

An improved heterogeneous gateway-based energy-aware multi-hop routing protocol for wireless sensor networks

Safiyanu Muhammad Babale
Dept. of Electronics/
Telecommunication Engineering
ABU Zaria,
Zaria, Nigeria
sufymmr2010@bupoly.edu.ng

Abdoulie Momudou Sunkary
Tekanye
Dept. of Electronics/
Telecommunication Engineering
ABU Zaria
00000000/218-0892

Habib Bello
Dept. of Electronics/
Telecommunication Engineering
ABU Zaria
Zaria, Nigeria
bellohabeebu@gmail.com

Masud Ibrahim
Dept. of Electrical Engineering
Binyaminu Usman Polytechnic
Hadejia
Hadejia, Nigeria
masudibrahim@bupoly.edu.ng

Sulaiman Hassan
dept. of Electrical Engineering
Bupoly Hadejia
Hadejia Nigeria
sulaimanhassan4real@gmail.com

Yusuf Ismaila Pindiga
Department of Electrical/
Electronic Engineering
Uni. of Applied Scie. Eng. &
Tech. The Gambia
1111-2222-3333-4444

Abstract - The area of Wireless Sensor Networks (WSNs) is a branch of IoT which has been used in recent years to perform multiple tasks in various domains intelligently. This includes surveillance, data gathering, and data transmission from hazardous environments to safer destinations. Energy awareness is a critical design issue in WSN due to the imbalance of energy consumption among nodes, which among other issues (lifetime, etc) are challenges affecting WSN enhancement and performance. An Improved HMGEAR (IHMGEAR) is proposed. In this approach, the threshold probability for selecting CHs is modified to take into consideration the distance of the nodes to the gateway, as well as the residual energy of each node. In addition, the heterogeneity of the last two regions (R3 and R4) was modified by introducing two level heterogeneity in the last two regions. For the purpose of validation, the developed IHMGEAR scheme was compared with the HMGEAR protocol using the number of alive nodes per round, number of dead nodes per round, throughput, residual energy, and the number of packets received by the receiver as performance matrices. After performing simulation, the results show that the IHMGEAR outperformed HMGEAR by 16.68%, 17.89, 7.86%, 23.93%, 7.86% respectively.

Keywords—HMGEAR, IHMGEAR, Energy-Aware, Multi-hop, WSN, Gateway, Heterogeneity Wireless Sensor Networks

I. INTRODUCTION

(WSNs) are collection of sensor nodes that are normally used to sense physical or environmental conditions, such as temperature, sound, pressure, vibration, etc [1] They are nodes capable of collecting, processing, and transmitting data from critical terrains to safer locations. They are utilized in various applications, such as in agriculture, healthcare, environmental monitoring and military surveillance. WSNs have the capability to aggregate data

and forward it to the Base Station (BS) or sink for further processing. Basically, sensor nodes consume energy while transmitting, processing, or receiving information. These sensor nodes work under the use of non-rechargeable battery, which can last over several years or months[2]. Therefore, energy efficiency serves as the major objective of WSN and it is responsible for enhancing the life expectancy of the network. To minimize energy consumption in WSNs, many energy preservation techniques such as clustering, data aggregation, effective node deployment, cluster-based routing protocols, collection tree protocols, etc. have been developed[3]. Clustering is a technique in which network energy consumption is well managed by minimizing the transmission range of the sensors. In the clustering technique, the network is divided into groups called clusters, the Cluster Head (CH) manages the group communication with the BS. Sensor nodes no longer transmit data directly to the BS, instead, CHs receive the whole group messages, aggregates, and forwards to the BS A unique example of cluster based hierarchical protocol is the Low Energy Adaptive Clustering Hierarchical (LEACH) based routing protocol that provides the foundation of clustering [4]. In LEACH, every Sensor Node (SN) randomly chooses a number between 0 and 1. If this number is less than a threshold value, that SN is elected as the CH for that round. The threshold value gives eligibility to SNs that can serve as CHs for each round and it is obtained [4] using equation (1) below:

$$T(n) = \begin{cases} \frac{P}{1 - P * \left(r \bmod \left(\frac{1}{P} \right) \right)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where:

$T(n)$ denotes the threshold value

P is the desired percentage of CHs

r depicts the current round

G represents the set of nodes which have not been CHs in the last $1/P$ rounds

Equation (1) is used in every round to determine SNs which can be elected as CHs. Nodes that are selected to serve as CHs for each round announce themselves as CHs by sending broadcast messages to the network.

