I.J. Modern Education and Computer Science, **2015, 5, 24-36**
Published Online May 2015 in MECS (http://www.mecs-press.org/)
DOI: 10.5815/ijmecs.2015.05.04

Energy Efficient Unequal Clustering Algorithm with Disjoint Multi-hop Routing Scheme for Wireless Sensor Networks

Muni Venkateswarlu K. and A. Kandasamy
Department of Mathematical and Computational Sciences,
National Institute of Technology Karnataka, Mangalore, 575 025, India
Email: {munivenkateshk, kandy}@nitk.ac.in

Chandrasekaran K.
Department of Computer Science and Engineering,
National Institute of Technology Karnataka, Mangalore, 575 025, India
Email: kch@nitk.ac.in

***Abstract*—**The main aim of this paper is to avoid hot-spot problem in wireless sensor network with uniform energy dissipation among cluster heads in the network. It proposes an energy efficient unequal clustering mechanism to form limited and equivalent number of clusters across different levels of wireless sensor network to enable invariable energy consumption among them. Concentrated cluster formation near base station ensures minimum relay burden on cluster heads to avoid hot-spot problem in multi-hop data forwarding model. Equivalent number of clusters at each level ensures in-common network load on each cluster head among different data forwarding routes. In addition, a simple disjoint multi-hop routing technique is proposed for smooth data forwarding process. Simulation results evidence that the proposed unequal clustering algorithm overcomes hot-spot problem with invariable energy dissipation among cluster heads across the network and elevates sensor network lifetime.

***Index Terms*—**Unequal Clustering, Multi-hop Routing, Wireless Sensor Network, Energy Dissipation, Lifetime, Network design space, Hot-spot Problem, Disjoint Routing

I. Introduction

Wireless Sensor Network (WSN) is a distributed collection of resource constrained tiny nodes capable of operating with minimal user attendance. Rapid development in the field of micro electro mechanical systems (MEMS) technology has provided small sized, low-power and low-cost sensor nodes with the capability of sensing various types of physical and environmental conditions. WSN improves the ability of human beings to monitor and control physical locations from far-off places [1]. Since each sensor node works independently without any central control, failure of some nodes does not affect other network activities. WSN is more reliable and secure when compared with other types of networks. WSN is the backbone for establishing smart environments. Each sensor node is equipped with one or more low powered sensors, a processor, memory, a power supply, a radio and an actuator [2]. Based on infrastructure, wireless sensor networks (WSNs) are categorized into two types: Structured WSNs and Unstructured WSNs. Nodes are deployed in predetermined way in structured WSN, whereas in unstructured WSN sensor nodes are randomly deployed. Usually, structured WSN has densely deployed sensor nodes which are not easily manageable and unstructured WSN will have limited number of sensor nodes which can be easily managed [3]. Based on how the sensor readings are delivered to base station, WSNs are distinguished as, Synchronous and Asynchronous sensor networks. Synchronous sensor networks send sensed information in real-time using multi-hop wireless communication. Whereas asynchronous sensor networks deliver readings with some delay (e.g., once in a day or week or month) [4].Since WSN has the ability to work with minimal human intervention, these are used in many fields like military, agriculture, industry, target tracking, data collection, rescue missions, national security, monitoring disaster prone areas, managing inventories, health care, home security and environmental studies [5][6].

Distinguished from traditional wireless networks, the sensor nodes of WSNs have limited power, low computational capacity and less memory. Due to non-replaceable and non-rechargeable properties of sensor node battery, it has been a major challenge to reduce the energy consumption in energy constrained wireless sensor networks [7]. To achieve this, sensor nodes are grouped together to form clusters. Each cluster consists of set of sensor nodes within the given range. Every cluster will have a leader, often referred as cluster head and the other sensor nodes become cluster members of that cluster. Cluster head may be elected by the sensors in the cluster or pre-assigned by network administrator.

