



## Energy Harvesting Aware Nano-Backup Clustering Algorithm for Wireless Nano Sensor Network

<sup>1</sup>Sikiru Olayinka Zakariyya, <sup>2</sup>Aliyu D Usman, <sup>2</sup>Abdoulie M. S Tekanyi, <sup>2</sup>Abdulmalik Shehu Yaro

<sup>1</sup>Department of Electrical and Electronics Engineering,  
University of Ilorin, Ilorin Kwara State

<sup>2</sup>Department of Electronics and Telecommunications Engineering,  
Faculty of Engineering,  
Ahmadu Bello University, Zaria

### ABSTRACT

Wireless communication between nanoscale devices in the terahertz band is receiving a lot of attention recently. Wireless Nano sensor networks are becoming a feasible means for medical monitoring application. Due to the critical nature of this application, the transmission of sensed data from the body to the Nano controller is crucial where there is no tolerant for data loss. With a view of conserving energy and extending network lifetime, a cluster-based algorithm has been proposed. However, the performance of clustering algorithms is limited by poor cluster formation and failure of nano-cluster head. As a result, some nano-nodes die faster that shorten overall network lifetime and reduce data reliability. In this paper, a nano backup cluster head scheme based on concentric layer architecture model is proposed to increase the network lifetime and reliability. The cluster formation model ensures nodes are distributed fairly at each layer to avoid inefficient clustering. The backup clustering algorithm addresses the problem of nano-cluster head failures in order to avoid interruption in data transmission. Performance of the proposed protocol was benchmarked against Energy-balanced Clustering routing protocol. Simulation results showed that the proposed protocol is effective in prolonging the network lifetime compared to the Energy-balanced Clustering routing protocol.

### ARTICLE INFO

#### Article History

Received: October, 2021

Received in revised form: November, 2021

Accepted: January, 2022

Published online: March, 2022

### KEYWORDS

Nanosensor; Routing; Clustering; Backup;  
Concentric

### INTRODUCTION

The creation of devices in a scale ranging from one to few hundred nanometers has been enabled by the advent of nanotechnology. Nano-machines integrated by nano-components (nano-batteries, nano-memories, nano-antennas) and capable of performing simple tasks, including sensing or actuation, can be referred to as the most essential functional unit at Nano-scale. Due to the small size and low complexity of an individual nano-machine, it can only execute a very simple task limited to its close environment. Coordination and sharing of information between several nanomachines will increase their probable implementation both in complexity and operation span of the individual devices (Akyildis et al., 2008; Akyildis & Jornet, 2010). The resulting Nano-sensor networks will have the ability to extend

over larger areas, non-invasively reach uncommon area and perform additional processing. The WNSN applications are unlimited and they can be applied to any field of life. WNSN applications could be classified as following: biomedical, environmental, industrial and military applications (Akyildis & Jornet, 2010). Moreover, considering of using nanotechnologies in manufacturing of different nanodevices, WNSN could be used also in other life activities such as consumer electronics, lifestyle, home appliances among others. The nanodevice range of communication as well as the overall performance of the wireless nanosensor network is affected mainly by the path loss of the terahertz frequency band and also by the very limited nanodevice resources and capacity. For that reason, there is a need for a suitable routing protocol that will guarantee



multihop communication in wireless nanosensor network (Pierobon et al., 2013).

Routing is a key role of the network layer of the communication protocol stack and it is defined as the process of establishing paths through one or several relays from a source to a sink. The routing protocols research in WSNs is still at an early stage as only a few categories of routing protocols such as the flooding base protocols, proximity routing and energy harvesting based routing protocol have been proposed (Yao et al., 2019).

The flooding-based protocol is considered to be the simplest amongst the aforementioned protocols based on its consistency with the energy and computation power of the nanonode (Yalgashev et al., 2015). But, the excessive transmission and broadcast storm nature of the flooding technique will increase nanonode energy consumption. With a view to improve the performance of flooding-based routing protocol, proximity routing protocol among which is CORONA was proposed (Tsioliariidou et al., 2015; Xu et al., 2016). In CORONA, nodes were categorized in the network into an anchor and user node which is effective for point to point communication. Although, terahertz channel attenuation characteristics were not considered. In an attempt to resolve the issue linked with CORONA, EEMR protocol was proposed (Xu et al., 2016). Nevertheless, failures of nano-nodes due to energy exhaustion was not considered by the protocol. The energy harvesting routing protocol is the most suitable protocol for self-energized nanonode as it aimed towards balancing the harvested and the consumed energy by the nano-node in the network for longer time operation. The first routing framework proposed for WSNs based on energy harvesting establish multi-hop routing based on features of terahertz channel (Pierobon et al., 2013). The protocol was reported to increase the throughput as well as reducing the energy consumption but with high computational complexity which may hamper its use in practice. An energy harvesting protocol based on greedy and optimal approach was proposed with the purpose of merging the Body area nanonetwork (BANNET) and a macroscale health monitoring system (Piro et al., 2014). This protocol incorporates both routing and MAC algorithm