[5] Developed “An enhanced Heterogeneous Gateway based Energy-Aware Multi-hop Routing (HMGear) Protocol”. The scheme is based on the introduction of heterogeneous nodes in the regions that were far from the BS as well as employing multi-hop communication technique among nodes in all the regions. This reduced the energy depletion of distant nodes as they transmitted their reports to the BS. The scheme further implemented an energy hole removal mechanism to prevent holes that were created as a result of death of nodes. With this, nodes transmitted their data based on certain energy threshold below which they could not transmit. Each energy-saving technique introduced in this scheme resulted in low energy consumption.

II. LITERATURE REVIEW

Hierarchical routing protocols in WSNs, are seen as the most energy-efficient schemes and have been widely used. Any of the schemes divide the network into groups called clusters, with each cluster having a central node, called Cluster Head (CH) [4]. These heads receive the sensed data from the local nodes, aggregate the data and report to the Base Station (BS) through a single-hop or multi-hop communication approach depending on the distance from the BS. Some examples of such routing models can be found in [14–16]. In the related literature, there are several cluster-based routing algorithms that have been proposed in wireless sensor networks. In [6] a hierarchical based cluster head protocol proposed an Energy Efficient Clustering Protocol to Enhance Performance of Heterogeneous Wireless Sensor Network (EECP-HWSN). The novel protocol selected the best possible node to be the CH based on real time information, this enhanced stability period and lifetime by reducing energy consumption in the form of reducing internal overhead and cost of processing energy. [7] Developed a new Energy Aware Cluster Based Multi-hop (EACBM) Routing Protocol for heterogeneous networks. The proposed algorithm used the concept of clustering and multi-hop communication to reduce the energy consumption of SNs. Also, Sub-clustering concept was used for those SNs which were not included in any cluster, or which were out of the reach of CH. The basic operation of EACBM routing protocol was clustering and multi-hop data transmission. [8] Presented a Hybrid

Heterogeneous Routing Scheme for Improved Network Performance in WSNs for Animal Tracking. The author designed a hybrid system with sensor nodes having two different energy levels. The location of each type of node was fixed and cannot be altered. The author considered the network as a farm automation, where animals need to be monitored on daily basis, the base station has to be located at a remote place. Sensors were placed on all types of animals for monitoring their activities. The distance from BS for each section of livestock will vary according to its position. [9] Presented an Energy-Efficient Multilevel Heterogeneous Routing Protocol for Wireless Sensor Networks. In this paper, the proposed E-BEENISH enhanced balanced energy efficient network-integrated super-heterogeneous (E-BEENISH) routing protocol, that used single-hop communication for four-level heterogeneous WSNs, improving the lifecycle of the WSNs, the number of stable regions and throughput, through an improved new threshold algorithm. Moreover, in order to make full use of the network energy, the ratio of the remaining energy to the global average energy and the ratio of the distance from the member node to the BS and the CH to the BS are weighted as a scheme for selecting the CH. The drawback of this protocol was seen in the increase in computational complexity due to numerous weighing factors which have greatly affected the stability of the network. Additionally the algorithm introduces network delay and jitter caused by the data transmission process. [10] developed A Gateway Based Routing Protocol for Heterogeneous Wireless Sensor Networks (EAGBRP). Energy-aware gateway-based routing protocol (EAGBRP) was a geographical location based on a clustered heterogeneous routing protocol for WSNs. EAGBRP was an extension of M-GEAR. In M-GEAR, the sensor nodes are divided into four logical regions based on their location in the sensing field. The BS in M-GEAR is installed out of the sensing area and a GW node was installed at the center of the sensing area. [5] Developed “An enhanced Heterogeneous Gateway based Energy-Aware Multi-hop Routing (HMGear) Protocol”. The scheme was based on the introduction of heterogeneous nodes in the regions that were far from the BS as well as employing multi-hop communication technique among nodes in all the regions. This reduced the energy depletion of distant nodes as they transmitted their reports to the BS. The scheme further implemented an energy hole removal mechanism to prevent holes that were created as a result death of nodes. With this, nodes transmitted their data based on certain energy threshold below which they could not transmit. The scheme reduced the death rate of nodes. Each energy-saving technique introduced in this scheme resulted in low energy consumption. However, the threshold probability for selecting cluster heads (CHs) proposed by [9] was based on residual energy only. This affect the effectiveness of the network; this is because, when a node was selected from a far corner of the field as CH, it dissipated a large amount of energy to transmit the data to the GW, as a result the CH