Clustering technique has numerous advantages, it can localize the route setup, conserve communication bandwidth, avoids redundant message exchanges, cuts on topology maintenance overhead, implements optimized management strategies to enhance network operations, schedules activities in the cluster, prevents medium access collision by limiting redundancy in coverage, decreases the number of relayed packets by aggregating data collected by sensors in the network, etc [8]. Sensor nodes in a cluster transmit the sensed information to their cluster head. Each cluster head aggregates the collected data and forwards it to sink node either directly or via multi-hop path through other cluster heads. In a clustered network, network traffic is composed of intra-cluster and inter-cluster traffic. Both Intra-cluster and inter-cluster communications could be single-hop or multi-hop. Previous research has shown that multi-hop communication between the source and destination is more energy efficient than direct or single-hop communication [9]. However, the hierarchical (clustering) paradigm causes uneven energy consumption between cluster head to cluster head communication (inter-cluster communication) and cluster members to cluster head (intra-cluster communication). To balance this energy expenditure, recent research proposes cluster head rotation mechanism. This technique balances the energy consumption among cluster heads and its members but not between cluster heads in inter-cluster multi-hop communication. Cluster heads close to sink node drain their energy faster due to heavy relay traffic and will die sooner than the other cluster heads. This lessens network lifetime and leads to low network coverage and creates network holes. This is called Hot-spot problem in WSN. To solve this problem several unequal clustering techniques are proposed in the recent literature to balance energy consumption among cluster heads in the network [7], [9], [10], [11], [12], [13]. In unequal clustering mechanism, clusters close to sink node are smaller in size than those are farther away. Thus, the cluster heads close to base station can preserve some energy for inter-cluster communication. But, unequal clustering scheme doesn't have any limit in choosing number of cluster heads. So, it creates huge number of cluster heads for every round of data transmission. This increases number of data forwarding nodes in data transmission between source node and base station which leads to wastage of valuable energy resources.

To improve energy efficiency of clustering scheme, trade-off between intra and inter-cluster communication should be handled carefully. Trade-off depends not only on cluster size but also on distance between the source and sink node. The cluster size is an important factor that determines the number of clusters to be formed and total energy consumption in the cluster. As the cluster size increases, the number of clusters to be formed decreases. Thus, the energy consumption by inter-cluster communication decreases, but the energy consumption by intra-cluster communication increases in proportionate to cluster size. On the other hand, an adverse situation occurs when the cluster size decreases. Therefore, the cluster size directly affects the performance of clustering scheme [7].

This paper presents an Energy-efficient UnEqual Clustering mechanism (EUEC) for WSN using equal and unequal clustering methods. It aims to achieve hot-spot free uniform energy dissipation sensor network. This paper proposes a simple disjoint multi-hop routing algorithm for smooth data transmission process between source and the destination.

II. Related Work

This section discusses related research work of the proposed unequal clustering mechanism.

Low Energy Adaptive Clustering Hierarchy (LEACH) [14] is one of the most popular distributed cluster-based routing protocols for WSN. Each node has a certain probability to become cluster head per round, and the task of being a cluster head is rotated between the nodes. LEACH is highly successful in distributing load uniformly across the network. But, its single hop routing does not serve the requirement of real world applications.

Lindsey and Raghavendra (2002) [15] introduced a chain-based clustering routing protocol, PEGASIS. This is considered as an improvement over LEACH routing protocol. The main aim of PEGASIS is to minimize the intra cluster communication overhead of LEACH protocol. The key idea of PEGASIS is to form chains with close by neighboring nodes using greedy approach. Each chain chooses a leader node to forward data to BS. Like LEACH, PEGASIS is single hop routing protocol.

Younis and Fahmy (2004) [16] introduced Hybrid Energy-Efficient Distributed clustering (HEED), a multi-hop WSN clustering algorithm. Unlike LEACH, HEED does not select cluster heads randomly. In HEED, cluster heads are elected based on two parameters: residual energy and intra-cluster communication cost. Every node elects least communication cost cluster head to join it. HEED cluster head selection strategy creates more number of cluster heads than the expected and this leads to variation in energy consumption in the network. Also, this may result poor network coverage. Since HEED does several iterations to form clusters, network lifetime decreases with increased energy dissipation. Cluster heads near base station may die earlier because of heavy relay traffic. This is known as hotspot problem (Liu, 2012).

