KINETIK, Vol. 3, No. 4, November 2018, Pp. 327-336
ISSN : 2503-2259
E-ISSN : 2503-2267

An Election Energy Threshold Based Multi-Hop Routing Protocol in a Grid-Clustered Wireless Sensor Network

F. S. Dadah[*1], A. Ore-Ofe[2], A. D. Usman[3], Y. A. Mshelia[4], M. O. Babatunde[5]
[1,2,4]Ahmadu Bello University/Department of Communications Engineering
[3]Kaduna Polytechnic/Department of Electrical
[5]Federal University/ Department of Computer Engineering
funomdadah@gmail.com[*1], ajayi.oreofe@yahoo.com[2], aliyu_d_usman@yahoo.com[3], yalimshelia@yahoo.com[4], babatundemartins@gmail.com[5]

Abstract

Owing to the limited energy of sensor nodes (SNs) in a wireless sensor network (WSN), it is important to reduce and balance the energy consumption of the SNs in order to extend the WSN lifetime. Clustering mechanism is a highly efficient and effective mechanism for minimizing the amount of energy that SNs consume during the transmission of data packets. In this paper, an election energy threshold based multi-hop routing protocol (mEEMRP) is presented. In order to minimize energy consumption, this routing protocol uses grid clustering, where the network field is divided into grid clusters. SNs in each grid cluster select a cluster head (CH) based on a weight factor that takes the node location, node's residual energy (RE) as well as the node's distance from the base station into consideration. An energy efficient multi-hop routing algorithm is adopted during the transmission of data packets from the cluster heads (CHs) to the base station (BS). This multi-hop routing algorithm uses an election energy threshold value, T_{nhCH} that takes into consideration the RE of CHs as well as the distance between CHs. Simulation results show a 1.77% and 10.65% improvement in terms of network lifetime for two network field scenarios over Energy Efficient Multi-hop Routing Protocol (EEMRP).

Keywords: *Wireless Sensor Network, Energy Efficient, Grid Clustering, Multi-Hop Routing, Network Lifetime*

1. Introduction

A wireless sensor network (WSN) is a network that is made up of several sensor nodes (SNs) or motes that work cooperatively and communicate over wireless channels. The communication between the SNs is governed by unique routing protocols [1]. The SNs have data processing and communicating capabilities as well as a sensing circuitry that enables the SNs to sense environmental conditions. These environmental conditions help to provide certain details about the environment [2]. The SNs transmit their sensed information as electromagnetic signals to a base station (BS) either directly or through multi-hop routes or using intermediate nodes [3]. Due to the unique functions they perform, a WSN is often used in areas that are not easily accessible [4]. As a result of this, the batteries that power the SNs are not easily replaced or recharged. Since the SNs have several resource constraints [2], one of which is limited energy, it becomes necessary to conserve energy during the sensing and routing of data to the BS. This becomes necessary to avoid sensor holes within the network and to increase the network lifetime [5]. Network lifetime is the maximum period that SNs are alive after they have been deployed in a region [4]. One of the techniques that are used to reduce the amount of energy that SNs consume and provide balance between SNs is clustering [5]. The clustering technique involves dividing the network region into smaller regions called clusters and selecting specific SNs within each smaller region to serve as cluster head (CH) nodes with the rest of the SNs serving as ordinary nodes. A CH aggregates data from ordinary nodes within a cluster and transmitting the aggregated data to the BS either directly or through multi-hop routes [6]. Clustering also provides a viable means of providing balance between SNs and CHs so that no SN ends up doing more work than another. To prevent interference, time division multiple access (TDMA) slots are assigned to each SN with each SN having a unique time slot during which it can transmit data to its CH [7].