died faster and this also affected the throughputs of the network. [11] Present a new hybrid energy-efficient protocol with the goal of reducing energy consumption, extending network stability, increasing network lifetime, and increasing throughput. The suggested method is an improved hybrid EEE-LEACH clustering procedure with round phases for each cycle. Instead of the two stages of the LEACH algorithm, the proposed protocol comprises four phases for each round; the first round involved selection of CH based on residual energy, the second phase involved selection of root node, this node act as gateway node and its function is to combined data from CHs and ANs for onward transmission to BS. In the third phase Every CH develops its routing table in this phase, which includes distances to all CHs, ANs, the root, and the BS. The same is true for ANs. However, the protocol is exceptionally complex in terms of computations which is due to the presence of too many coordinators used in the protocol. As a result the may experience jitter and delay. [12] Propose an efficient routing protocol for UAV-WSNs data collection to address the high energy consumption and premature death of some sensor nodes (SNs) caused by existing routing protocols. Firstly, the UAV-WSNs data collection framework is established, and a UAV communication coverage model is derived. Secondly, according to the data transmission link, the network area preliminarily was divided into air-to-ground routing area and ground-to-ground routing area. Based on this, a multi-hop routing protocol based on unequal-sized clustering is proposed to promote the balance of energy consumption between clusters. However, the design of the protocol struggled with centralized UAV control, this has led to excessive latency in data aggregation and UAV repositioning in a very large-scale network deployment. In addition, the protocol was not designed for movable node which is practical in real life applications such as wildlife tracking and disaster management. In this research, an Improved Heterogeneous Gateway-based Energy-Aware Multi-hop Routing (IHMGEAR) protocol is proposed. In this approach, the threshold probability for selecting CHs is modified to take into consideration the distance of the nodes to gateway as well as the residual energy of each node. Similarly, two level heterogeneity is also proposed in region 3 and 4 all these were done to further improve the network lifetime and increase the stability of the network.

III. METHODOLOGY

The network model which is based on [9] the network divides the sensor nodes into four logical regions on the basis of predefined threshold distance as shown in figure (1) . If nodes whose distance (D) is less than the predefined distance threshold (Dmax) and are closer to BS are deployed in Region 1 (R1), but nodes whose distance (D) is less than Dmax from BS and closer to GW are deployed in Region 2 (R2). The nodes whose distance is beyond the threshold distance are divided into equal Regions (R3 and R4), those that are closer to GW are deployed in R3, while those whose

distance (D) from the GW is greater than the predefined distance threshold (Dmax) and faraway from the GW are place in R4. Additionally the energy of nodes in R3 and R4 is heterogeneous in nature. This heterogeneity is of two level; advance and intermediate SNs for both R3 and R4. This was done to improve the energy balancing of the network.

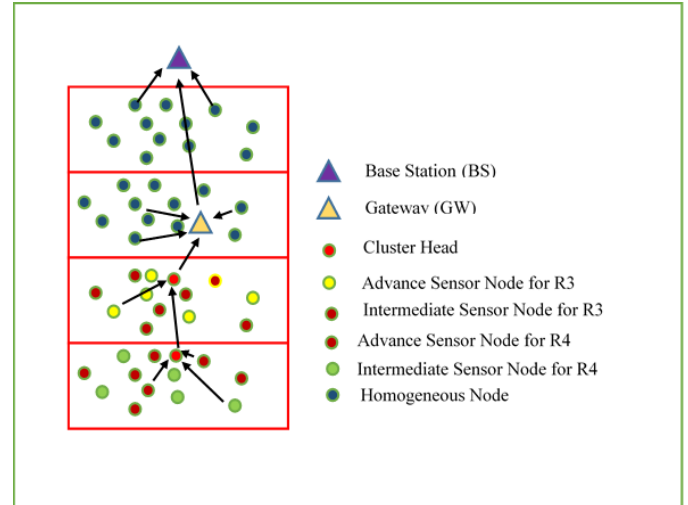


Figure 1: IHMGEAR Proposed Model

The selection probabilities for CHs selection are computed in R3 and R4 using equation (3.1), (3.2), (3.3) and (3.4). The computation of selection probability (P_Z) is based on the energy heterogeneity of the nodes in the two regions. Where $Z1$ can be $int1$ for intermediate SNs, or $adv1$ for advance SNs in R3, similarly $Z2$ can be $int2$ for intermediate SNs, or $adv2$ for advance SNs in R4.