To address hot spot problem, Li et al. (2005), introduced an unequal clustering mechanism, Energy Efficient Unequal Clustering (EEUC) [10] to balance energy consumption among cluster heads. EEUC form small clusters near base station and the size increases as the distance progress. Thus the cluster heads close to base station preserve energy for inter-cluster communication. The author also proposed an energy aware multihop routing protocol for inter-cluster communication in EEUC mechanism. EEUC creates varied number of cluster heads based on parameters like r_{comp}, c etc from round to round and does not guarantee different cluster head nodes for each round.

Lee et al. (2008) have proposed another unequal clustering algorithm, Energy-Efficient Distributed Unequal Clustering (EEDUC) [11] to create distributed clusters in WSN. EEDUC is an extension of EEUC [10] mechanism. Here also, clusters closer to the base station have smaller size than those farther away from the base station. It considers relay traffic for selecting forwarding cluster head to forward data towards base station. Since EEDUC is a descendent of EEUC, it inherits EEUC disadvantages too.

Soro and Heinzelman (2005) proposed Unequal Clustering Size (UCS) [12] network organization model for WSN. The main aim of UCS is to enhance the network lifetime by distributing the load uniformly among cluster heads, whose positions are predetermined. Having base station at center of the network, the cluster heads are arranged symmetrically in concentric circles in two levels called, Layers. Respective clusters in their respective layers are of same size and shape with cluster heads at center. But, the cluster size and shape differ from layer to layer. The aggregated data from cluster heads will be delivered to sink node through cluster head to cluster head (inter-cluster) communication. Predefined positions for cluster heads are not advisable for real-time applications. Also, layered approach does not suites for large scale networks.

Bai et al. (2009) introduced multi-hop clustering algorithm, Power-Efficient Zoning Clustering Algorithm for WSN (PEZ) [13], to extend network lifetime by minimizing energy consumption. It is developed based on two most popular clustering protocols, LEACH and PEGASIS. PEZ divides its network into fan-shaped regions placing base station at center. Each region is considered as a cluster. Multi-hop data communication delivers data to BS. Like, UCS, PEZ also uses layered network model which limits its applicability to small scale networks.

Mao and Hou (2007) have introduced a novel edge-based routing protocol, called BeamStar for WSNs [17]. The aim of BeamStar is to reduce size and cost of the sensor node. This protocol utilizes infrastructure potential provided by an edge based network to carry out the network operations. It assumes that, the network is equipped with a directional antenna with power control capabilities. Using this, BS can reach any part of the network to provide control information to sensor nodes by varying its transmission power level and beam width. This shifts the control and network management overhead burden from sensor nodes to BS. The power controlled capability base station scans the complete network with different power transmission levels (Sector number (SN)) in different angles (Ring Number (RN)) to provide location information for the nodes. With this location information, sensor nodes can en-route sensed data to BS using controlled broadcasting mechanism. The data is forwarded by using simple forwarding rules provided by BS. Since flooding is used for data transmission, it does not guarantee data delivery and leads to energy wastage. Also the control overhead is high for regular network health check-up.

Kuong Ho et al. (2009) proposed a routing protocol for edge-based WSNs, called, CHIRON [18]. It is developed based on one of the most popular hierarchical routing protocols, PEGASIS. Also, it uses the same technique of BeamStar to provide location information for the nodes in the network. It outperforms BeamStar with respect to delay time and network lifetime. CHIRON operates in four different phases. First phase is Group construction phase, where the sensing field is divided into smaller groups using BeamStar methodology. The nodes with same Ids form groups. Chain formation phase is the second phase. Here PEGASIS chain formation process is used to construct smaller chains. Leader node election phase is the next phase in CHIRON. Node with maximum residual energy is elected as “Leader node” for the current round. Cluster Head (CH) to Cluster Head communication delivers data to destination node (BS). CH selection process repeats in round robin fashion. The last phase is data collection and transmission phase. In this phase, whenever an event occurs, the sensor nodes sense the data form their surroundings. The sensed data will be collected and aggregated by chain leader. The same is forwarded to BS using multi-hop, leader-to-leader communication. The CHIRON data transmission process is similar to that of PEGASIS protocol. Data forwarding mechanism used is unreliable as it forwards data randomly towards destination node.