Dadah, F., Ore-Ofe, A., Usman, A., Mshelia, Y., & Babatunde, M. (2018). An Election Energy Threshold Based Multi-Hop Routing Protocol in a Grid-Clustered Wireless Sensor Network. Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control, 3(4), 327-336. doi:http://dx.doi.org/10.22219/kinetik.v3i4.661
Receive July 15, 2018; Revise September 26, 2018; Accepted September 26, 2018

2. Review of Similar Works

Proposed a WSN clustering algorithm based on energy information and CHs expectation called Low Energy Adaptive Clustering Hierarchy with Sliding Window and Dynamic number of Nodes (LEACH-SWDN) [8]. Results showed an improvement in the network lifetime and uniformity in energy consumption in the network cycle over Low Energy Adaptive Clustering Hierarchy (LEACH) protocol. [7] proposed an energy efficient threshold-based clustering protocol (a modified LEACH) for WSNs which provided a new way of creating distributed clusters. Simulation results showed improvement over LEACH in terms of time till first node dies and reduction in average residual energy. [9] proposed an application aware and heterogeneity aware routing protocol in WSNs called Application-aware Threshold-based Centralized Energy Efficient Clustering (ATCEEC). Results from simulation showed ATCEEC performed better than LEACH, Stable Election-based routing Protocol (SEP), Enhanced-SEP and Distributed Energy Efficient Clustering (DEEC) protocol in terms of stability period, network lifetime, instability period, number of CHs and the number of packets delivered to the BS. [10] proposed an energy efficient clustering algorithm (EECA) for fixed and mobile SNs by considering three scenarios; fixed nodes (EECA-F), constant mobility nodes (EECA-M1) and dynamic mobility nodes (EECA-M2). In all three scenarios, the respective protocols considered node degree, consumed energy of node and distance of the node from the BS. Results showed improvement in energy saving of SNs by reducing the power consumption of nodes. [11] proposed Yet Another LEACH (YA-LEACH). This routing protocol used centralized cluster formation to ensure optimal clusters and allow CHs to extend their operation into multiple rounds in order to achieve energy savings. Results from simulation showed an increase in network lifetime and data throughput. [1] proposed a novel cluster arrangement energy efficient routing protocol (CAERP). Improvements were obtained in terms of network lifetime and average residual energy. [12] proposed a novel energy aware hierarchical cluster-based (NEAHC) routing protocol to minimize total energy consumption and ensure fairness of energy consumption between nodes. Results that were obtained showed increase in network lifetime, energy consumption per round and reliable delivery of data packets to the BS. [13] proposed an energy efficient cross layer based adaptive threshold routing protocol for WSNs. The protocol was implemented on heterogeneous networks. Simulations results showed improvement over other routing protocols in terms of data packets received at the BS, number of nodes alive and network residual energy. [14] proposed an energy efficient multi-hop routing protocol (EEMRP) based on grid clustering to tackle the problem of unbalanced energy consumption of SNs. Simulation results showed a better performance of energy balance in larger networks and an extension in network lifetime compared to other routing protocols. [15] proposed a distributed energy-efficient clustering (DCE) protocol for heterogeneous WSNs based on double-phase CH election. Simulation results showed that the proposed DCE protocol performs better than other protocols in terms of stability period.

From the reviewed literatures, it is evident that the problem of limited energy of the SNs remains a major issue that needs to be addressed. This paper presents an election energy threshold based multi-hop routing protocol (*m*EEMRP) that uses grid clustering and an election energy threshold which determines next hop cluster heads (CHs) during the multi-hop routing of data to the BS.

2.1 Election Energy Threshold Based Multi-Hop Routing Protocol (*m*EEMRP)

The election energy threshold based multi-hop routing protocol (*m*EEMRP) is a protocol that uses grid clustering to achieve reduction in energy consumption of SNs as well as provide balance between SNs and CHs. The routing protocol uses an election energy threshold, T_{nhCH}, as a means of determining next hop CHs during the multi-hop routing of aggregated data from CHs to the BS.