Since $P(P_{adv}, P_{int})$ represents the CH probability, therefore the modified selection probabilities which is based on the work of Jibreel et al., (2022) for the two regions is given by equations (3.1), (3.2), (3.3) and (3.4) respectively:

$$P_{adv1} = \left(\frac{P_{opt}(1+b)}{1+am+bx} \right) \frac{E_i}{E_0} \quad (2)$$

$$P_{f1} = \left(\frac{P_{opt}(1+a)}{1+am+bx} \right) \frac{E_i}{E_0} \quad (3)$$

$$P_{adv2} = \left(\frac{P_{opt}(1+a)}{1+am+cx} \right) \frac{E_i}{E_0} \quad (4)$$

$$P_{f2} = \left(\frac{P_{opt}(1+c)}{1+am+cx} \right) \frac{E_i}{E_0} \quad (5)$$

where:

E_i represents the residual energy of the node

E_0 denotes the initial energy of the node

a, b, and c are the factors for advance sensor nodes and intermediate sensor nodes in the network.

x and m represent the percentage of sensor nodes equipped with a and b times more energy resources than the homogeneous sensor nodes in the network.

P_{opt} is the probability by which each node can become a CH *Authors and Affiliations*

1) Energy consumption model

The consumption of energy in a WSN is divided into two broad categories: transmitting data and receiving data. The amount of energy a sensor node dissipates during the transmission of data, $E_{Tx}(k,d)$ is due to the transmitter circuitry $E_{Tx-elec}(k)$ and the transmitter amplifier $E_{Tx-amp}(k,d)$ as well as the distance between the transmitter and the receiver (Nikolidakis et al., 2013). The energy $E_{(non-BS)}$ low energy sensor in Region 1 spent in relaying k bits report to BS is given by Equation (5)

$$E_{(non-BS)} = E_{TX}(K, d_{BS}) \quad (6)$$

where, d_{BS} is the distance between the homogeneous nodes in Region 1 and the BS.

Each low energy sensor in Region 2 (R2) spent its energy $E_{(non-gw)}$ in relaying k bits report to the GW node and is given by Equation (5) [9]

$$E_{(non-gw)} = E_{TX}(K, d_{gw}) \quad (7)$$

where, d_{gw} denotes the distance between the homogeneous nodes in R2 and the gateway node.

The energy $E_{(gw-BS)}$ spent by the GW node in receiving k bits of data from R2 and R3, aggregating them, and relaying the report to the BS is given by Equation (7) [9]:

$$E_{gw-BS} = kE_{elec} + kE_{elec} \left(\frac{n}{c}\right) + k \left(\frac{n}{c}\right) E_{DA} + E_{TX}(K, d_{BS}) \quad (8)$$

where:

E_{elec} represents the electronic energy of the transmitter

n denotes the number of nodes deployed in the network

c depicts the number of clusters in the network

E_{DA} stands for energy for data aggregation.

The energy spent in receiving and relaying k bits report by the cluster head CH1 in R3 to the GW node is given by Equation (8):

$$E_{CH1-gw} = kE_{elec} + kE_{elec} \left(\frac{n}{c} - 1\right) + E_{TX}(K, d_{gw}) \quad (9)$$

The energy spent in receiving and relaying k bits report from the Cluster Head (CH2) in R4 to the CH1 in R3 is given by Equation (9):

$$E_{CH2-CH1} = kE_{elec} + \left(\frac{n}{c} - 1\right) + E_{TX}(K, d_{CH1}) \quad (10)$$

where, d_{CH1} denotes the distance between the cluster heads in R3 and R4.

Total energy E_{Tused} in the network is given by Equation (10):

$$E_T = E_{non-BS} + E_{gw-BS} + E_{CH1-gw} + E_{CH2-CH1} \quad (11)$$

Similarly, the threshold value for CHs selection was modified to take into account, residual energy and distance between node to GW station as criteria for the selection of CHs in R3 and R4. A node is likely to be selected as CH if its distance to GW is nearly equal to the average distance of the network sensor node to gateway.