To overcome the drawbacks of BeamStar, Hao-Li Wang and Yu-Yang Chao proposed a routing protocol for edge-based WSNs, Cluster-based BeamStar (CBS) [19]. CBS also uses the same concept of BeamStar to provide location information for sensor nodes with refined sensing process. CBS outperforms BeamStar in efficient usage of power, inter-node communication and scan time. CBS protocol is explained in three phases. In the first phase, Locating phase, sensing field is scanned using BeamStar mechanism by adjusting the transmission power level. The second phase is, Cluster building phase. Here it forms clusters with nodes having same Ids. The node with maximum residual energy is elected as Cluster Head (CH), just like in CHIRON. Data transmission is the last phase in CBS. It uses LEACH protocol to carry out data transmission process. In this phase, CH aggregates the data from the cluster members and forwards the same to BS via inter cluster head transmission. New round starts with an advertisement if CH’s energy falls below the given threshold. The cluster member with greater residual energy announces itself as a new cluster head for the current round. The radius selection strategy used creates huge number of rings in the network as a result several clusters are formed and is suitable for large scale networks only.

III. Preliminaries

Following section discuss the perquisites of proposed mechanism.

A. System Model

The proposed model assumes the following.

- All sensor nodes are homogeneous with same capabilities.
- Nodes are not equipped with GPS (Global Positioning System) capable unit and are location unaware.
- Sensor nodes are deployed with uniform probability in a circular field.
- Base station is equipped with directional antenna with power control capability.
- Every node is capable to change its transmission power level depending up on the distance to receiver.
- Network has data to send continuously and there is only one sink node to receive data in the network.
- Links are symmetric. Based on RSSI (Received Signal Strength Indication), any node can compute approximate distance to another node for a given transmission power level.

B. Radio Model

Proposed model uses the same radio model that is used in [10]. For the radio hardware, the transmitter dissipates energy to run the transmitter radio electronics and power amplifier, and the receiver dissipates energy to run the receive radio electronics as shown in Fig. 1 [20].

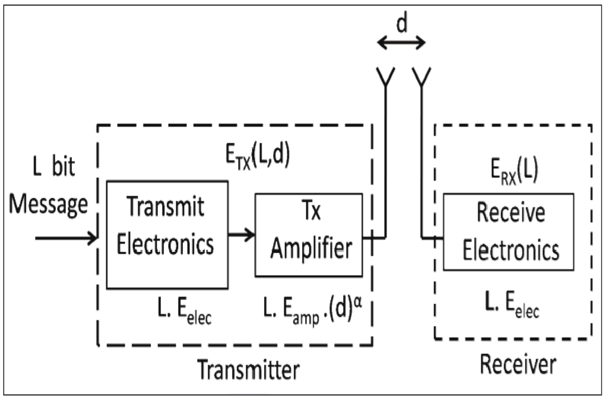

Fig. 1. Radio Model

Here, both the free space (d2powerloss) and the multi path fading (d4powerloss) channel models were used depending on the distance between the transmitter and the receiver. If the distance is less than the given threshold, the free space (fs) model is used. Otherwise, the multi path (mp) model is used. The energy spent (E_{TX}) to transmit L-bit packet over distance d is given as follows.

$$E_{TX}(L,d) = \begin{cases} L.E_{elec} + L.\epsilon_{fs}.d^2 if d < d_0 \\ L.E_{elec} + L.\epsilon_{mp}.d^4 if d \geq d_0 \end{cases} \quad (1)$$

where threshold d_0 is calculated as

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \quad (2)$$

To receive L bits, radio spends $E_{RX}(L)$ energy which is given below

$$E_{TX}(L) = L.E_{elec} \quad (3)$$

Also, the proposed model assumes that the sensor consumes E_{DA} (nJ/bit/signal) amount of energy for data aggregation.

