ESBL: An Energy-Efficient Scheme by Balancing Load in Group Based WSNs

Amjad Mehmood[1,2], M. Nouman[1], Muhammad Muneer Umar[3], Houbing Song[4]
[1]Guangdong Provincial Key Laboratory on Petrochemical Equipment Fault Diagnosis
Guangdong University of Petrochemical Technology
Maoming, Guangdong 525000 - China
[2] Institute of Information Technology, Kohat University of Science & Technology, Kohat, KPK - Pakistan
[e-mail: amjadiitkust@gmail.com, mnoman55@gmail.com]
[3] Department of Management and Information Technology
Jubail Industrial College, Royal Commission for Jubail & Yanbu, Jubail Industrial City 31961 - Saudi Arabia
[e-mail: muneerumar@hotmail.com]
[4] Department of Electrical and Computer Engineering, West Virginia University,
Montgomery, WV 25136 - USA
[e-mail: Houbing.Song@mail.wvu.edu]
*Corresponding author: Houbing Song

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Abstract

Energy efficiency in Wireless Sensor Networks (WSNs) is very appealing research area due to serious constrains on resources like storage, processing, and communication power of the sensor nodes. Due to limited capabilities of sensing nodes, such networks are composed of a large number of nodes. The higher number of nodes increases the overall performance in data collection from environment and transmission of packets among nodes. In such networks the nodes sense data and ultimately forward the information to a Base Station (BS). The main issues in WSNs revolve around energy consumption and delay in relaying of data. A lot of research work has been published in this area of achieving energy efficiency in the network. Various techniques have been proposed to divide such networks; like grid division of network, group based division, clustering, making logical layers of network, variable size clusters or groups and so on. In this paper a new technique of group based WSNs is proposed by using some features from recent published protocols i.e. "*Energy-Efficient Multi-level and Distance Aware Clustering (EEMDC)*" and "*Energy-Efficient Multi-level and Distance Aware Clustering (EEUC)*". The proposed work is not only energy-efficient but also minimizes the delay in relaying of data from the sensor nodes to BS. Simulation results show, that it outperforms LEACH protocol by 38%, EEMDC by 10% and EEUC by 13%.

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1. Introduction

Wireless sensor networks (WSNs) have become very popular in different fields due to their effectiveness and improvement in research and application sides [1]. WSNs are used to cover many types of sensory tasks. Such networks are consisted of many cheap, small and autonomous devices [2]. Which sense some information and provide it to the front end. These networks are usually deployed in an open environment [3].

The small sensing devices in WSNs operate on very limited amount of energy. The main research issue in such systems is that how to elongate the life span of network as long as possible by considering the nodes as non-rechargeable and operate on a best routing technique [4]. In this paper our focus is to enhance the energy efficiency of a network to prolong its life span.

In WSNs, the nodes are usually grouped together, where there are many proposals on the group formation deployment methodologies and mechanisms. Many researches have been suggested on cluster based networks [4,6,13,14,20,21], where nodes combine to form a cluster. The main node in each cluster is known as Cluster Head (CH). The main responsibility of CHs is to communicate with other clusters and the Base Station (BS). CHs are usually chosen by considering their high remaining residual energy [5]. The reason behind it is that the CHs consume more residual energy due to their higher operational frequencies as compared to other nodes. The CHs nearer to the BS, having more burdens due to more traffic, tend to die earlier. For this purpose an efficient topological technique is required [6].

Other than Cluster based networks, Group based networks have also proven their significance in WSNs [7]. In group based networks fewer nodes combine to form a group. Each group has its own group ID and a central node is selected in each group. Central node manages the communication process and keeps the record of group IDs of the whole network. The communication inside the groups is done through neighbor nodes. Each node forward its data to its neighbor towards the destination node. All the nodes on the border of the group range are called border nodes, specifically the border nodes to some specific group. Communication between groups is routed through their border nodes [7] and selection of a border node depends upon the destination group.

In our proposed protocol the Energy-Efficient Scheme by Balancing Load (ESBL) in Group based WSNs, we extend Energy-Efficient Multi-level and Distance Aware Clustering (EEMDC) [8] by adding some features of Energy-Efficient Unequal Clustering (EEUC) [5]. A new method is also introduced in which sensor nodes with lower energy are sent to sleeping mode. A specific threshold is defined at each stage to determine energy level of nodes. This technique in-effect equally utilizes the energy of all nodes in the network.

A new type of node in the network is also proposed and named as Chief Node. In this paper tasks and duties are assigned to the chief node. The chief node ensures that sensor nodes don't die earlier by identifying the nodes which are losing their batteries in a speedy manner as compared to the others.

The protocol ESBL can be very useful in a network of large number of sensing nodes operating in an open environment. Nodes in such type of networks are usually scattered in remote places and cannot be maintained in short period of time. We can take an example of a WSN installed in a jungle for monitoring animals through motion sensor cameras. The nodes in such network cannot be physically accessed for battery maintenance. Therefore these networks always need an energy-efficient protocol like ESBL.

Our paper consists of five sections. In section 2, we briefly discuss the related work already done in this area of study. We present our proposed work in section 3. In section 4 we explain the algorithmic solution and flow charts. Simulation results are shown in section 5. In the last section we conclude the summary of the paper. At the end of the paper references have been mentioned.

2. Related Work

A lot of work has been done in the area of energy-efficiency in WSNs. It became a very practical field now-a-days. For energy-efficiency in WSNs, different protocols with various mechanisms have been proposed. Some of them produce an efficient impact on such type of networks. In Low Energy Adaptive Clustering Hierarchy (LEACH) protocol [9], the CHs are selected in a probabilistic way. It uses single hop communication from nodes to CH and CH to nodes. The CH selection is simply performed after one round. LEACH is a distributed protocol [9].