The threshold values are given by equation (12) and (13) respectively:

$$T(n)_{z1} = \begin{cases} \left(\frac{P_{z1}}{1 - P_{z1} \left(r \bmod \left(\frac{1}{P_{z1}} \right) \right)} \right) \left(\frac{|\alpha(iavg) + \beta(i,GW)|}{\alpha(iavg)} \right) & \text{if } n \in H_e \\ \text{Otherwise} & \end{cases}$$

(12)

where, H_e is the set of heterogeneous nodes that has not become a CH in the past $\frac{1}{P_z}$ round r in R3.

$$T(n)_{z2} = \begin{cases} \left(\frac{P_{z2}}{1 - P_{z2} \left(r \bmod \left(\frac{1}{P_{z2}} \right) \right)} \right) \left(\frac{|\alpha(iavg) + \beta(i,GW)|}{\alpha(iavg)} \right) & \text{if } n \in H_o \\ \text{Otherwise} & \end{cases}$$

(13)

where, H_o is the set of heterogeneous nodes that has not become a CH in the past $\frac{1}{P_{hetz}}$ round (r) in R4

$\beta(i, GW)$ is the distance of node i to GW

$\alpha(iavg)$ denotes the average distance of the network sensor nodes to the BS

$$\alpha(iavg) = [\alpha(1, GW) + \alpha(2, GW) + \alpha(3, GW) + \alpha(4, GW) + \alpha(5, GW) + \alpha(6, GW) + \dots + \alpha(N, GW)] / N \quad (14)$$

In the first round, CHs are elected separately in each of the non-clustered Regions (R3 and R4). The advance nodes are

considered as the first set of CHs on the basis of their higher energy. Then in the subsequent round, CHs are chosen based on their residual energy and their proximity to GW. Each node elects itself once every $(r_i 1/p)$ round, where r_i represents the number of rounds to be CH for the sets of node S_i . A node can become CH only once in an epoch $(1/p)$ and the nodes that were not elected as CH in the current round set C. Where C represents the set of nodes S_i that have not become CHs in the current round. The probability of a node to (belong to set C) increases in each round. The process is presented using pseudo code below:

Pseudo code: Choosing the first set of CH

```

1 Initialization
   N: Number of Sensor nodes in the network
2   Ei: Residual Energy of the node i
3   Eth1: Energy threshold for nodes in region 3
4   Eth4: Energy threshold for nodes in region 4
5   α(iavg): average distance of nodes to GW
6   β(i, GW) is the distance of node i to GW
7   p: probability of a node becoming a cluster head
8   C: Set of nodes that have not become CH in the last 1/p round
9   for each node in region 1
10  do:
11  determine Eth1, Eth1 and α(iavg)
12  Eth1 = maximum energy of distant node in region 3
13  Eth2 = maximum energy of distant node in region 4
14  α(iavg) = average distance of all the nodes to GW
15  if node i has not been a cluster head in the last  $r_i 1/p$ 
16  and
17  Ei > Eth1
18  and
19  β(i, GW) < α(iavg)
20  then node i is set to SCH in region 3
21  likewise
22  if node i has not been a cluster head in the last  $r_i 1/p$ 
23  and
24  Ei > Eth2
25  and
26  β(i, GW) < α(iavg)
27  then node i is set to SCH in region 4

```

IV. RESULT AND DISCUSSION

The results of the Improved Heterogeneous Gateway-based Energy-Aware Multi-hop Routing (IHMGEAR) and the Enhance Heterogeneous Gateway-based Energy-Aware Multi-hop Routing (HMGEAR) of [5] are discussed comparatively. Simulation is carried out using MATLAB 2018b to generate the results and the graphs. The results are compared in terms of Number of Nodes alive, Number of dead nodes, residual energy, throughput, and Number of packets received by Base station.