C. Problems Of Unbalanced Energy Consumption

Energy consumption happens at two different levels in cluster based WSN [9]. They are: Inter-cluster energy consumption and Intra-cluster energy consumption. The first category represents the energy consumed for communicating with other cluster heads as well as with sink node. Whereas the later corresponds to energy consumption within the cluster for data transmission and data aggregation. Inter-cluster communication consumes more energy than intra-cluster communication. This is because, every cluster head aggregates the data collected from its cluster members and forwards it as a single-length data packet to next cluster head. Also, cluster heads relays the upstream data traffic towards sink node. Due to this, cluster heads located near sink node are burdened with heavy relay traffic and will drain their energy and die faster leaving network partitioned. This is known as hot-spot problem. To solve this problem, unequal clustering technique [10], [11], [12], [13], [9] has been proposed in the recent literature. This mechanism creates clusters in different sizes, the size of cluster increases as the distance increases from base station. The idea behind creating smaller clusters near base station is to preserve some energy for inter-cluster communication.

Even though unequal clustering mechanism avoids hot spot problem, it brings some additional problem into the network. It is successful in distributing energy dissipation among cluster heads but not between cluster members and cluster heads. Problems with unequal clustering are listed below.

- As the network size increases, the cluster size increases and leads to poor connectivity.
- Since it has no control on percentage of cluster heads it creates, number of cluster heads selected varies rapidly from round to round.
- Irregular cluster formation leads to imbalanced energy dissipation among sensor nodes in the network. This uneven energy consumption influences network performance and lifetime.
- This methodology suits only for large scale and densely populated sensor networks.
- Control overhead involved in cluster head selection is high.
- Unequal clustering technique doesn’t guarantee fully connected network.

To overcome the pitfalls listed above, this paper proposes an Energy Efficient Unequal-in-Equal Clustering Algorithm in this paper. It combines advantages of equal and unequal clustering techniques to form hybrid clusters in the network.

D. Goals Of The Proposed Work

The following goals are set to achieve with the proposed mechanism.

- To balance energy consumption among inter cluster-heads communication with less control over head.
- To avoid hot-spot problem completely.
- To create limited number of cluster heads in each data forwarding round.
- To elevate sensor network’s lifetime with uniform load distribution among cluster heads.
- To guarantee well connected network with minimum control overhead.

IV. Energy-Efficient Unequal Clustering Algorithm With Disjoint Multi-Hop Routing Scheme For WSNs

Clustering means, partitioning the network into clusters, each one with a cluster head and some ordinary nodes as its members. To distribute energy consumption across the network, cluster heads are rotated among sensor nodes in each data gathering round or in the given intervals of time. This section describes Energy-Efficient Unequal Clustering Algorithm with Disjoint Multi-hop Routing Scheme in detail.

A. Energy-Efficient Unequal Clustering Algorithm

This section proposes Energy-Efficient Unequal Clustering Algorithm in detail.

Network Design Space

In the network deployment stage, base station broadcasts an advertisement at a certain power level to all the sensor nodes in the network. Based on RSSI value each node calculates its approximate distance to BS. This helps node to select proper power level to communicate with base station and helps in final cluster head selection strategy.

To organize wireless sensor network into clusters, we use identities of sensor nodes. As described in Preliminaries section, the sensor nodes are not GPS enabled and are not location aware. So, to provide location information, we perform intelligent location discovery process as described below. Here we consider a WSN with base station equipped with directional antenna with power control capability and is not energy constrained. The area covered for each transmission by base station is called a Sector. The transmission power of the directional antenna determines the radius R of each sector and beam width θ determines span of the sector. This process is shown in Fig. 2 [17]. The base station can adjust its transmission power level to reach all sensor nodes in the network.