For betterment in energy consumption, a new technique of forming sensor nodes into a chain is proposed in a protocol named as Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [10]. Sensor nodes find a nearer node in the cluster other than CH, for creating multi-hop communication. Some other works also include a hierarchical routing protocol (HRP) aiming for prolonging the network life [11]. A protocol in which sensor nodes select their coordinator and is a multi-hop communication protocol introduced in [12]. A number of protocols have been developed based on LEACH protocol. One of them is partition-based LEACH (pLEACH) [13], in which CH selection mechanism is based on highest remaining residual energy of candidate nodes.

Hybrid Energy efficient distributive protocol (HEED), proposed by Younas and Fahemy, [14] is also an extension of LEACH protocol. It uses multi-hop routing technique when the CH communicates to the BS. The CH selection is done by calculating the cost. In HEED, each node works individually and it doesn't give any idea about the size and density of the network. Some hierarchical clustering protocols came into the scenario [15], considering the weight of each node and its distance from other nodes as well as its energy.

In a protocol [16], a technique of random arrangement of sensor nodes is performed to make clusters. The work in [17] proposes an optimal energy consumption mechanism by distributing energy load among all the nodes to increase lifetime of a network. A protocol [18], proposes efficient routing algorithm to make the network energy efficient.

In the field of energy efficiency a multi-hop protocol has also been introduced. This protocol suggested a new concept of predefined nodes [19]. Another protocol uses an imbalanced clustering technique [20] in the area of energy efficiency in WSNs.
In distance energy cluster structure algorithm (DECSA) [21], the network is divided into three levels. At each level CHs communicate to the other levels' CHs in the path of the BS and it doesn't directly communicate to BS.

Energy consumption between different nodes in the cluster based WSN must be same to increase the lifetime of WSN and it is the biggest concerned [22]. The Energy-Aware Hierarchical Clustering (EAHC) algorithm [23] has the ability to reduce the communication complexities. In this protocol, CH selection is made among nodes of higher energy. After a specific period of time CH is rotated to increase the energy efficiency, but it doesn't reduce the number of CHs in a WSN.

Minimum Transmission Energy (MTE) [24] protocol, has the ability to reduce the workload and increase the energy efficiency by sending data only to nodes which possess MTE. While selecting a CH among nodes, MTE doesn't check the amount of energy left with a particular node which can lead to destroy the network operation and also can decrease the lifetime of a network. When there is a large WSN, it became impractical approach where every CH sends information directly to the BS in LEACH. This can also lead to decrease the level of energy in a network.

Energy-Efficient Heterogeneous Clustered (EEHC) protocol for WSNs [25]. This protocol can be applied to any environment in which nodes are homogeneous in nature. Any node in the cluster can become a CH depending upon the remaining energy of a node.

Tree-base Clustering protocol (TBC) [26] proposes a tree-shaped structure of nodes. While CH is the root of the tree and the height of the tree can be specified by the distance between a node and CH. A single-hop technique is used for sending data from CH to BS.

A protocol EADC [26], which utilizes threshold value to send data from CH to BS. CH can send data directly to the BS if the threshold value extracted from the proposed protocol is greater than the distance of these two network nodes, i.e. CH and BS. On the other hand, if the distance is higher than threshold amount it will use CHs, which have higher energy on the path as a relay to send data to BS.

A protocol (EECS) [27], has been proposed in the context of energy efficiency and proposing a clustering scheme, this protocol has been used in applications where data gathering is required and CH selection criteria depend on the outstanding residual energy of the network nodes, as it uses better way in terms of CH distribution and thus increases the life of the network.

In Dynamic Clustering and Distance Aware Routing Protocol (DDAR) [28] energy consumption can be controlled by analyzing the remaining energy, distance and dynamic number of CHs in the network. In the setup phase, each node sends its information, like outstanding energy, to the BS and then BS finds the best possible CH in available nodes of network for communication.

The efficiency of group based topologies have been proven by many researchers in their articles [7].

Another work introducing EEUC [5] reduces the networks energy consumption by using unequal clustering mechanism. The farther the cluster, if large in size, uses more energy for intra-cluster communication. While the closer cluster, if smaller in size, is burdened with relay of other cluster traffic. EEUC mechanism has proposed the basic sizes for making cluster in the network and also CH selection algorithm. The effort of EEUC is aimed to equalize the consumption of energy in all nodes.

The latest work in this field of study is EEMDC protocol for WSNs [8]. In EEMDC there are three logical layers in network divided by area factor. Layering depends on hop count. In other words, it is the distance from BS. The practice shows that it is more efficient as compared to previous approaches.

3. Proposed Technique

As the EEMDC protocol has been discussed in section 2, having three logical layers based on hop count distance. We propose a new concept in addition to EEMDC of having dynamic sizes of groups in each layer of the network. Each group in group based network communicates with other groups through the border nodes nearest to the destination group [29]. As this mechanism has already been suggested in EEUC mechanism where the variable sizes of clusters were implemented, which was a cluster based distributed network. We integrate the idea of dynamic sizes of clusters in our group based protocol. The implementation of distributed group based network with layered structure for WSN shows a positive change in consumption of energy in the network. The EEUC mechanism [5] has been discussed here briefly.