2.2 Radio Energy Model

Energy consumption in WSNs consists of two parts [7]: transmitting data and receiving data. The amount of energy consumed when transmitting data is given as [6].

$$E_{Tx}(k, d) = E_{elec}.k + E_{amp}.k.d^{z} \quad (1)$$

Notation Equaiton 1:
E_{elec} is the transmitter circuitry dissipation per bit.
E_{amp} is the transmitter amplifier dissipation.

k is the bit length.
d is the distance of transmission between the transmitter and receiver.
z is the path loss exponent (with $2 \leq z \leq 4$).
The amount of energy consumed when receiving data is given as [7]:

$$E_{Rx}(k) = E_{elec} \times k \quad (2)$$

Notation Equation 2:
E_{elec} is the transmitter circuitry dissipation per bit
k is the bit length

Figure 1 shows the radio energy model as it applies to data transmission and reception.

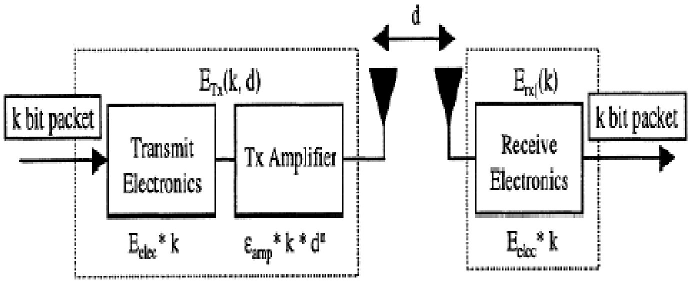

Figure 1. Radio Energy Dissipation Model [16]

2.3 Multi-hop Routing

Multi-hop routing in WSN is routing of sensed data to the BS through multiple hops, as opposed to sending such data directly to the BS [6]. Multi-hop routing among CHs entails forwarding aggregated data through multiple CHs to the BS [1] in every round. CHs close to the BS transmit data directly to the BS but where the distance between the CH and the BS is very large, more energy will be consumed in transmitting the sensed data to the BS according to the radio energy model [14], can be seen Figure 2.

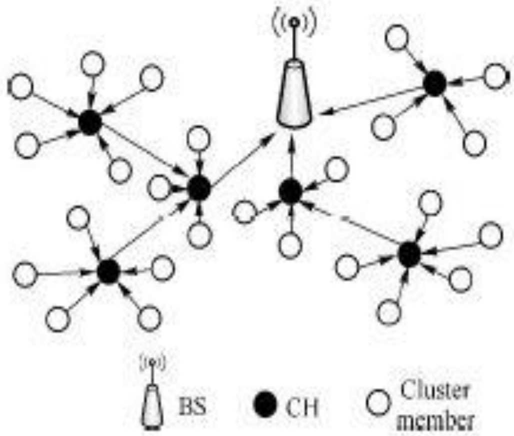

Figure 2. Network Topology Formed by Multi-hop Communication [12]

2.4 Cluster Head Selection Weight Factor

The *m*EEMRP protocol uses a weight factor in the selection of CHs for the multi-hop routing of data to the BS. This weight factor considers the RE of CHs and the distance of CHs from the BS. The weight factor, W_i^0, is represented as [14].

$$W_i^0 = \frac{E_i(t) - \propto \times E_r(t)av}{\propto \times E_r(t)av} \times \frac{d_{av}}{d_{(s_i, s_0)}} \quad (3)$$

if $E_i(t) > \alpha \times E_r(t)_{av}$

Notation Equation 3:
$E_i(t)$ is the residual energy of the i-th node
$E_r(t)_{av}$ is the average residual energy of the network in round r
α is the weighted coefficient of SNs, $0 < \alpha \leq 1$
$d(s_i,s_0)$ is the distance between SN i and the BS
d_{av} is the average distance between SNs and the BS

2.5 Election Energy Threshold (T_{nhCH})

During the network initialization, all SNs send their residual energy (RE) levels and location to the BS. This way, the BS has global knowledge of the entire network area. The election energy threshold presented in this paper is determined by taking the average value of the RE of neighbor CHs to a transmitting CH. The threshold is used to determine the appropriate CH to serve as a next hop during the routing of data to the BS. This is represented as.