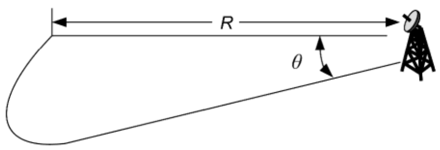

Fig. 2. Sector formation of power-controlled directional antenna

A WSN with N sensor nodes deployed uniformly in a circular field within the radius R from the base station is considered here. The power control capability directional antenna is located at center of the network field and it can reach any part of the network by varying its transmission power level and beam width. For illustration purpose, we consider one quarter of circular field. The network is divided into number of rings and each ring is scanned with the given transmission power level r_i. This provides Ring Number (*RN*), one of the two values of location information, that uniquely identifies the ring to which the sensor node belongs. By varying beam width θ of directional antenna, each sector will be scanned to provide Sector Number (*SN*) for each sensor node of the network. The following section explains the process of zone formation in the network [21].

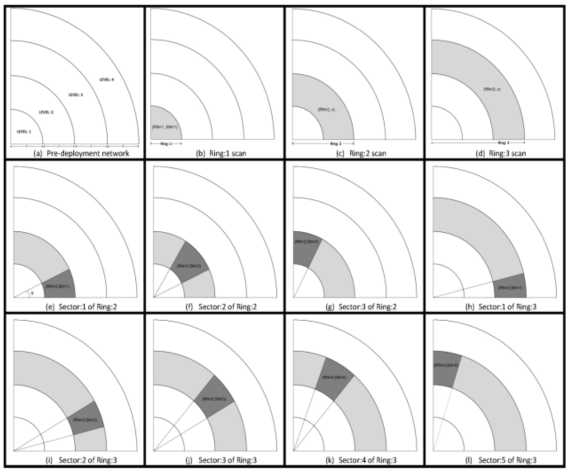

Fig. 3. Scanning Process

Let k be maximum number of levels in the network, then we have

$$r_1 = \frac{R}{k} \tag{4}$$

where R is radius of the network.

Let r_i be the transmission power level or radius of i^{th} ring in meters and is calculated as follows

$$r_i = i \times r_1 \forall i = 1,23, \dots \dots k \tag{5}$$

where r_1 is radius of 1st ring.

Let θ_i be the span or beam-width of i^{th} ring in degrees and is calculated as follows

$$\theta_i = \frac{90}{2i-1} \forall i = 1,2,3, \dots \dots k \tag{6}$$

By varying θ_i value, each time we scan a sector of i^{th} ring. Using r_i, we get area (a_i) of i^{th} ring as

$$a_i = \frac{1}{4}\pi r_i^2 = i^2 \times a_1 \forall i = 1,2,3 \dots . k \tag{7}$$

where ai is area of ith ring with radius ri.

From the (7), we get area of i^{th} region or level as

$$A_i = (2i - 1) \times a_1 \forall i = 1,2,3 \ldots \ldots k \quad (8)$$

where A_i is the area of i^{th} region.

Form (8), each level i can be divided into *(2i−1)* equal partitions called, Zones.

With different transmission power levels of directional antenna at base station, ring-wise scan will be done to provide Ring Number *RN* to each sensor node in the network. After that, by varying θ value of directional antenna for each level, we provide Sector Number SN second value in the node identity. These two values, *(RN,SN)*, uniquely represent sensor node location where it belongs to i.e., zone information. After getting identities, sensor nodes organize themselves into hierarchical clusters except the nodes from first ring. Nodes from this ring communicate with base station directly, this arrangement is made to cut-off relay traffic burden on first ring sensor nodes. Also, this setup avoids hot-spot problem at first level of clustering process in the network. Fig. 3 gives a generalized view of discussed network architectural model.