3.1 EEUC Mechanism

While deploying network by EEUC mechanism, BS sends certain message to all the nodes in a network to calculate the distance between BS and Nodes which in turn helps nodes in communication and also in terms of creating different sizes of clusters. EEUC mechanism utilizes unequal clustering technique and inter-cluster multi-hop routing technique. In unequal clustering, CHs collect sensed data from all the nodes in a cluster and forwards it to the BS. In the CH selection process different temporary CHs are selected among different nodes on the basis of a predefined threshold value and then these CHs contend to become final CHs. Clusters close to the BS will be of smaller sizes to reduce energy consumption in the inter-cluster multi-hop communication. In inter-cluster multi-hop communication, CHs first collect data among all cluster nodes and then forward collectively as a packet to the BS. In PEGASIS, relay nodes mingle the incoming data with its data while in EEUC relay nodes doesn't mingle the data.

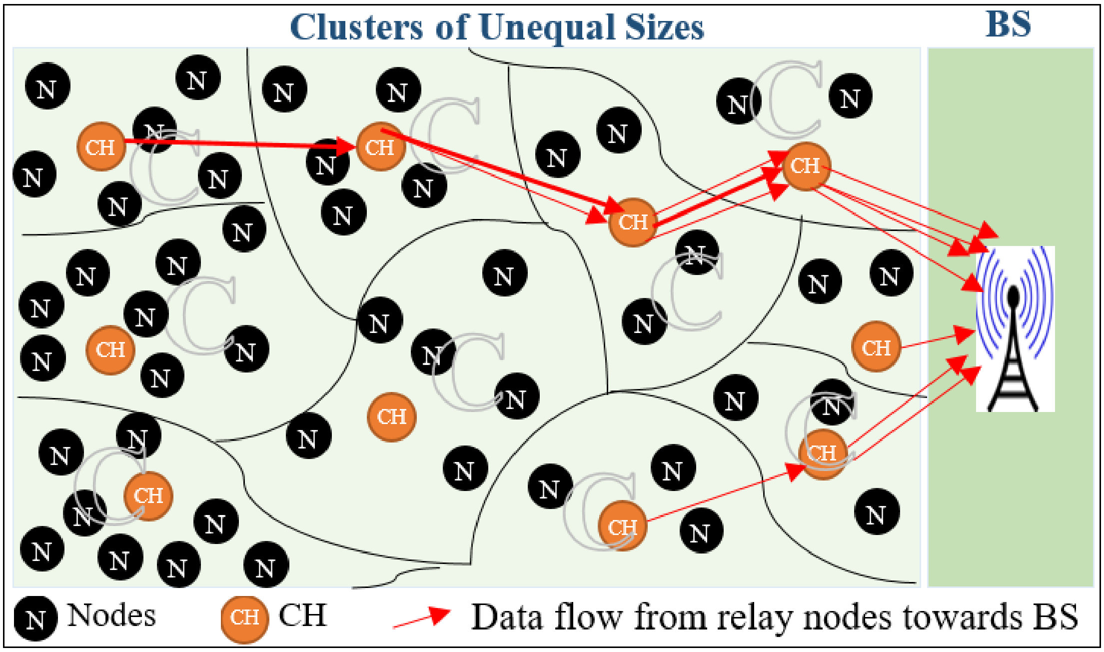

Fig. 1. EEUC Diagram

We implemented this mechanism on group based network. Where there is no CH and the communication techniques are different. The groups are replaced with clusters in our scenario and border nodes are responsible for communication with other groups.

In addition, we are also introducing a delay factor for those sensor nodes, which consumes more energy as compared to others. The delay factor commands some specific sensor nodes to go into sleep [30]. At the beginning each node calculates its number of neighbors to which it can send packets directly through one hop communication. This process is performed at each layer separately, as we are following three layered structure proposed in EEMDC. In network those nodes should be identified which are in dense amount in a specific area [31].

The node having maximum number of neighbors claims itself as a chief node of that specific layer. By this process we have three nodes claiming themselves as chief nodes because of the three layered structure. All nodes send their remaining residual energy along with their node IDs and their neighbor nodes ID's to their group's central-nodes. The head nodes pass them to the border node of that group. The border nodes move it forward to the chief nodes of their layer, and the same process is performed repeatedly after each T_1. A defined period of time is denoted by T_1 to specify the length of intervals. The purpose to do this process is to maintain the residual energy of all node at almost equal by implementing few algorithms discussed below.

The tasks performed by chief nodes include:

i. Collection of each node's remaining residual energy within the layer
ii. Calculation of average energy on the basis of given information

iii. Calculation of threshold using the formula $E_{avg} - A_T$, where $0 < A_T < E_{avg}$. It is used to calculate a smaller value then the average energy. The lower the value of A_T intends to the higher number of transitions due to little difference between the average energy and the threshold energy. We used a proportional value $A_T = E_{avg} /2$ in our implementations.

iv. The chief node stores two queues named as REST and NEXT in its memory.

v. The chief node checks and compares the threshold amount with the provided residual energy of all the nodes. If it finds nodes remaining energy smaller than the threshold amount, then it stores those nodes IDs in the REST queue. When it finds another node whose battery life is lesser than the threshold amount then an additional check is performed. That check ensures the current node, which is a candidate to keep its ID in REST queue, is either a neighbor or not of those who are already in REST queue. If a neighbor's ID is found in the REST queue, the chief node keeps it in NEXT queue.

vi. The nodes which are in REST queue sleeps until the end of an iteration.

vii. This process is repeated after each time interval T_1. In each iteration, the chief nodes scan NEXT queue and swap those nodes, one by one, to REST queue which satisfies the checks in step 5.