The simulation parameters are presented in the table below:

Table 1: Simulation Parameters

S/N	Parameter (unit)	Value
1	Network field	100m x 100m
2	Number of nodes	100
3	Initial energy of normal nodes (E_0)	0.5J
4	Message size	4000 bits
5	Radio electronics energy)	50Nj/bit
6	Free space energy (E_{fs})	10 Nj/bit/m ²
7	Amplification Energy (E_{mp})	0.0013Pj/bit/m ²
8	Probability (P_{opt})	0.1
9	Energy level for Advance nodes (adv1)	3
10	Energy level for intermediate nodes (int1)	2
11	Energy level for intermediate nodes (int2)	1.5
12	Energy level for Advance nodes (adv2)	2

A. Number of Nodes Alive per round

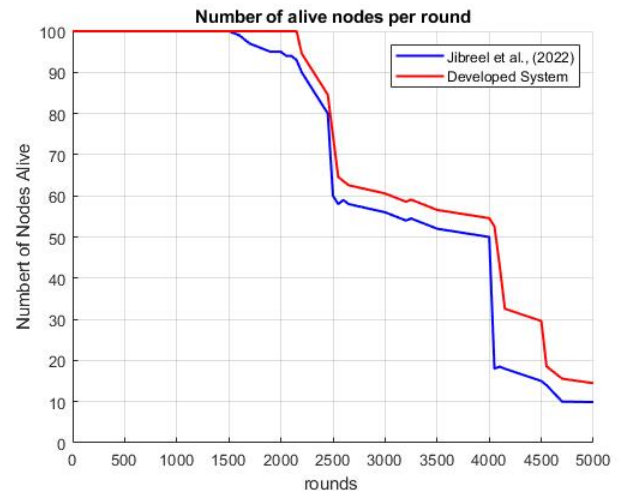


Figure 2: Number of Nodes Alive

The network number of nodes alive per round is studied and results are presented in Figure 2. The figure shows the number of active sensors for each clustering round in HMGEAR and the developed IHMGEAR protocol. As shown in the figure, all the 100 deployed nodes stay longer alive in the developed protocol when compared to the HMGEAR. It can be observed that the number of nodes alive has significantly increased after 1500th round, in addition, between 4000th to 4500 round there was a drastic drop in the percentage of the nodes alive, and this was also significantly improved. This has demonstrated better network stability in the in the developed protocol.

B. Number of Dead Nodes per Round

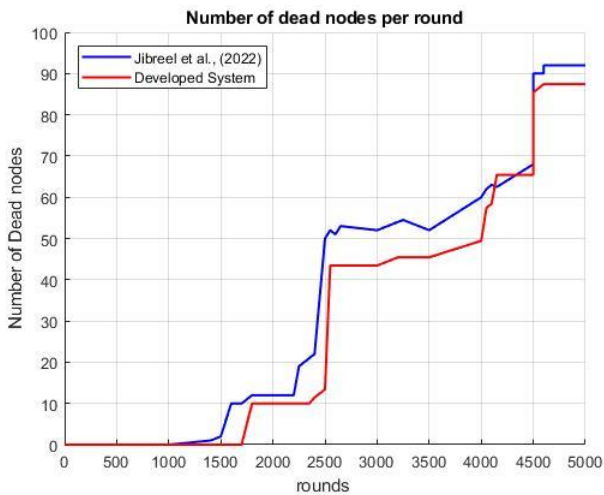


Figure 3: number of Dead Node per Round

Figure 3 shows the number of dead nodes per round, in a network for the developed IHMGEAR and the HMGEAR protocol. It is observed that the new protocol has a better stability period than the existing protocol. Figure 3 confirms the results presented in Figure 4 and shows that the proposed algorithm maintained a low death rate of the nodes for all rounds until all nodes are dead. It is observed from the Figure 4 that the death of the first node occurred after 1100 rounds in the HMGEAR protocol and after 1750 rounds in the developed protocol. As shown in figure 4., the IHMGEAR outperformed the HMGEAR with an average percentage improvement of 17.89% after 5000 rounds. This confirms that, for each round it safest to use IHMGEAR protocol.