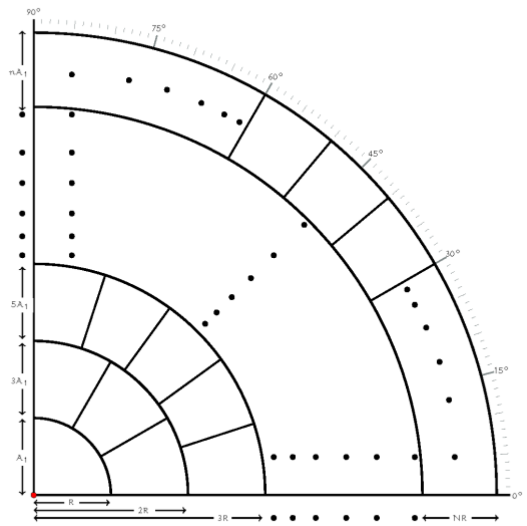

Fig. 4. Novel network organization mechanism

With this novel network design space, we have divided the whole network into equally spaced chunks called, Zones. These equally sized zones are utilized to form clusters in our proposed clustering mechanism. Fig. 4 presents the discussed network design space with node Ids.

This novel network design space divides whole sensor network into equally spaced chunks called, Zones. These equally sized zones are used to form initial level clusters in the proposed clustering mechanism. Fig. 5 presents the discussed network design space with node Ids.

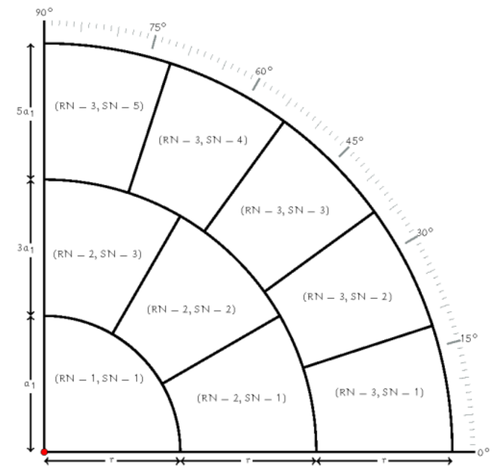

Fig. 5. 3-Ring Network with Node Ids

Cluster Radius Computation

Since every WSN is energy constrained, maximizing network lifetime under given energy constraints is the primary challenge for all researchers. From the literature, the very basic idea to conserve energy in any WSN is, Clustering. To distribute energy consumption load, the role of cluster head is being rotated periodically among sensor nodes in the network. However, cluster head rotation balances energy consumption between cluster heads and its members only. Cluster head rotation performs better with intra-cluster communications and in single-hop routing scenarios. But, in real for inter-cluster multihop communication scenario, cluster head rotation hardly balances the energy consumption among cluster heads. This paper also supports the argument that using node's residual energy as the only criterion in cluster head selection is not sufficient to balance energy consumption across the network [10].

To avoid hot-spot problem, proposed algorithm creates M number of cluster heads at each level and M is calculated as follows,

$$M = 2l_{max} - 1 \quad (9)$$

where l_{max} stands for maximum number of levels in the network considered.

From this we get number of cluster heads to be formed for each zone at level i.

$$C = \lceil M/\{2i - 1\} \rceil, \forall i > 1 \quad (10)$$

The proposed mechanism creates more than one cluster in a zone, radius of each cluster is calculated as follows.

Let z_a be the area of zone.
Let c_z be number of cluster heads needed.
Let r_{ch} be radius of cluster head.
We have,

$$c_z * \pi * r_{ch}^2 = z_a \quad (11)$$

From the above equation, radius of a cluster is calculated as follows,

$$r_{ch} = \sqrt{\frac{z_a}{c_z * \pi}} \tag{12}$$

Cluster Head Selection Phase

In this phase, cluster heads are selected primarily based on their communication cost. To distribute energy consumption across the network, the role of cluster head is being rotated among cluster nodes in each data forwarding round.

Initially, several tentative cluster heads are selected from each region with some probability P. Here P is varied dynamically from level to level as the percentage of cluster heads vary. Equation (13) gives probability value Pi for level i. These tentative cluster heads compete each other to become final cluster heads, while the non-competing nodes would be in sleep mode, until final cluster heads are selected.

$$P_i = \frac{l+\propto}{z-\beta}, \forall i > 1 \tag{13}$$

where l represents level number, z represents number of zones in that level and $\propto, \beta$ are random values between (0, 1).