4. Process Flow Diagrams

4.1 Chief Node Selection

When the remaining residual energy of a chief node equals the defined critical level, it chooses a new chief node based on the following formula:

$$RE + (Neigh \times D)$$

Where RE indicates the remaining energy of a node while Neigh is used for number of neighboring nodes. D is a positive integer used to put the weightage in the number of neighbors to determine chief node selection. The algorithm, **Algo. 1**, inputs the remaining energy, number of neighbors and the node ID of the candidate chief nodes. For each node a value C_i is calculated using RE and Neigh, where i indicates the current node's ID. The highest number of D leads to higher variation in the values of C's. In case of larger number of nodes the number of neighbors will be higher, therefore it is better to use a smaller value of D. We used D=8 in our implementations. The algorithm, at the end, returns an object named as *maximal* which keeps the node's ID having highest C for selection of a chief node.

Algo. 1. Chief Node Selection Algorithm

```
sESBLChief(RE, Neigh, NodeID)
maximal.Value = 0
maximal.NodeID=0
foreach nodeID i = 1 to N
C_i = (RE) + (Neigh × D)
If C_i ≥ maximal.Value
then maximal.NodeID = i
end foreach
return maximal
```

The algorithm of selection of a chief node is explained with the following diagram.

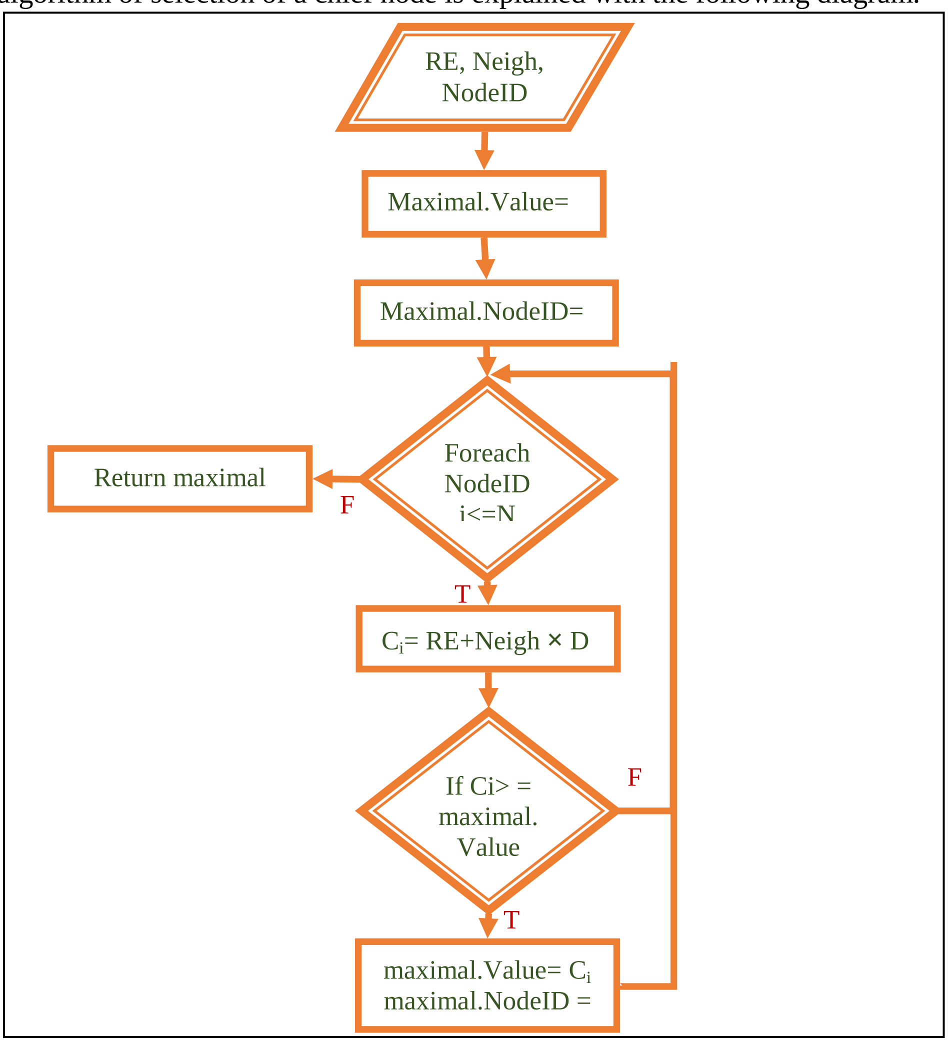

Fig. 2. Flow Chart Diagram – Chief Node Selection

4.2 Process Flow on Chief Node in ESBL

Section 3 described the functionalities of a chief node. The diagram in **Fig. 3** explains the whole process performed by a chief node:

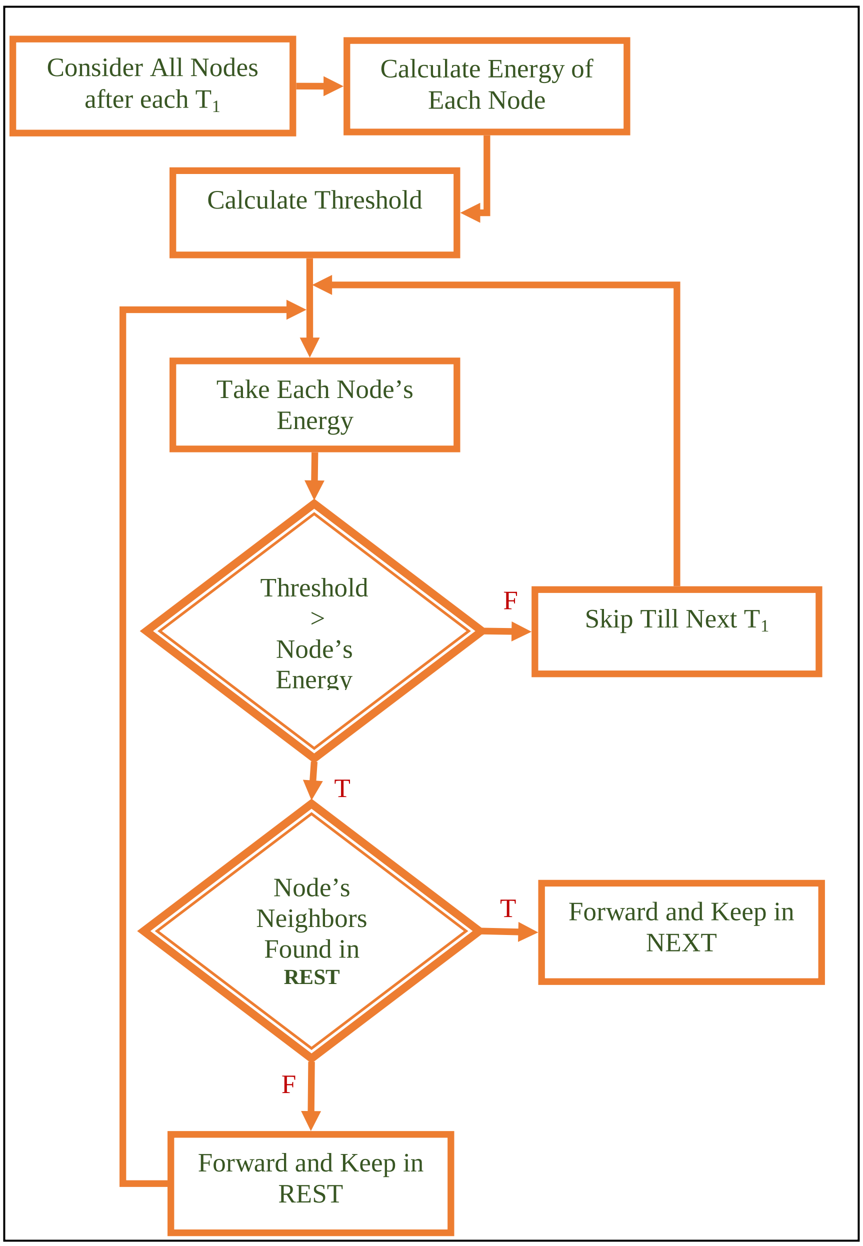

Fig. 3. Flow Chart Diagram – Chief Node's Responsibilities

4.3 Algorithm Describing Chief Node's Functionality in ESBL

Algo. 2 describes the functionality of chief node's flow in the network. After each T_1; all the nodes send their remaining energy information to the chief nodes via their group's head-nodes and then through the border nodes. This algorithm describes how the node is kept in REST queue or a NEXT queue. The average of all the nodes energies is calculated by considering their provided energies. The threshold is defined by subtracting a positive number A_T from the average of energies. Then all the nodes are scanned using a *foreach* loop to compare their energies with the value of threshold. If a node's energy is fond lesser or equal to the value of threshold then it is kept in the REST queue. During this loop for keep a node in REST, its neighbor node is also checked in REST. If found, then the node is kept in NEXT queue.

Algo. 2. Chief Node Functionality Algorithm

```
funcChief(nodeID, energy, neighborID)
Energy_Total = 0;
foreach node i = 1 to N
do
Energy_Total  = Energy_Total  + node_i.energy;
end foreach
Energy_Avg = Energy_Total / N
Threshold = Energy_Avg - A_T
do
foreach node j = 1 to N
if (node_j.energy = < Threshold)
foreach node in REST
if  REST.nodeID = node.neighborID;
store nodeID in NEXT
else
store nodeID in REST
end if
end for
end if
end for
```

4.4 Message Flow from Sensor node to BS in ESBL

The sensor nodes sense data from the environment and then transfer it to their groups' central nodes through one or more than one hop communication [32][33]. Each group central node forwards the collected data to the border node which is connected to another border node of another group towards the BS. The same process is repeated until the data is received at the BS [34][35].

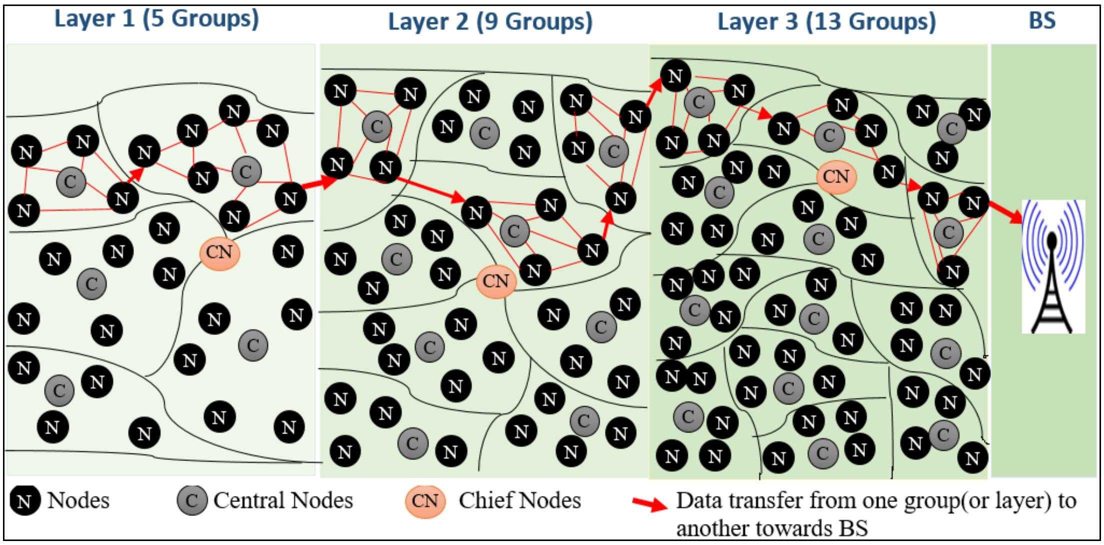

Fig. 4. Message Flow Diagram

4.5 Chief Node Processing in ESBL

Each node sends its own ID, remaining residual energy and the ID's of neighbors to its central node and then the central node forwards it to the chief node of the same layer. The chief node concludes them according to the formula given in the flowchart and algorithm, and replies back to those nodes whose remaining energy is less than threshold value. Moreover, the chief nodes send a command either of REST or NEXT with the replies, as explained in Section 3.