that regulates nano-nodes communication. Though, the use of handshake mechanism limit the performance gain of the protocol in relation to flooding scheme. An On-Off Keying based TDMA protocol was developed for the monitoring of intrabody disease. A cylindrical hexagonal cell-based network architecture was assumed based on the fact that the nano patch antennas are graphene-based in a honeycomb crystal lattice (Lee et al., 2015). However, the protocol did not give attention to the energy harvesting process of the nanosensor node. In order to improve the protocol developed in the work of (Piro et al., 2014), an efficient means of data collection was developed in a Body Area Nanonetwork by considering the transmission path loss (Liu et al., 2017). The scheme was heavily dependent on the distance of a nanonode and associated nanorouter. Although, a nanonode outside the coverage of a nanorouter need to wait until it receives a signal by one of the available nanorouter which results into delay.

An artificial bee colony algorithm based routing was proposed for intrabody health monitoring in the work of Fahim et al (Fahim et al., 2020). The algorithm exhibit an improve performance in comparison with the flooding scheme. But, a nanonode outside the coverage of a nanorouter need to wait until it receives a signal by one of the available nanorouter which results into delay. In order to improve the performance of nano-nodes communicating at terahertz frequency, an energy-conserving routing method using a hybrid cluster with centralized scheduling was proposed (Afsana et al., 2018). NANO-SIM was employed in simulating the ECR scheme and the performance was evaluated in terms of outage probability, outage capacity and energy efficiency. It was reported from the simulation result that the ECR scheme balance the energy consumed in WSNs and also reduce the data collision due to the multilayer topology and transmission time allocation. However, consideration is not given to failure of cluster head which might results into loss of data packets. However, a reasonable mechanism for updating the cluster head is not provided. Finally, energy balanced routing protocol for intrabody wireless nanosensor network was proposed (Xu et al., 2019). Intra cluster transmission between nano-nodes and cluster head is in a cluster is achieved using one hop

while the multihop transmission is used between cluster head and the nano controller. However, consideration is not given to failure of cluster head which might results into loss of data packets.

Cluster based routing protocol has been proposed in conventional wireless sensor network (WSN) to improve network performance (Salami et al., 2019; Behara et al., 2019). Although, the existing routing protocol in the WSN is not directly applicable to WNSN due to their nano-scale properties which limit the amount of complex protocol that could be run on them (Canovas-Carrasco et al., 2016; Rikhtegar et al., 2017). For that reason, a new cluster based propotol for body nanosensor network has been proposed to address the nanosensor nodes challenges (Afsana et al., 2018; Xu et al., 2019). For example, Afsana et al, (2018) proposed an energy conserving routing protocol with the aim of improving the performanc of communicating nanonode using a hybrid clustering technique. The protocol was able to balance the energy consumed in the network. Also, Xu et al, (2019) proposed an energy balanced clustering routing protocol for intrabody wireless nanosensor network with the aim of improving network lifetime and conserving energy. Even if clustering can decrease energy consumption, its main problem is that energy consumption is focused on the NCHs (Canovas-Carrasco et al., 2018). The NCH nodes deplete energy faster than non-NCH nodes as they need to perform more tasks. Moreover, due to the multi-hop routing nature of a WNSN, the nodes along the routing paths tend to have heavier workload and consequently deplete their energy faster than other nodes (Zakariyya et al., 2020). During the data transmission phase, if the energy of a CH depletes below the required energy to perform inter-cluster transmission, all the data gathered by the cluster head will be lost and the coverage of the cluster is in danger. As a result, some nano-nodes die faster that shorten overall network lifetime and reduce data reliability. Hence, there is a need to carefully develop a cluster based wireless nanosensor network protocol to improve data transmission and prolong network lifetime with minimum energy consumption.

This work addresses these cluster-related problems by proposing an Energy

harvesting aware nano-backup clustering algorithm for wireless nanosensor network. In this paper, a concentric layer architecture cluster formation model and a nano-backup clustering algorithm were developed for the operation of the proposed scheme. The cluster formation model ensures node are distributed fairly at each layer to avoid inefficient clustering. The backup clustering algorithm addresses the problem of NCH failures which prevents the NCH from exhausting its energy in order to avoid interruption in data transmission and prolong network lifetime.

