysis of the ITU Multipath Fade Depth Models for Microwave Link Design in the C, Ku, and Ka-Bands." *Mathematical and Software Engineering* 2.1 (2016): 1-8.
16. Kalu, C., Ozuomba, S. & Jonathan, O. A. (2015). Rain rate trend-line estimation models and web application for the global ITU rain zones. *European Journal of Engineering and Technology, 3 (9)*, 14-29
17. Itoro J. Akpan, Ozuomba Simeon and Kalu Constance. “DEVELOPMENT OF A GUARD CHANNEL-BASED PRIORITIZED HANDOFF SCHEME WITH CHANNEL BORROWING MECHANISM FOR CELLULAR NETWORKS”. Journal of Multidisciplinary Engineering Science and Technology (JMEST)
18. Akpan, U., Kalu, C., Ozuomba, Simeon, & Obot, A. (2013). Development of Improved Scheme for Minimising Handoff Failure due to Poor Signal Quality. *International Journal of Engineering Research and Technology*, *2*(10), 2764-2771.
19. Omini Samuel , Kalu Constance and Ozuomba Simeon , “DEVELOPMENT OF FUZZY INFERENCE SYSTEM-BASED ANALYSIS OF NON-PRIORITIZED HANDOFF SCHEME WITH STATISTICALLY MODELLED IDLECHANNEL BORROWINGMECHANISM FOR CELLULAR NETWORKS” International Multilingual Journal of Science and Technology (IMJST)
20. Kotian, R., Exarchakos, G., Stavros, S., & Liotta, A. (2017). Impact of transmission power control in multi-hop networks. *Future Generation Computer Systems*, *75*, 94-107.
21. Chhaya, L., Sharma, P., Bhagwatikar, G., & Kumar, A. (2017). Wireless sensor network based smart grid communications: Cyber attacks, intrusion detection system and topology control. *Electronics*, *6*(1), 5.
22. Ali, A., Ming, Y., Chakraborty, S., & Iram, S. (2017). A comprehensive survey on real-time applications of WSN. *Future internet*, *9*(4), 77.
23. Pal, A., & Nasipuri, A. (2019). Joint power control and routing for rechargeable wireless sensor networks. *IEEE Access*, *7*, 123992-124007.
24. Mokrenko, O. (2015). *Energy management of a Wireless Sensor Network at application level* (Doctoral dissertation).
25. Moschitta, A., & Neri, I. (2014). Power consumption assessment in wireless sensor networks. In *ICT-energy-concepts towards zero-power information and communication technology*. IntechOpen.
26. Garlapati, N., & Mohammed, A. A. (2012). Evaluation of Power Conservation Algorithms in Industrial Wireless Sensor Networks.
27. Liu, X. (2012). A survey on clustering routing protocols in wireless sensor networks. *sensors*, *12*(8), 11113-11153.
28. Guy, C. (2006, October). Wireless sensor networks. In *Sixth international symposium on instrumentation and control technology: Signal analysis, measurement theory, photo-electronic technology, and artificial intelligence* (Vol. 6357, p. 63571I). International Society for Optics and Photonics.
29. Simjee, F. I., & Chou, P. H. (2008). Efficient charging of supercapacitors for extended lifetime of wireless sensor nodes. *IEEE Transactions on power electronics*, *23*(3), 1526-1536.
30. Seah, W. K., Eu, Z. A., & Tan, H. P. (2009, May). Wireless sensor networks powered by ambient energy harvesting (WSN-HEAP)-Survey and challenges. In *2009 1st International Conference on Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology* (pp. 1-5). Ieee.
31. Taneja, J., Jeong, J., & Culler, D. (2008, April). Design, modeling, and capacity planning for micro-solar power sensor networks. In *2008 International Conference on Information Processing in Sensor Networks (ipsn 2008)* (pp. 407-418). IEEE.

32. Yick, J., Mukherjee, B., & Ghosal, D. (2008). Wireless sensor network survey. *Computer networks*, *52*(12), 2292-2330.
33. Sen, J. (2012). Security in wireless sensor networks. *Wireless Sensor Networks: Current Status and Future Trends*, *407*, 408.