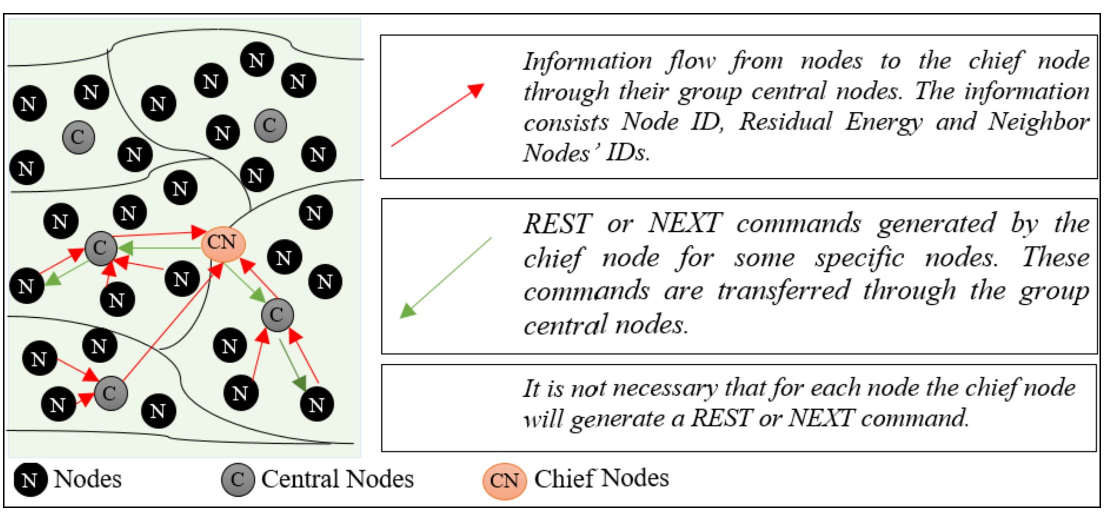

Fig. 5. Chief Node Process Diagram

5. Simulation

The below simulations have been performed in an object oriented simulator known as Castalia. It is popular for WSN and WBAN. **Table 1** shows the parameters used in the simulations. The figures show that ESBL has better results as compared to some of the well-known cluster based protocols suggested for WSNs.

Table 1. Network Model Parameters

Simulation Parameter	Value
Network Area	100m*100m
Initial Energy	12 Joules
CH Percentage	0.05
Packet header Size	25 byte
Data Size	500 byte
Num of Nodes	100 nodes
Simulation Time	1500 Sec
Control Packet Size	100 bit
Broadcast packet size	25 bytes
Round Length	20 sec

The simulation results demonstrate that ESBL protocol survives, in term of network lifetime, 38% more than LEACH , 19% more than HEED, 17% more than DDAR, 13% more than EEUC, and 10% more than EEMDC. Below results, in **Fig. 6**, show first node die time over the simulation time. In ESBL, by using the technique of load balancing and keeping some nodes in sleeping mode, the nodes perform more for a long duration as compared to other protocols. Furthermore, the protocol periodically checks the energies of nodes and changes the chief nodes accordingly, therefore all the nodes equally consume their lives and the first node dies very lately.

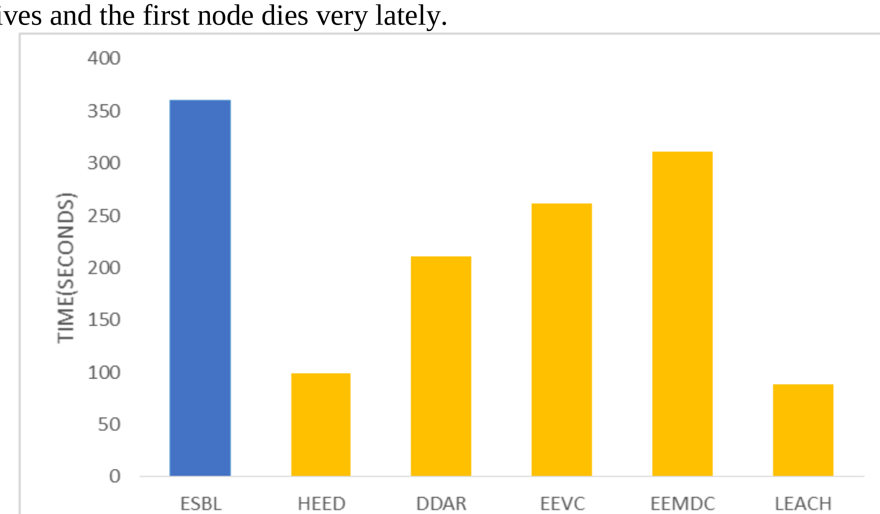

Fig. 6. First Node Die with respect to Simulation Time

In ESBL, the aggregate power consumed by nodes in a specified period of time is much lower than other stated protocols. If a node consumes more, then it is backed and supported by other nodes to reduce its load. Therefore the nodes do not exhaust their batteries quickly. **Fig. 7** shows the last node die with regard to simulation time. It explains that last node of ESBL dies at 1338.1 seconds. While in the same case other protocols give reasonably lower values. The other protocols HEED, DDAR, EEUC, EEMDC and LEACH, have values as 999.6, 1109.787, 1161.88 , 1223.52 and 810.84 seconds respectively. So it clearly shows that ESBL has outperformed its competitor protocols.