$$T_{nhCH} = \frac{\sum_{n=1}^{m} \text{RE (neighbour CHs)}}{m} \quad (4)$$

Notation Equation 4:
T_{nhCH} is the election energy threshold
RE (neighbor CHs) is the residual energy of neighbor CHs
m is the number of neighbor CHs

The threshold value obtained from equation (3), along with the distances calculated as presented in Huang *et al*., (2017) of the neighboring CHs is used in determining the next hop in the establishment of the multi-hop route. A distance threshold value, d_0 is used to determine maximum transmission distance. This value is taken as 87.7m.

$$d_0 = \sqrt{\frac{E_{amp1}}{E_{amp2}}} \quad (5)$$

Notation Equation 5:
d_0 is the distance threshold
E_{amp1} is the amplifier transmitter dissipation if $d < d_0$ which is 10 pJ/bit/m^2
E_{amp2} is the amplifier transmitter dissipation if $d \geq d_0$ which is 0.0013 pJ/bit/m^2

2.6 Network Parameters

Two network scenarios were considered for the development of the *m*EEMRP. The two network scenarios were considered in order to show scalability of the routing protocol. The network scenarios considered are 200m^2 and 400m^2.
Other network parameters are presented thus:
1. The location of the BS and all sensor nodes are fixed.
2. The deployment of sensor nodes was random.
3. The number of SNs deployed is 400.
4. The location of the BS (100,200) is known in advance in the 200m^2 sensor field.
5. The location of the BS (200,400) is known in advance in the 400m^2 sensor field.
6. Rectangle numbers in the 200m^2 sensor field is 4.
7. Rectangle numbers in the 400m^2 sensor field is 8.
8. Rectangle width for both network scenarios is 50m.
9. The data packet size is 800 bits.
10. Initial energy of SNs is 0.5 J.
11. Grid numbers of each rectangle in the 200m^2 is: A = 4,4,4,4
12. Grid numbers of each rectangle in the 400m^2 is: A = 5,6,7,7,7,7,6,5
13. E_{amp1} is 10 pJ/bit/m^2
14. E_{amp2} is 0.0013 pJ/bit/m^2

2.7 Grid Clustering

Grid clusters are employed in this work as a means of reducing the amount of energy SNs consume and providing balance between SNs. The grid clusters are obtained by dividing the network area into rectangular grids (Huang *et al*., 2017). The grid clusters are obtained based on the network parameters presented and as presented in Figure 3.

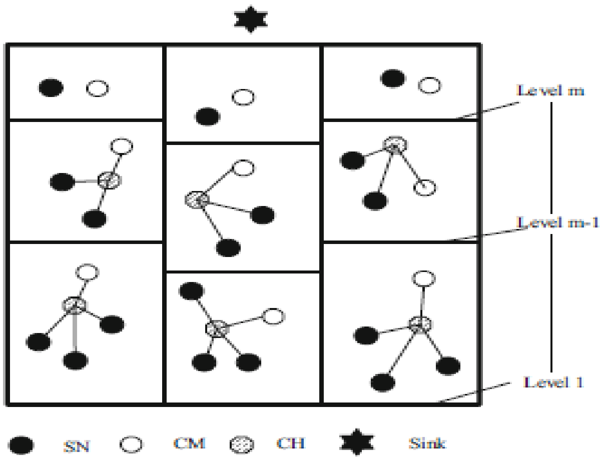

Figure 3. Network Area Division into Grids [14]

The energy efficient multi-hop routing protocol is presented in the flowchart shown in Figure 4.