### ENERGY CONSUMPTION MODEL

The energy consumed in transmitting and receiving data are the major energy consumed by the deployed nanonodes in the nanosensor network. If the amount of energy required to transmit a pulse and to transmit a packet of  $x$  bits as well as to receive a pulse and to receive a packet of  $x$  bits by a nanonode is given as  $E_p^{tx}$ ,  $E^{tx}(x)$ ,  $E_p^{rx}$ ,  $E^{rx}(x)$ , respectively. By adopting time spread on-off keying modulation scheme, where in transmitting a message the presence of a pulse for a specific duration represents a bit 1 while its absence represents a bit 0, Jornet and Akyildis reported that the energy required to transmit a pulse and energy required to receive a pulse is equal to 1 pJ and 0.1 pJ respectively that is (Jornet & Akyildis, 2011):

$$E_p^{rx} = \frac{E_p^{tx}}{10} \quad (1)$$

It is important to note that energy is consumed by the transmitter only when it transmits a pulse (that is, bit 1), whereas energy is consumed by the receiver whenever it receives a bit 1 or bit 0. Moreover, by considering a packet of  $x$  bits, the energy required to handle the transmission and reception are respectively defined as:

$$E^{tx}(x) = x \cdot w \cdot E_p^{tx} \quad (2)$$

$$E^{rx}(x) = x \cdot E_p^{rx} \quad (3)$$

Where,  $x$  denotes the number of packets and  $w$  represents the coding weight and is generally set to 0.5

### NETWORK ARCHITECTURE

In The network is structured into  $L$  layers such that the nano-nodes can easily locate the layers on which they belong to. This

work is based on the assumption that the network field is circular as depicted in Figure 1.

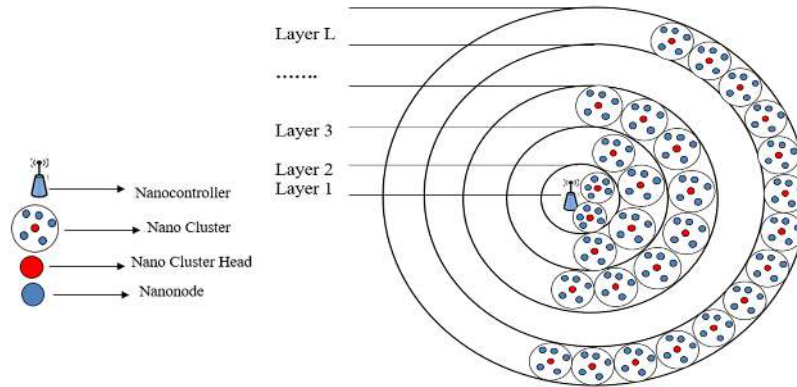


Figure 1: Layers of Nano-Clusters

Each layer has a radius of  $Lr_{xx}/2$ , where  $L$  is the number of layers, and  $r_{xx}$  is the transmission range of each nano-node. The layers are separated in such a way that any nano-node of a given layer covers its neighboring layers throughout the transmission range.

When a transmitted message ( $T_{xx}$ ) is obtained from Nano-Controller (NC), all nanonodes measure their distances ( $dx$ ) from NC, equate the layer radius with their distances, and register themselves to appropriate layers as presented in the layering and cluster formation algorithm.

#### Derivation of Nanonode Distribution Formula in Each Layer

Definition: Suppose there are  $N$  nano-nodes deployed in the network as shown in Figure 1, where  $N$  is the set of nano-nodes that is,  $N = \{1, 2, 3, \dots, N\}$ . With respect to the nano-controller, the network is divided into several layers,  $L$  with each layer having different clusters  $K$ . Presume there are  $M$  nanonodes in the cluster. Let  $M$  be the set of nano-nodes in the nano-cluster, that is  $M = \{1, 2, 3, \dots, M\}$  where,  $M \in N$ . Assuming a fair distribution of nano-nodes at each layer such that higher layer has twice the number of nodes than lower layer. This helps in avoiding inefficient clustering (node uncertainty). Let the number of nanonodes at the  $i^{th}$  layer be denoted as  $(L_i)$ . Based on the assumption, this is expressed mathematically as:

$$L_{i+1} = 2 \times L_i \quad (4)$$

For the sake of derivation, the number of nodes at layer 1 is denoted as  $n$  nodes and applying equation (4), it is observed that layer 2 has  $2n$  nodes, layer 3 has  $4n$  nodes, and so on. The nodes at each layer is in the form of series as presented in equation (5).

$$N = n + 2n + 4n + \dots + kn \quad (5)$$

Equation (5) follows a Geometric Progression (GP) series and is rewriting as:

$$S_n = n \times 2^{i-1} \quad (6)$$

where,  $n$  denotes the number of nano-nodes and  $i$  is the number of layers. From equation (6), it is observed that nodes at each layer are fairly distributed. Furthermore, it is necessary to ensure nodes are divided unbiasedly at each layer. For that reason, assume  $a$  is the maximum number of layers. Since  $N$  is defined as the total number of deployed nano-nodes, hence, the layer wise division of the nano-nodes ( $L_d$ ) is expressed as:

$$L_d = \frac{N}{2^{a-1}} \quad (7)$$

Since it is already established that nodes are fairly distributed at each layer in equation (6), then, the number of nodes in each layer is determined by combining equation (6) and equation (7) as follows:

$$L_i = 2^{i-1} \times \frac{N}{2^{a-1}} \quad (8)$$

where,  $L_i$  is the number of nano-nodes in the  $i^{th}$  layer and  $a$  is the maximum number of layers.