C. Residual Energy

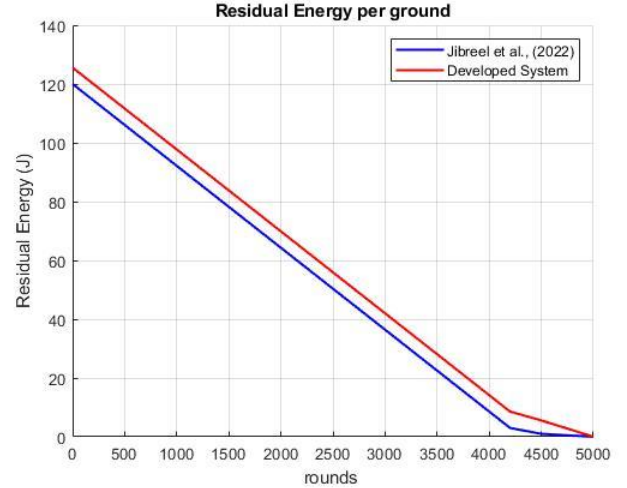


Figure 4: Residual Energy

Figure 4 shows the performance of the developed protocol in terms of residual energy per round in comparison to the existing HMGEAR protocol. It is noticed from the result in figure 4 that the developed scheme outperformed the HMGEAR protocol. The improvement was steady right from the 1st round up to the 4500th round as seen from the figure. Moreover, after about 4200th round the residual energy was zero for all the nodes in HMGEAR, which is in contrast to the modified scheme where the node maintains their energy until the last round. This is due to the introduction of two-level heterogeneity in R3 and R4 which further modified the selection probability of the nodes to save energy. Furthermore, the modification of the threshold value introduced in the scheme has ensured that only nodes that have highest residual energy and closest to the GW are selected as CHs, thus saving the energy of SNs.

D. Packet Sent to BS per round

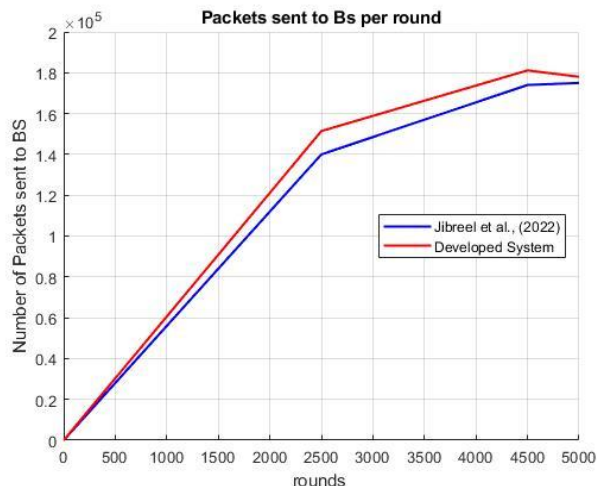


Figure 5: Packet Sent to BS per round

Figure 5 is a plot showing the performance of the developed IHMGEAR and the HMGEAR in terms of the number of packets sent to BS per round. This figure was generated to analyze how the two protocols paired in terms of throughput efficiency. The two protocols began with the same throughput rate, however after 1000th round noticeable improvement was observed. This improvement is as a result of the residual energy and distance criteria that were considered in electing the cluster heads. The nodes with high residual energy and also closer to GW are elected as the Cluster heads. Hence these nodes used less energy to transmit data to the BS. This translated to even more packets sent to the BS as a result of reduced in number of dead nodes.

E. Packet Received by BS per round

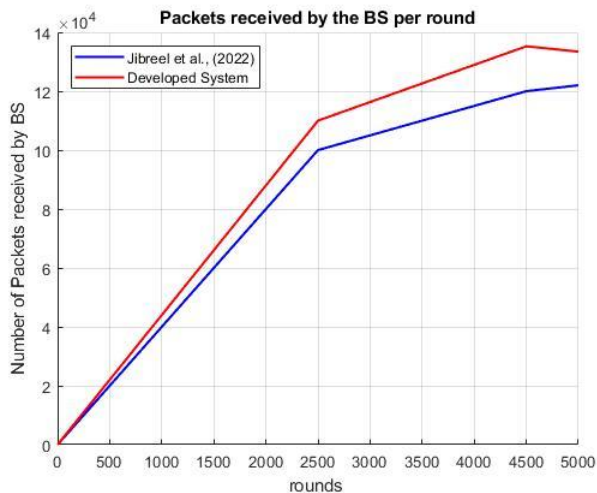


Figure 6: Packet Received by the BS per Round

Figure 6 shows the performance of the developed IHMGEAR and the HMGEAR protocol in terms of number of packets received by the BS per round. As seen from the figure, the BS received more packets in the developed

scheme when compared to the ones received by the HMGEAR protocol. This has demonstrated the superiority of the developed scheme over the existing HMGEAR protocol. This is due to more efficient energy conservation techniques employed in the developed scheme; this include sleep scheduling, threshold modification, and improved heterogeneity. This allow more data to be sent by the nodes to increase the rate of reception by the BS.