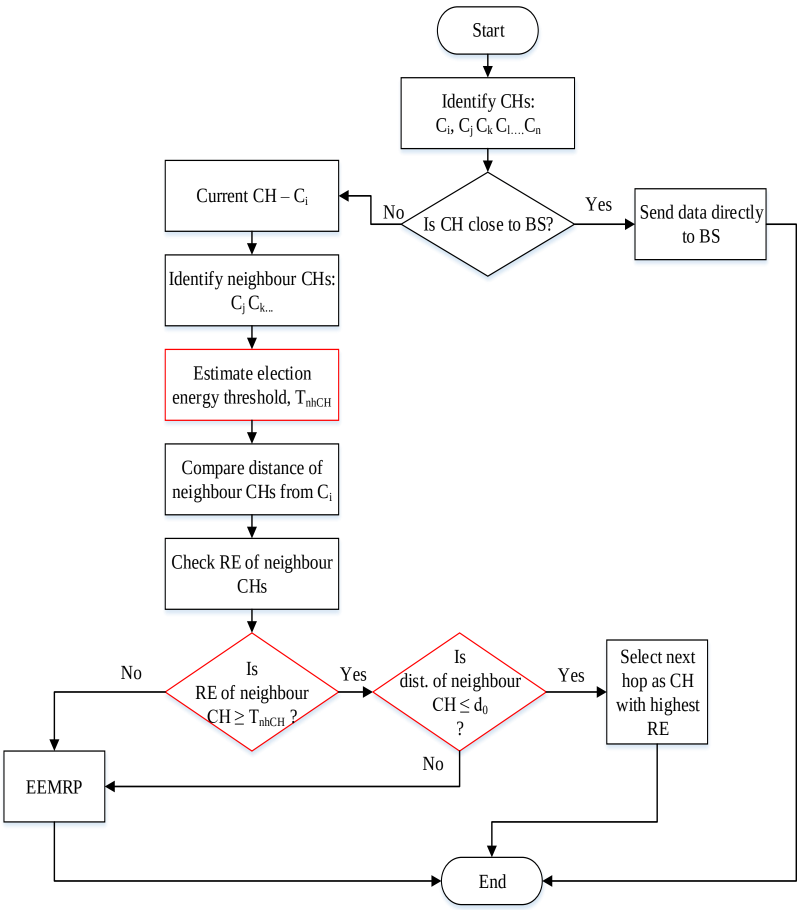

Figure 4. Flowchart of the Improved Multi-hop Routing Protocol (mEEMRP)

3. Results and Discussions

Simulations were carried out on MATLAB R2015b. The simulations were done for two network scenarios; 200m^2 and 400m^2. The results obtained are presented in the following sub-section.

3.1 200m^2 Network Field

The simulations carried out yielded results for network lifetime/node death percentage and energy consumption percentage.

3.1.1 Network Lifetime

Network lifetime is defined in terms of first node death (FND), half of nodes alive (HNA) or last node death (LND). In this paper, the network lifetime is taken as the time it takes for 100% of the nodes in the WSN to use up their energy and die (i.e LND).

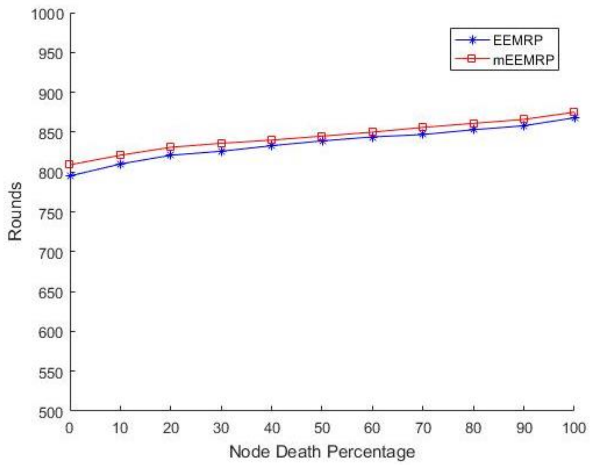

Figure 5. Node Death Percentage Plot for a 200m² Network Field

Figure 5 shows the plot of node death percentage against rounds. The result shows a 1.77% improvement in the network lifetime of the *m*EEMRP protocol over the EEMRP. This improvement is as a result of the election energy threshold that is used when data is routed to the BS. This ensures that the load is evenly distributed between the CHs. The results obtained are summarized in the Table 1.