34. Kifayat, K., Merabti, M., Shi, Q., & Llewellyn-Jones, D. (2010). Security in wireless sensor networks. In *Handbook of information and communication security* (pp. 513-552). Springer, Berlin, Heidelberg.
35. Yick, J., Mukherjee, B., & Ghosal, D. (2008). Wireless sensor network survey. *Computer networks*, *52*(12), 2292-2330.
36. Kumar, P., & Lee, H. J. (2012). Security issues in healthcare applications using wireless medical sensor networks: A survey. *sensors*, *12*(1), 55-91.
37. Todolí-Ferrandis, D., Silvestre-Blanes, J., Santonja-Climent, S., Sempere-Paya, V., & Vera-Pérez, J. (2018). Deploy&Forget wireless sensor networks for itinerant applications. *Computer Standards & Interfaces*, *56*, 27-40.
38. Rüth, J., Schmidt, F., Serror, M., Wehrle, K., & Zimmermann, T. (2017). Communication and Networking for the industrial Internet of Things. In *Industrial Internet of Things* (pp. 317-346). Springer, Cham.
39. Akkari, W., Bouhdid, B., & Belghith, A. (2015, January). LEATCH: Low Energy Adaptive Tier Clustering Hierarchy. In *ANT/SEIT* (pp. 365-372).
40. Pawa, T. D. S. (2011). *Analysis of low energy adaptive clustering hierarchy (LEACH) protocol* (Doctoral dissertation).
41. Agarwal, K., Agarwal, K., & Muruganandam, K. (2018, September). Low energy adaptive clustering hierarchy (leach) protocol: Simulation and analysis using matlab. In *2018 International Conference on Computing, Power and Communication Technologies (GUCON)* (pp. 60-64). IEEE.
42. Saha, A. K., Khan, M. S. U., & Rahman, M. M. (2019, December). Region based low energy adaptive clustering hierarchy (R-LEACH) protocol: prolonging the lifetime of WSN. In *Proceedings of the 6th International Conference on Networking, Systems and Security* (pp. 127-132).
43. Jan, B., Farman, H., Javed, H., Montrucchio, B., Khan, M., & Ali, S. (2017). Energy efficient hierarchical clustering approaches in wireless sensor networks: A survey. *Wireless Communications and Mobile Computing*, *2017*.
44. Azad, P., & Sharma, V. (2013). Cluster head selection in wireless sensor networks under fuzzy environment. *ISRN Sensor Networks*, *2013*.
45. Liu, Y., Wu, Q., Zhao, T., Tie, Y., Bai, F., & Jin, M. (2019). An improved energy-efficient routing protocol for wireless sensor networks. *Sensors*, *19*(20), 4579.
46. Baskaran, M., & Sadagopan, C. (2015). Synchronous firefly algorithm for cluster head selection in WSN. *The Scientific World Journal*, *2015*
47. Kang, S. H., & Nguyen, T. (2012). Distance based thresholds for cluster head selection in wireless sensor networks. *IEEE Communications Letters*, *16*(9), 1396-1399.
48. Jorio, A., El Fkihi, S., Elbhiri, B., & Aboutajdine, D. (2014). Low Energy Adaptive Clustering in Wireless Sensor Network Based on Spectral Clustering. *International Journal on Advances in Networks and Services Volume 7, Number 3 & 4, 2014*.
49. Comeau, F., & Aslam, N. (2011). Analysis of LEACH energy parameters. *Procedia Computer Science*, *5*, 933-938.
50. Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000, January). Energy-efficient communication protocol for wireless microsensor networks. In *Proceedings of the 33rd annual Hawaii international conference on system sciences* (pp. 10-pp). IEEE.
51. Arumugam, G. S., & Ponnuchamy, T. (2015). EE-LEACH: development of energy-efficient LEACH Protocol for data gathering in WSN. *EURASIP Journal on Wireless Communications and Networking*, *2015*(1), 1-9.
52. Del-Valle-Soto, C., Mex-Perera, C., Nolazco-Flores, J. A., Velázquez, R., & Rossa-Sierra, A. (2020). Wireless Sensor Network Energy Model and Its Use in the Optimization of Routing Protocols. *Energies*, *13*(3), 728.