#### Deployment of Nano-node in the Network Architecture

In a circular region, the positions of the deployed nano-nodes in  $x$  and  $y$

coordinates are determined as follows (Akbar et al, 2016):

$$x_{node} = x_0 + R \cos(t) \quad (9)$$

$$y_{node} = y_0 + R \sin(t) \quad (10)$$

where:

$x_{node}$  represents x position of the nano-nodes  
 $y_{node}$  corresponds to y position of the nano-nodes

$x_0$  denotes the origin (x-center of the circle)  
 $y_0$  stands for the origin (y-center of the circle)  
 $R$  is the radius of the circle  
 $t$  represents the angle at which the nodes are distributed, where,  $0 \leq t \leq 2\pi$

For a network with different layers and clusters, the x and y coordinates of the nano-nodes are given in the same way as for circular region, where the value of  $R$  and  $t$  varies for each layer and cluster as follows:

$$x_{node,ij} = x_0 + R_i \cos(t_{ij}) \quad (11)$$

$$y_{node,ij} = y_0 + R_i \sin(t_{ij}) \quad (12)$$

where,  $i$  denotes number of layers and  $j$  represents the number of clusters.

However,  $j$  varies for each  $i$  as follows:

$$j = \begin{cases} 1, \dots, 2 & \text{for } i = 1 \\ 1, \dots, 4 & \text{for } i = 2 \\ 1, \dots, 8 & \text{for } i = 3 \end{cases} \quad (13)$$

The followings are the notations of the elements used in the layering and cluster formation algorithm:

$n$  is the number of deployed nano-nodes

$d_{n,NC}^i$  denotes the  $i^{th}$  nano-nodes distance from the nano-controller

$L_i$  represents the  $i^{th}$  layer number to which nano-node is assigned

$a$  stands for the maximum number of layers

$r_{xx}$  corresponds to the transmission range of each nano-node

#### Algorithm 1: Layering and Cluster Formation Algorithm

Input:  $r_{xx}$ ,  $n$ ,  $a$

Output:  $L_i$ ,  $R_i$

1. for  $i = 1: a$
2. Determine the radius of each layer using  $R_i = ir_{xx}/2$
3. Calculate the number of nodes per layer using equation (8)
4. end for
5. Deploy the nano-nodes using equation (9) - (12)
6. for each nano-nodes do
7. Compute the distance  $d_{n,NC}^i$  between  $i^{th}$  nano-nodes and the nano-controller using equation (14)
8. 
$$d_{n,NC}^i = \sqrt{(X_{NC} - X_n)^2 + (Y_{NC} - Y_n)^2} \quad (14)$$
9. if  $(d_{n,NC}^i \leq R_1)$  then
10.  $n \in L_1$
11. if  $(d_{n,NC}^i \leq R_2)$  then
12.  $n \in L_2$
13. if  $(d_{n,NC}^i \leq R_3)$  then
14.  $n \in L_3$
15. end if
16. end if
17. end if
18. end for

#### Clustering and Nano-Backup Cluster Head Selection Algorithm

To achieve smooth communication of nano-nodes in a nano-sensor network, the backup clustering algorithm is required to be developed. The assignment of all nano-nodes to their respective layers is preceded by the

nano-cluster head election, where the preliminary NCHs are chosen automatically based on their residual energy. Let  $N$  be the total number of nano-nodes in the  $L^{th}$  layer. The NCH for each cluster layer is determined as follows:

- i. For  $n = 1$  to  $N$ , determine the energy weight ratio  $w_n$  using equation (15)
 
$$w_n = \frac{E_{rn}}{E_m} \quad (15)$$
 where,  $E_{rn}$  is the residual energy of  $n^{th}$  nano-node and  $E_m$  denotes the maximum energy which corresponds to the initial energy of all nano-node.
- ii. Each nano-node multicast their weight ratio obtained in equation (15) to neighbouring nano-node in a cluster.
- iii. The nano-nodes with the largest  $w_n$  value obtained from equation (15) is declared as the NCH of that particular cluster using equation (16).

$$NCH = \max [w_n] \text{ for } n = 1 \text{ to } N \quad (16)$$

Upon the completion of nano cluster head election, the new NCHs multicast short range messages to all other nano-nodes within the same cluster informing them about its new status. The second best Nano-Cluster Member (NCM) with high residual energy will be saved as the Nano-Backup Cluster Head (NBCH) in each cluster for the current NCH. To reduce clustering overhead, clustering is done only once for the whole network. Only the NCH and NBCH are changed after each transmission.