Table 1. Summary of Results on Network Lifetime for a 200m² Network Field

Network Lifetime	EEMRP	mEEMRP	Percentage Improvement
FND	800	817	2.12%
LND	849	864	1.77%

3.1.2 Energy Consumption Percentage

Energy consumption percentage is the percentage of the total initial energy of the network that has been used as the network lifetime increases.

Figure 6 shows the result obtained for simulations carried out in a 200m^2 network field. The result shows an improved energy consumption plot for the *m*EEMRP compared to the EEMRP. The average percentage improvement of the *m*EEMRP over EEMRP is 4.83%. This is due to the election energy threshold that is adopted during the multi-hop routing of data to the BS. The threshold ensures that CHs with sufficient energy are selected as next hops during the multi-hop routing of data. A summary of the results obtained is presented in Table 2.

Table 2. Summary of Results on Energy Consumption Percentage for a 200m² Network Field

Percentage Interval (%)	No. of Rounds EEMRP	No. of Rounds mEEMRP
20	90	120
40	280	310
60	480	500
80	680	700
100	849	864
Average	475.8	498.8
Percentage Improvement	4.83%	

3.2 400m^2 Network Field

Simulations were carried for a 400m^2 network field and results for network lifetime/node death percentage and energy consumption percentage were obtained.

3.2.1 Network Lifetime

Network lifetime is taken as the time it takes for the last node in the network to die, i.e LND. Figure 7 shows the result for network lifetime in a 400m^2 network field. The *m*EEMRP yields a 10.65% improvement over EEMRP. This improvement is as a result of the election energy threshold that is adopted during the multi-hop routing of data to the BS. This ensures that the load is evenly distributed between the CHs. A summary of the results is presented in Table 3.