V. CONCLUSION

In this research, an Improved HMGEAR was developed, based on the work of [5] The aim of this work was to increase the effectiveness of the existing work by introducing two level heterogeneity in Regions R3 and R4 of the existing scheme. This was done in order to improve energy balance and increase the stability of the existing HMGEAR protocol to achieve optimum performance at reduced cost of resources. In addition, the threshold for the selection of CHs in the last two regions was modified to take into account the distance of nodes to the GW and its residual energy as selection criteria for CHs selection in the two regions. This was done so that only nodes that were closer to the GW and having higher residual energy were selected as CHs, which prevented distant and weak nodes from becoming CHs. Simulation was carried out to obtain the result that showed that the new scheme outperformed the existing scheme in terms of stability period, throughput, residual energy, and the number of packets sent to BS.

REFERENCE

- [1] 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 Comput.*, vol. 20, no. 4, pp. 3071–3083, 2017, doi: 10.1007/s10586-017-0993-2.
- [2] A. Sarkar and T. S. Murugan, "Cluster head selection for energy efficient and delay-less routing in wireless sensor network," p. 11276, 2019.
- [3] F. Jibreel, "Improved- Gateway-Based Energy-Aware Multi-Hop Routing Protocol for WSNs," *Int. J. Innov. Sci. Res. Technol.*, vol. 3, no. 12, pp. 2456–2165, 2018.
- [4] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in *Proceedings of the Annual Hawaii International Conference on System Sciences*, 2000.
- [5] F. Jibreel, E. Tuyishimire, and M. I. Daabo, "An Enhanced Heterogeneous Gateway-Based Energy-Aware Multi-Hop Routing Protocol for Wireless Sensor Networks," *Inf.*, vol. 13, no. 4, pp. 1–15, 2022, doi: 10.3390/info13040166.
- [6] S. V Purkar and R. S. Deshpande, "Energy Efficient Clustering Protocol to Enhance Performance of Heterogeneous Wireless Sensor Network: EECPEP-HWSN," *J. Comput. Networks Commun.*, vol. 2018,

2018, doi: 10.1155/2018/2078627.

- [7] A. S. Toor and A. K. Jain, "A new Energy Aware Cluster Based Multi-hop Energy Efficient routing protocol for Wireless Sensor Networks," in *2018 6th IEEE International Conference on Smart Energy Grid Engineering, SEGE 2018*, IEEE, 2018, pp. 133–137. doi: 10.1109/SEGE.2018.8499464.
- [8] T. M. Behera, S. K. Mohapatra, U. C. Samal, and M. S. Khan, "Hybrid heterogeneous routing scheme for improved network performance in WSNs for animal tracking," *Internet of Things (Netherlands)*, vol. 6, 2019, doi: 10.1016/j.iot.2019.03.001.
- [9] Y. Zhang, X. Zhang, S. Ning, J. Gao, and Y. Liu, "Energy-Efficient Multilevel Heterogeneous Routing Protocol for Wireless Sensor Networks," *IEEE Access*, vol. 7, pp. 55873–55884, 2019, doi: 10.1109/ACCESS.2019.2900742.
- [10] M. M. Hoque, M. G. Rashed, M. H. Kabir, A. F. M. Z. Abadin, and M. I. Pramanik, "EAGBRP: A Gateway Based Routing Protocol for Heterogeneous Wireless Sensor Networks," *J. Sci. Res.*, vol. 13, no. 2, pp. 467–481, 2021, doi: 10.3329/jsr.v13i2.50005.
- [11] H. U. Rahman, A. Ghani, I. Khan, N. Ahmad, S. Vimal, and M. Bilal, "Improving network efficiency in wireless body area networks using dual forwarder selection technique," *Pers. Ubiquitous Comput.*, vol. 26, no. 1, pp. 11–24, 2022, doi: 10.1007/s00779-021-01539-y.
- [12] Y. Xiuwu, L. Qin, L. Yong, H. Mufang, Z. Ke, and X. Renrong, "Uneven clustering routing algorithm based on glowworm swarm optimization," *Ad Hoc Networks*, vol. 93, p. 101923, 2019, doi: 10.1016/j.adhoc.2019.101923.