### Algorithm 2: Nano Cluster Head and Back-up Selection Algorithm

**Input:**  $E_{rn}, E_m$

**Output:**  $NCH, BCH$

1. **for** each deployed nano-nodes
2.     Calculate the energy weight ratio ( $w_n$ ) of the nano-nodes using equation (15)
3.     All nano-nodes multicast their  $w_n$  to other nodes in their associated cluster
4.     **if** nano-node weight is the maximum ( $w_{nmax}$ ) **then**
5.         Nano-node is the NCH
6.     **else**
7.         Nano-node is normal node
8.     **end if**
9. **end for**
10. NCHs multicast short range messages to all other nano nodes within the same cluster
11. NCH assign the second best NCM with high residual energy as NBCH

### Nano-node Communication Mechanism

A dynamic TDMA based scheduling is employed to forward the sensed data to the NC. This is because classical TDMA is not applied as time slot is allocated to nano-nodes based on the available data for transmission rather than fix time allocation, where time slot is wasted when a nano-node has no data to transmit. This involves the nano-controller seeking data transmission request from all nano-nodes periodically. The nodes with data to transmit respond by sending a data

transmission request. The NCH sends data transmission request to the nano-controller whose structured composition is shown in Table 1. The request consists of information about the cluster member ID, nano-cluster head ID, back-up cluster head ID, layer information, amount of data to be transmitted, residual energy of the nano-cluster head ( $E_{r,NCH}$ ) and residual energy of the back-up cluster head ( $E_{r,NBCH}$ ).

**Table 1:** Structured Composition of Transmission Message Request

Layer ID	Cluster ID	NCH ID	NBCH ID	$E_{r,NCH}$	$E_{r,NBCH}$	Amount of Data
----------	------------	--------	---------	-------------	--------------	----------------

In turn, the NC estimate the time for a complete round of transmission, estimate the amount of energy required for the transmission in each cluster, and compares with the residual energy of each NCH to determine at what time to switch to the back-up cluster head and

specify packet transmission order for the Active Data Transmission Nodes (ADTNs)

### ADTNs Data Transmission

At the beginning of data transmission process, the NC sends a wake-up message to activate the outermost layer in turn, activating

all the ADTNs of that layer for data transmission.

In the intra-cluster period, ADTNs forward their data to respective NCHs, either directly (that is, ADTN to NCH) or via another NCM, depending on energy per bit consumption to transmit. Let the  $i^{th}$  nano-node be the ADTN with a distance  $d^i_{NCH}$  from the NCH, while  $n_j$  be the neighbor cluster member with a distance  $d^j_{NCH}$  from the NCH,  $d^{ij}_N$  is the distance between the  $i^{th}$  and  $j^{th}$  nano-node and adopting multihop transmission with neighbor cluster member, the total energy consumed based on multihop transmission is mathematically expressed as:

$$E_{mul} = \sum_{i=1}^N E_{bit}(d^{ij}_N) + E_r(d^{ij}_N) + E_{bit}(d^j_{NCH}) \quad (16)$$

where:

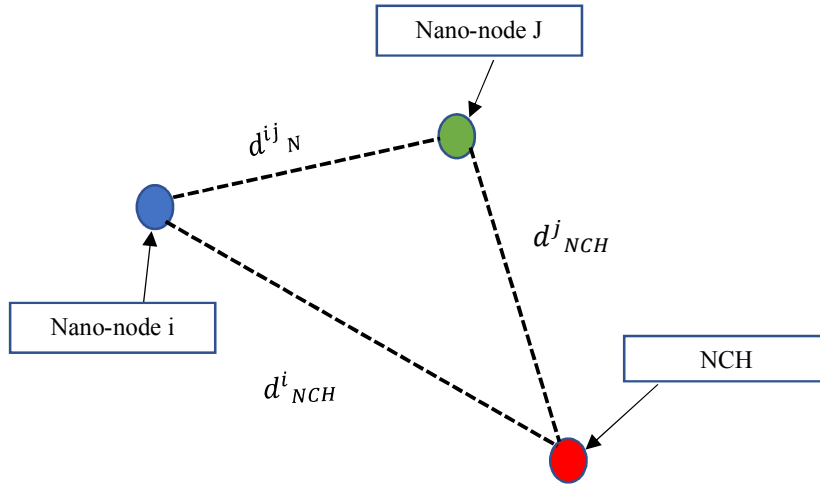
$E_{mul}$  represents the energy consumed using multihop transmission

$E_{bit}(d^{ij}_N)$  denotes energy consumed to transmit from nanonode  $i$  to a neighbor  $j$  at a distance  $d^{ij}_N$

$E_r(d^{ij}_N)$  stands for the energy consumed by node  $j$  in receiving from neighbor node  $i$

$E_{bit}(d^j_{NCH})$  is the energy consumed to transmit from neighbor node  $j$  to the NCH at a distance  $d^j_{NCH}$

$E_{bit}(d^i_{NCH})$  represents the energy consumed using direct transmission from node  $i$  to NCH



**Figure 2:** Nano-node and Nano-Cluster Head Communication Process

The diagram in Figure 2 depicts the graphical illustration of the node communicating with the nano cluster head. The data is transmitted directly from  $i$  nano-node to NCH if,  $E_{mul} > E_{bit}(d^i_{NCH})$ , otherwise, an intermediate hop is used.