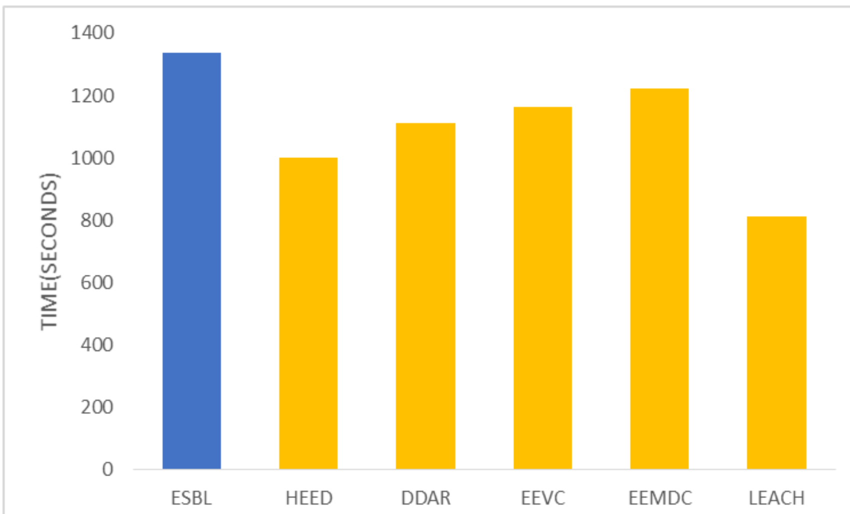

Fig. 7. Last Node Die with respect to Simulation Time

Fig. 8 shows the average energy consumption of nodes in the studied protocols during a period of 550 seconds. The simulation results show that ESBL consumes less energy as compared to the other protocols. It is because ESBL protocol uses a REST queue to keep some nodes in idle position to reduce their energy consumption. ESBL gives a litter lesser values as compared to its parent protocols EECU and EEMDC. At the end of simulation ESBL, EEUC and EEMDC have consumed 54.34%, 47.17% and 46.34% of energies respectively.

Results in **Fig. 9** show number of nodes alive along the time. LEACH gives very poor performance due to its simple implementation. ESBL combines best of both EEUC and EEMDC, therefore it gives better results than the both EECU and EEMDC. It gives 90 nodes alive after 800s in the simulation results. LEACH, HEED, DDAR, EEUC, and EEMDC have 1, 61, 72, 80, and 85 of nodes alive, respectively, after 800 s. Due to load balancing technique in ESBL, all the nodes consume their energies equally which ultimately reduce the overburden on some nodes. Therefore, this technique effects the overall performance of the network by reducing the death rate of the nodes over a specified period of time.