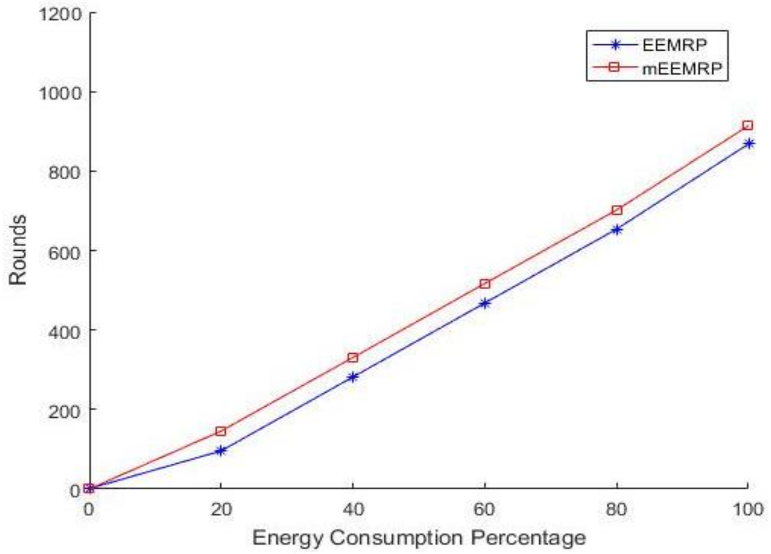

Figure 6. Energy Consumption Plot for a 200m^2 Network Field

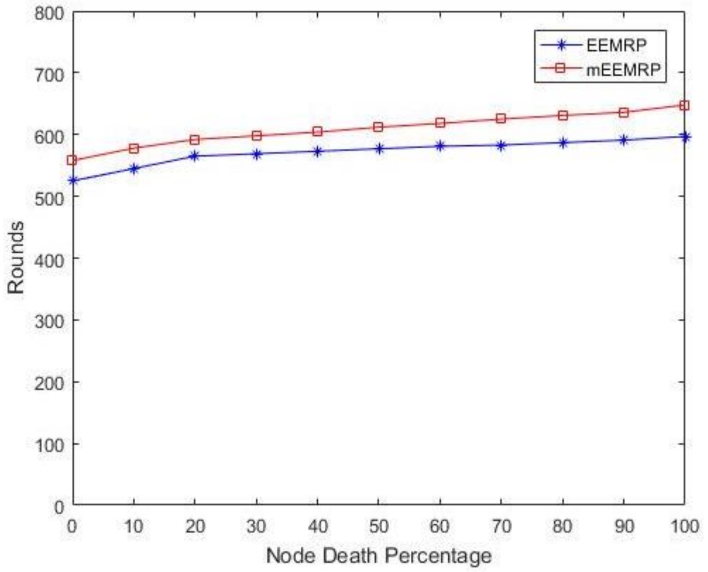

Figure 7. Node Death Percentage Plot for a 400m^2 Network Field

Table 3. Summary of Results on Node Death Percentage for 400m^2 Network Field

Network Lifetime	EEMRP	mEEMRP	Percentage Improvement
FND	523	564	7.84%
LND	601	665	10.65%

3.2.2 Energy Consumption Percentage

The result for energy consumption percentage in a 400m^2 is presented in Figure 8. The result obtained shows that *m*EEMRP has an improvement of 9.2% over EEMRP. This is due to the election energy threshold that is adopted during the multi-hop routing of data to the BS. The threshold ensures that CHs with sufficient energy are selected as next hops during the multi-hop routing of data. A summary of the result is presented in Table 4.

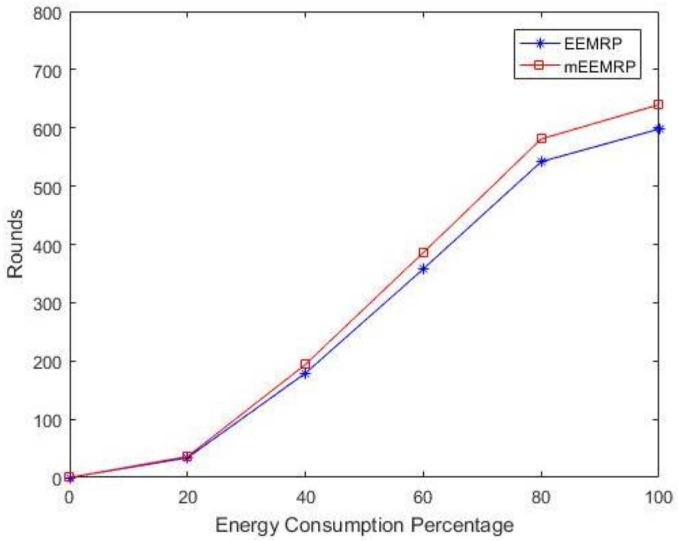

Figure 8. Energy Consumption Plot for a 400m^2 Network Field

Table 4. Summary of Results on Energy Consumption Percentage for a 400m^2 Network Field

Percentage Interval (%)	No. of Rounds EEMRP	No. of Rounds mEEMRP
20	30	30
40	280	300
60	450	480
80	530	590
100	601	665
Average	378.2	413
Percentage Improvement	9.2%	

4. Conclusion

In this paper, an election energy threshold based multi-hop routing protocol (*m*EEMRP) that uses grid clustering and an election energy threshold is presented. The routing protocol uses grid clustering where grid clusters close to the BS have smaller sizes and transmit data to the BS directly. Grid clusters that are located far away from the BS have larger sizes and transmit data to the BS through multi-hop routing so as to reduce energy consumed during data transmission. The sizes of clusters are varied based on distance from the BS so as to provide balance between the SNs in the network field.

Results from simulation show significant improvements in terms of network lifetime and energy consumption percentage for two network field scenarios when compared to EEMRP. The two network field scenarios were used to show that the routing protocol is scalable and applicable as network size increases.

As a recommendation for future work, this routing protocol can be implemented on mobile nodes and consider the effect of interference between neighboring CHs.

References

[1] K. Vijayan and A. Raaza, *"A Novel Cluster Arrangement Energy Efficient Routing Protocol for Wireless Sensor Networks,"* Indian Journal of science and Technology, Vol. 9, No. 2, 2016.