In the inter-cluster period, the NCHs aggregates data and forward them to NCHs of an adjacent lower layer for further transmission to the NC.

Assuming that in a single data transmission round the average energy required by a NCH to complete cluster operation is  $E_{NCHopr}$ , then it is expressed as:

$$E_{NCHopr} = n.E_{rx}^{NCM} + n.E_{agg} + E_{tx}^{NCH,NC} + n.E_{rx}^{NCH} \quad (17)$$

where:

$E_{NCHopr}$  represent energy required by the nano cluster head to carry out cluster operation

$E_{rx}^{NCM}$  denotes the energy consumed in receiving data from  $n$  cluster member.

$E_{rx}^{NCH}$  symbolizes the energy consumed in receiving data from higher layer NCH.

$E_{agg}$  stands for the energy spent on aggregating  $n$  data

$E_{tx}^{NCH,NC}$  is the energy consumed to transmit the data to the NC directly or to another NCH.

After a period of time, it is expected that a NCH is likely deplete its energy during

cluster operation due to data forwarding. This is determined by the NC and a switching message is sent to handover to the NBCH.

Assuming  $E_{r,NCH}$  is the residual energy of the NCH at the beginning of a round,

a switching occurs to the NBCH if the condition  $E_{r,NCH} \leq E_{NCHopr}$  is true.

In the data transmission process algorithm presented in algorithm 3, the notations  $i$  denotes the layer IDs and  $j$  represents the cluster IDs.

**Algorithm 3: Algorithm for data transmission process**

1. **for** each layer do
2.   NC sends wake up message;
3.   **while** intra-cluster period do
4.     calculate the  $E_{mul}$  using eqn (16)
5.     **if** ( $E_{mul} < E_{direct}$ ) **then**
6.       ADTN transmit data to respective NCH<sub>j</sub> through a neighbor
7.     **else**
8.       ADTN transmit data directly to the respective NCH<sub>j</sub>
9.     **end if**
10.   **end**
11.   **while** inter-cluster –inter –layer period do
12.     **if**  $L_i == L_1$  && NCH<sub>i,j</sub> received multiple information
13.       NCH<sub>i,j</sub> performs aggregation;
14.       NCH<sub>i,j</sub> transmit aggregated data to NC;
15.     **else**
16.       NCH<sub>i,j</sub> transmit aggregated data to the lower layer NCH<sub>i-1,j</sub>
17.     **end if**
18.     **if** ( $E_{r,NCH_{i,j}} \leq E_{NCH_{i,j}opr}$ ) **then**
19.       assign cluster responsibility to NBCH<sub>i,j</sub>
20.     **else**
21.       NCH<sub>i,j</sub> continues operation
22.     **end if**
23.   **end**
24. **end**

**SIMULATION RESULTS**

The simulation scenario in this work is based on the assumption that nanonodes are deployed in human hand to construct a nanonetwork. All the nano-nodes have the

same initial energy. The remaining simulation parameters values assumed in the network model are shown in Table 2. Results are extracted using MATLAB as a simulation tool to characterize the network models.

**Table 2:** Simulation Parameters

Parameter	Value
Data Packet Size (byte)	128
Range of transmission (mm)	4
Node Maximum Energy ( $\mu$ J)	4
Coding weight symbol	0.5
Pulse duration (fs)	100
pulse transmission interval (ps)	10
Radius of simulation (mm)	6
Number of nanonodes	100
Total number of layers	3
Threshold energy (pJ)	0.14



### Comparison of Network Lifetime

The diagram in Figure 3 shows the comparison of network lifetime between the developed protocol and recent EBCR protocol developed by Xu et al, 2019 based on three metrics called First Node Dead (FND), Half Node Dead (HND) and Eighty Percent Node Dead (EPND). The first node dead refers to the times it took the first node to die in the network. HND refers to the time it takes to record 50% dead nodes in the network while EPND simply denoted the times it took 80% of the node to die in the network. It was observed from Figure 3 that the EBCR protocol recorded FND at 1010 as against the 1135th period it takes the proposed protocol to record first dead node.

Also, in EBCR, HND occurs at 1450th round as against the proposed protocol with its HND at 1851th round. On the other hand, in EBCR, EPND occurs at 1621th round as against the proposed protocol with its EPND at 2323th round. In terms of the average percentage improvement, the proposed scheme yields an average improvement of 27.77 %, over the existing EBCR protocol in terms of network lifetime. The reason for this improvement is due to the benefits of equalized nodes distribution based on the layering model, together with the use of multihop transmission, as well as selection of backup cluster head for the layers along the path of data forwarding to the nano-controller.