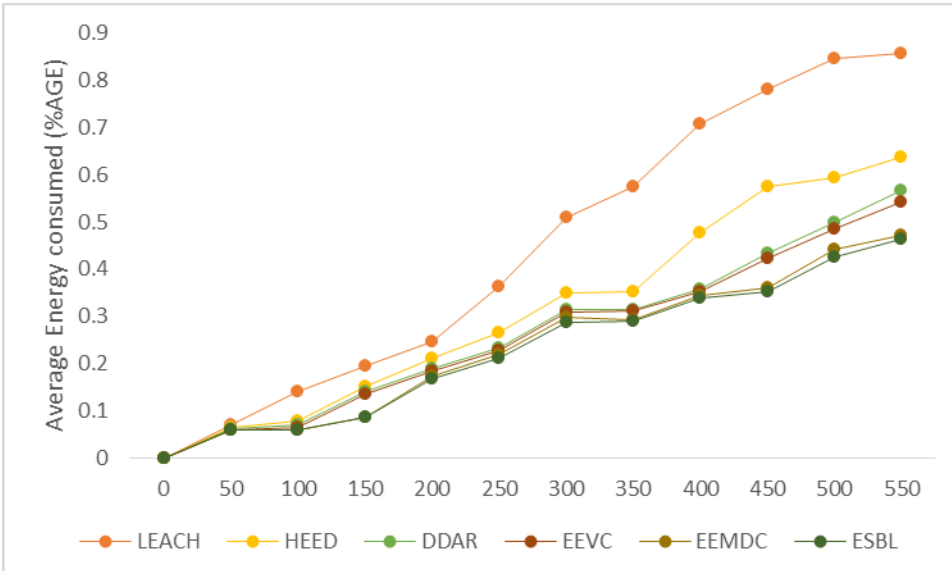

Fig. 8. Energy Consumption with respect Simulation Time

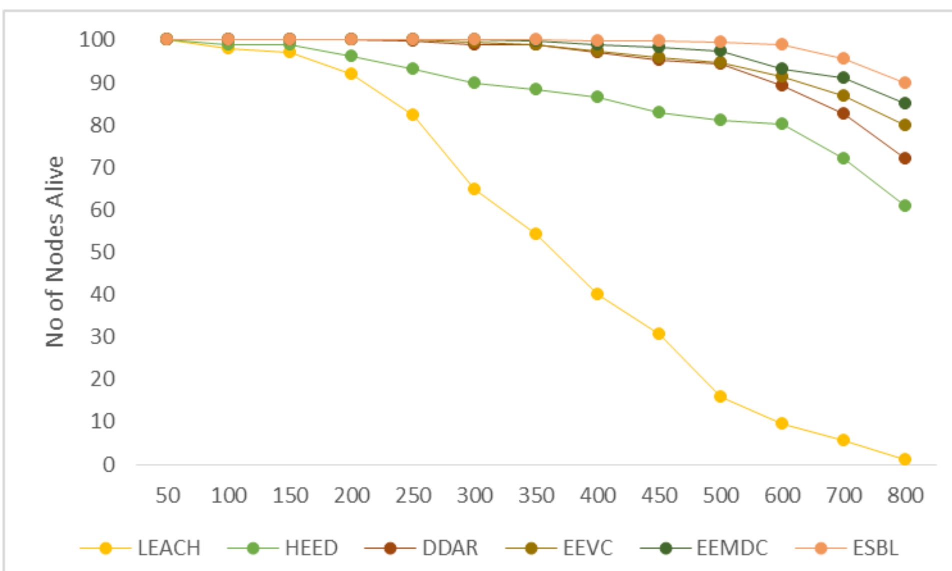

Fig. 9. Number of Nodes Alive with respect to Simulation Time

6. Conclusion and Future Work

The protocol ESBL is highly inspired from two known protocols EEMDC and EEUC. EEMDC has a layered architecture while EEUC has a technique of unequal clustering in the network. ESBL adds a new feature of preventing some nodes from rapid death and changes the trend of clustering to the group based network.

By combining these features in a new protocol makes it sure to balance the energy consumption of all the nodes at same pace. If some nodes are consuming their energies rapidly, then the support of other nodes becomes available to the said nodes by the protocol. Such nodes are kept in rest mode and sleep commands are sent after each specified time interval.

An alternate plan is also needed to be addressed for the chief node concept in case there is a very large scaled network. The chief node may not perform well if its layer has thousands of sensing nodes. For such situation some of the responsibilities can be distributed among the central nodes of the groups. Moreover multi-hopping in dynamic sized group based network can be designed with multiple aspects. The proposed protocol does not address the security issues. Security threats can be discovered and protection measurements can be implemented on the chief nodes. There are no existing security measures for keeping chief node safe from external harmful attacks.

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Amjad Mehmood received the Ph.D. degree in Wireless Networks from the Kohat University of Science & Technology, Kohat, in 2014. Currently, he is pursuing post-doc from Guangdong Provincial Key Laboratory on Petrochemical Equipment Fault Diagnosis at Guangdong University of Petrochemical Technology, Maoming, China. He did the virtual post-doc from West Virginia University, USA, and the MS degree in Distributed Computing from Kohat University of Science & Technology, Kohat. In 2003, he joined the Kohat University of Science & Technology, Kohat, KP, where he's been currently serving as a senior faculty member and the Coordinator of MS/PhD program. Dr. Amjad is interested to work in the areas of cyber-physical systems, internet of things, connected vehicles, wireless communications and networking, optical communications and networking, smart grid communications and networking, and body sensor networks. His research wok is supported by the Guangdong Provincial Key Laboratory on Petrochemical Equipment Fault Diagnosis Maoming, China. Dr.Amjad's supervised many students of BCS, MCS, MS and PhD in the above mentioned interests. He has also remained the part of organizing different workshops, seminar and training sessions on different technologies at the University under the umbrella of Computer Science Society of IIT, KUST. Dr. Amajd has been serving as the technical program committee member for numerous international conferences, including CCNC, SCPA, INFOCOM, SCAN, and so on.Dr. Amjad is a reviewer or associate editor for many peer-reviewed international journals. Dr. Amjad has published more than 36 academic articles in peer-reviewed international journals and conferences around the world.

Muhammad Noman is currently working as a programmer in software house, Islamabad, Pakistan. Now, perusing in MS. He is doing his research work in security and routing protocols for MANETs and WSNs. He has also published some research articles in reputable journals.

Muhammad Muneer Umar is currently working as a lecturer in computer science at Jubail Industrial College, Royal Commission for Jubail & Yanbu. Saudi Arabia. He is also enrolled in PhD in computer science at Kohat University of Science and Technology, Pakistan. He is doing his research work in security and routing protocols for MANETs and WSNs. He has also published some research articles in reputable journals.

Houbing Song (M'12–SM'14) received the Ph.D. degree in electrical engineering from the University of Virginia, Charlottesville, VA, in August 2012. In August 2012, he joined the Department of Electrical and Computer Engineering, West Virginia University, Montgomery, WV, where he is currently an Assistant Professor and the Founding Director of both the Security and Optimization for Networked Globe Laboratory (SONG Lab, www.SONGLab.us), and West Virginia Center of Excellence for Cyber-Physical Systems sponsored by West Virginia Higher Education Policy Commission. In 2007 he was an Engineering Research Associate with the Texas A&M Transportation Institute. He is the editor of four books, including Smart Cities: Foundations, Principles and Applications, Hoboken, NJ: Wiley, 2017, Security and Privacy in Cyber-Physical Systems: Foundations, Principles and Applications, Chichester, UK: Wiley, 2017, Cyber-Physical Systems: Foundations, Principles and Applications, Waltham, MA: Elsevier, 2016, and Industrial Internet of Things: Cybermanufacturing Systems, Cham, Switzerland: Springer, 2016. He is the author of more than 100 articles. His research interests include cyber-physical systems, internet of things, cloud computing, big data analytics, connected vehicle, wireless communications and networking, and optical communications and networking. Dr. Song is a member of ACM. Dr. Song was the very first recipient of the Golden Bear Scholar Award, the highest faculty research award at West Virginia University Institute of Technology (WVU Tech), in 2016.