[2] K. Akkaya and M. Younis, *"A Survey on Routing Protocols for Wireless Sensor Networks,"* Ad Hoc Networks, Vol. 3, No. 3, Pp. 325–349, 2005.

[3] S. K. Gupta, Pratyay Kuila, and P. K. Jana, *"GA Based Energy Efficient and Balanced Routing in k-Connected Wireless Sensor Networks,"* in Proceedings of the First International Conference on Intelligent Computing and Communication, Pp. 679–686, 2017.

[4] M. Jan, P. Nanda, S. He, and R. Liu, *"Enhancing Lifetime and Quality of Data in Cluster-Based Hierarchical Routing Protocol for Wireless Sensor Network,"* in IEEE 10th International Conference on High Performance Computing and Communications, 2013.

[5] A. Nayyar and A. Gupta, *"A Comprehensive Review of Cluster-Based Energy Efficient Routing Protocols in Wireless Sensor Networks,"* IJRCCT, Vol. 3, No. 1, Pp. 104–110, 2014.

[6] P. Naranjo, M. Shojafar, A. Abraham, and E. Baccarelli, *"A New Stable Election-Based Routing Algorithm to Preserve Aliveness and Energy in Fog-Supported Wireless Sensor Networks,"* in IEEE International Conference on Systems, Man, and Cybernetics (SMC), 2016.

[7] M. Bsoul, A. Al-Khasawneh, A. E. Abdallah, E. E. Abdallah, and I. Obeidat, *"An Energy-Efficient Threshold-Based Clustering Protocol for Wireless Sensor Networks,"* Wireless Personal Communications, Vol. 70, No. 1, Pp. 99–112, May 2013.

[8] A. Wang, D. Yang, and D. Sun, *"A Clustering Algorithm Based on Energy Information and Cluster Heads Expectation for Wireless Sensor Networks,"* Computers & Electrical Engineering, Vol. 38, No. 3, Pp. 662–671, 2012.

[9] N. Javaid, M. Aslam, K. Djouani, Z. Khan, and T. Alghamdi, *"ATCEEC: A New Energy Efficient Routing Protocol for Wireless Sensor Networks,"* in IEEE International Conference on Communications (ICC), 2014.

[10] A. Guiloufi, N. Nasri, and A. Kachouri, *"Energy-Efficient Clustering Algorithms for Fixed and Mobile Wireless Sensor Networks,"* in International Wireless Communications and Mobile Computing Conference (IWCMC), 2014.

[11] W. Gwavava and O. Ramanaiah, *"YA-LEACH: Yet another LEACH for Wireless Sensor Networks,"* in International Conference on Information Processing (ICIP), 2015.

[12] W. Ke, O. Yangrui, J. Hong, Z. Heli, and L. Xi, *"Energy Aware Hierarchical Cluster-Based Routing Protocol for WSNs,"* Journal of China Universities of Posts and Telecommunications, Vol. 23, No. 4, Pp. 46–52, 2016.

[13] R. Singh and A. Verma, *"Energy Efficient Cross Layer Based Adaptive Threshold Routing Protocol for WSN,"* AEU-International Journal of Electronics and Communications, Vol. 72, Pp. 166–173, 2017.

[14] J. Huang, Y. Hong, Z. Zhao, and Y. Yuan, *"An Energy-Efficient Multi-Hop Routing Protocol Based on Grid Clustering for Wireless Sensor Networks,"* Cluster Computing, Vol. 20, No. 4, Pp. 3071–3083, Dec. 2017.

[15] R. Han, W. Yang, Y. Wang, and K. You, *"DCE: A Distributed Energy-Efficient Clustering Protocol for Wireless Sensor Network Based on Double-Phase Cluster-Head Election,"* Sensors, Vol. 17, No. 5, Pp. 998, 2017.

[16] Z. Ma, G. Li, and Q. Gong, *"Improvement on LEACH-C Protocol of Wireless Sensor Network (LEACH-CC),"* International Journal of Future Generation Communication and Networking, Vol. 9, No. 2, Pp. 183–192, 2016.