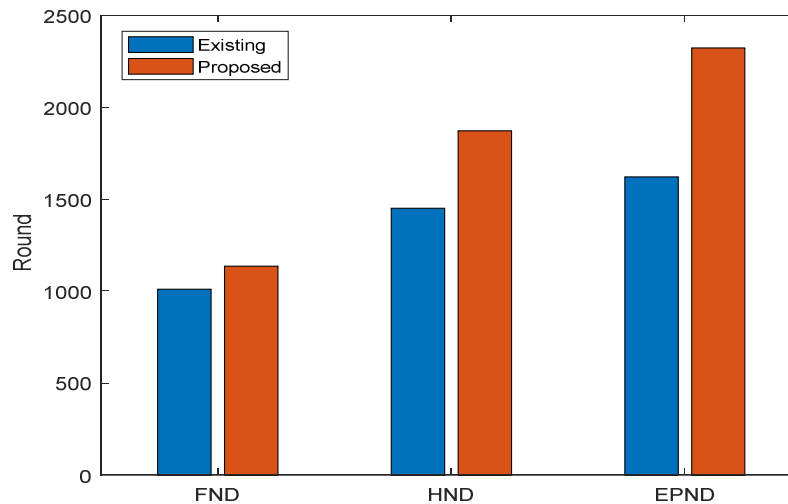


Figure 3: Network Lifetime

### Comparison of Average Residual Energy

The diagram in Figure 4 illustrates the comparison of average residual energy between the developed protocol and the recent EBCR protocol. It was observed from Figure 4, that the energy pattern for both protocols follows same trends. From Figure 4, it is deduced that the average energy of the developed protocol at different rounds is higher than that of the EBCR protocol. The reason for this improvement is that the EBCR protocol

employed direct transmission between the active nodes and their respective nano-cluster head during data transmission irrespective of the node distance to the cluster head which could have affected their communications. This shows that the proposed protocol is more efficient in saving network energy as multihop transmission of data is not only limited to inter cluster but also to the intra cluster phase of the network.

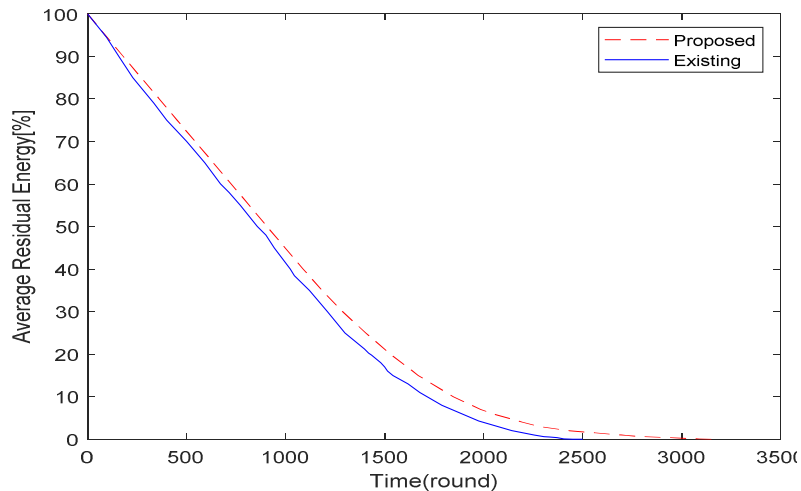


Figure 4: Average Residual Energy

## CONCLUSION

This research work presented the development of an energy harvesting aware cluster-based routing protocol for WNSN. A cluster formation model based on concentric layer architecture as well as a backup clustering algorithm were developed and implemented. The developed protocol balanced the energy consumption in the network and improved the network lifetime. Simulations were carried out on MATLAB R2020a to evaluate the performance of the developed protocol and the results obtained showed that the developed protocol improved the network lifetime. The protocol was benchmarked against the recent EBCR protocol. The result of the comparison showed that the developed protocol exhibited average performance improvement of 27.77 % over EBCR protocol in terms of network lifetime with high residual energy.

## REFERENCES

- Afsana, F., Asif-Ur-Rahman, M., Ahmed, M. R., Mahmud, M., & Kaiser, M. S. (2018). An Energy Conserving Routing Scheme for Wireless Body Sensor Nanonetwork Communication. *IEEE Access*, 6, 9186–9200. doi:10.1109/access.2018.2789437.
- M. Akbar, M., Javaid, N., Imran, M., Rao, A., Younis, M. S., and Niaz, I. A. (2016). A multi-hop angular routing protocol for wireless sensor networks. *International Journal of Distributed Sensor Networks*, 12(9). doi:10.1177/1550147716662945
- Akyildiz, I. F., Brunetti, F., & Blázquez, C. (2008). Nanonetworks: A new communication paradigm. *Computer Networks*, 52(12), 2260–2279. doi:10.1016/j.comnet.2008.04.001
- Akyildiz, I. F., & Jornet, J. M. (2010). Electromagnetic wireless nanosensor networks. *Nano Communication Networks*, 1(1), 3–19.
- Behera, T. M. et al., (2019). Residual Energy-Based Cluster-Head Selection in WSNs for IoT Application. *IEEE Internet of Things Journal*, 6(3), 5132-5139.
- Canovas-Carrasco, S., Garcia-Sanchez, A.-J., Garcia-Sanchez, F., & Garcia-Haro, J. (2016). Conceptual Design of a Nano-Networking Device. *Sensors*, 16(12), 2104. doi:10.3390/s16122104
- Canovas-Carrasco, S., Garcia-Sanchez, A.-J., Garcia-Sanchez, F., & Garcia-Haro, J. (2016). On the Nature of Energy-Feasible Wireless Nanosensor Networks. *Sensors*, 18(5). doi:10.3390/s18051356
- Fahim, H., Javaid, S., Li, W., Mabrouk, I. B., Hasan, M. A., & Rasheed, M. B. B. (2020). An Efficient Routing Scheme for Intrabody Nanonetworks Using Artificial Bee



- Colony Algorithm. *IEEE Access*, 8, 98946–98957.
- Jornet, J. M., & Akyildiz, I. F. (2011). Information capacity of pulse-based wireless nanosensor networks. In *8th Annual IEEE communications society conference on sensor, mesh and ad hoc communications and networks (SECON 2011)* 80–88. doi:10.1109/SAHCN.2011.5984951.
- Lee, S. J., Jung, C. (Andrew), Choi, K., & Kim, S. (2015). Design of Wireless Nanosensor Networks for Intrabody Application. *International Journal of Distributed Sensor Networks*, 11(7), 176761.
- Liaskos, C., Tsioliaridou, A., Ioannidis, S., Kantartzis, N., & Pitsillides, A. (2016). A deployable routing system for nanonetworks. 2016 IEEE International Conference on Communications (ICC).
- Liu, B., Liu, J., Wu., Z & Jiang, X. (2017). On the Design of an Energy Efficient Data Collection Scheme for Body Area NanoNetworks. *International Journal of Wireless & Mobile Networks*, 9(3).
- Nikolidakis, S. A., Kandris, D., Vergados, D. D., and Douligeris, C. (2013). Energy efficient routing in wireless sensor networks through balanced clustering. *Algorithms*, 6, 29-42.
- Pierobon, M., Jornet, J. M., Akkari, N., Almasri, S., & Akyildiz, I. F. (2013). A routing framework for energy harvesting wireless nanosensor networks in the Terahertz Band. *Wireless Networks*, 20(5), 1169–1183.
- Piro, G., Boggia, G., & Grieco, L. A. (2014). On the design of an energy-harvesting protocol stack for Body Area Nano-NETworks. *Nano Communication Networks*, 6(2), 74–84.
- Salami, A. F., Zakariyya, O. S., Amuda, S. A. Y., Sadiq, B. O. & Abdulrahman, O. A. (2019). Didactic Performance Review of Selected Topology-Aware Routing Strategies for Clustering Sensor Networks. *Nigerian Journal of Technological Development (NJTD)*, 16(4), 174-182.
- Tsioliaridou, A., Liaskos, C., Ioannidis, S., & Pitsillides, A. (2015). CORONA. *Proceedings of the Second Annual International Conference on Nanoscale Computing and Communication - NANOCOM'15*. doi:10.1145/2800795.2800809
- Xu, J., Zhang, R., & Wang, Z. (2016). An Energy Efficient Multi-hop Routing Protocol for Terahertz Wireless Nanosensor Networks. *Lecture Notes in Computer Science*, 367–376.
- Xu, J., Zhang, Y., Jiang, J., & Kan, J. (2019). An Energy Balance Clustering Routing Protocol for Intra-Body Wireless Nanosensor Networks. *Sensors*, 19(22), 4875.
- Yalgashev, O., Bakhouya, M., Gaber, J., & Manier, M.-A. (2015). Adaptive Transmission Range Control for Electromagnetic-based Broadcasting in Nanonetworks. *Procedia Computer Science*, 52, 1077–1082. doi:10.1016/j.procs.2015.05.116
- Yao, X.-W., Wu, Y.-C.-G., & Huang, W. (2019). Routing techniques in wireless nanonetworks: A survey. *Nano Communication Networks*, 21, 100250. doi:10.1016/j.nancom.2019.100250
- Yu, H., Ng, B., Seah, W. K. G., & Qu, Y. (2017). TTL-based efficient forwarding for the backhaul tier in nanonetworks. 2017 14th IEEE Annual Consumer Communications & Networking Conference (CCNC).
- Zakariyya, O. S., Yaro, A. S., Usman, A. D., Sani, S. M. & Tekanyi, A. M. S. (2020). A feasibility study of cluster-based energy harvesting aware routing protocol for body nanosensor network. *IEEE Multi-Conference on Trans-disciplinary Sciences, Engineering & Information Systems and Computing Applications 2020*, 18-21.