From (12) cluster radius r_{ch} is computed for each tentative cluster head as its competition radius. Each tentative cluster head broadcasts COMPETE_CLUSTER_HEAD_MSG which contains its Node Id(Node_ID), Zone Id(Zone_Id) and Spent energy(Spent_Energy). Each tentative cluster head maintains a Neighbor_Tentative_CH set to save its neighboring tentative cluster heads information. Tentative cluster head s is said to be a neighbor of another tentative cluster head t if s belongs to the same zone as t belongs and is in t's competition diameter or t is in s's competition diameter. Final cluster head selection is made based on neighboring nodes from set Neighbor_Tentative_CH.

After Neighbor_Tentative_CH set construction, each tentative cluster head takes the decision whether it can act as a final cluster head or not, based on its Neighbor_Tentative_CH set. If Neighbor_Tentative_CH set is NULL for the tentative cluster head t, then t becomes final cluster head since it doesn't have any competition. Otherwise, tentative cluster head t checks its Neighbor_Tentative_CH set to find a node with least communication cost. If t finds itself has least communication cost, then t wins the competition and becomes final cluster head. Tentative cluster head which wins the competition announces itself as final cluster head by broadcasting FINAL_CLUSTER_HEAD_MSG with incremented cluster head counter to inform all its Neighbor_Tentative_CH set. Tentative cluster head which receives FINAL_CLUSTER_HEAD_MSG from its Neighbor_Tentative_CH set will give-up the competition and inform all its neighbors by broadcasting QUIT_CLUSTER_HEAD_COMPITITION_MSG. If a tentative cluster head t receives QUIT_CLUSTER_HEAD_COMPITITION_MSG from its neighbor s, node t will remove tentative cluster head s from its Neighbor_Tentative_CH set. After all this, if a tentative cluster head becomes final cluster head, it guarantees that there will not be another cluster head within its cluster radius r_{ch}. Cluster head selection process is explained for an arbitrary sensor node s in the pseudo code given in Fig. 6 and the flow chart for the same is presented in Fig. 7.

```
ComputeRand(Ln,Zn)
α ← Rand(0,1)
β ← Rand(0,1)
return (Ln  α) (Zn · β)

λ ← ComputeRand(Rn,Ln)
if λ  T, then
        s.Status ← Tentative_Cluster_Head
        Call COMPETE_CLUSTER_HEAD_MSG(Node_ID,Zone_ID,Spent_Energy)
else
        s.Status ← Dormant
        EXIT
end if

On call COMPETE_CLUSTER_HEAD_MSG(Node_ID,Zone_ID,Spent_Energy) from node t
if s.ZoneID  t.ZoneID AND d(s,t) < s.r_ch then
        Push t to s. Neighbor Tentative CH
end if
while s.Status  Tentative_Cluster_Head do
        if s. Neighbor_Tentative_CH = NULL AND ··Counter <= C then
                s.Status ← FINAL CLUSTER HEAD MSG
                Call FINAL_CLUSTER_HEAD_MSG (NodeID)
                EXIT
        else if s.CommunicationCost < t.CommunicationCost ∀ t ∈ s. Neighbor_Tentative_CH
                        AND -- Counter <= C AND d(s.BSDistance) < d(t.BSDistance) then
                s.Status ← FINAL_CLUSTER_HEAD_MSG
                Call FINAL_CLUSTER_HEAD_MSG (NodeID)
                EXIT
        end if
end while

On call FINAL_CLUSTER_HEAD_MSG (NodeID) from node t
if t ∈ s. Neighbor Tentative CH then
        s.Status ← NonCH
        Call QUIT_CLUSTER_HEAD_COMPITITION_MSG(NodeId)
        EXIT
end if

QUIT_CLUSTER_HEAD_COMPITITION_MSG(NodeId) from node t
if t ∈ s. Neighbor_Tentative_CH then
        Delete t from s. Neighbor Tentative CH
end if
```

Fig. 6. Cluster head selection pseudo code

Cluster Formation Phase

Once final cluster heads are selected, each cluster head broadcasts a CH_ADV_MSG across the network. Sleeping nodes wake-up and join its nearest cluster head with largest received signal strength by sending a JOIN_CH_MSG.

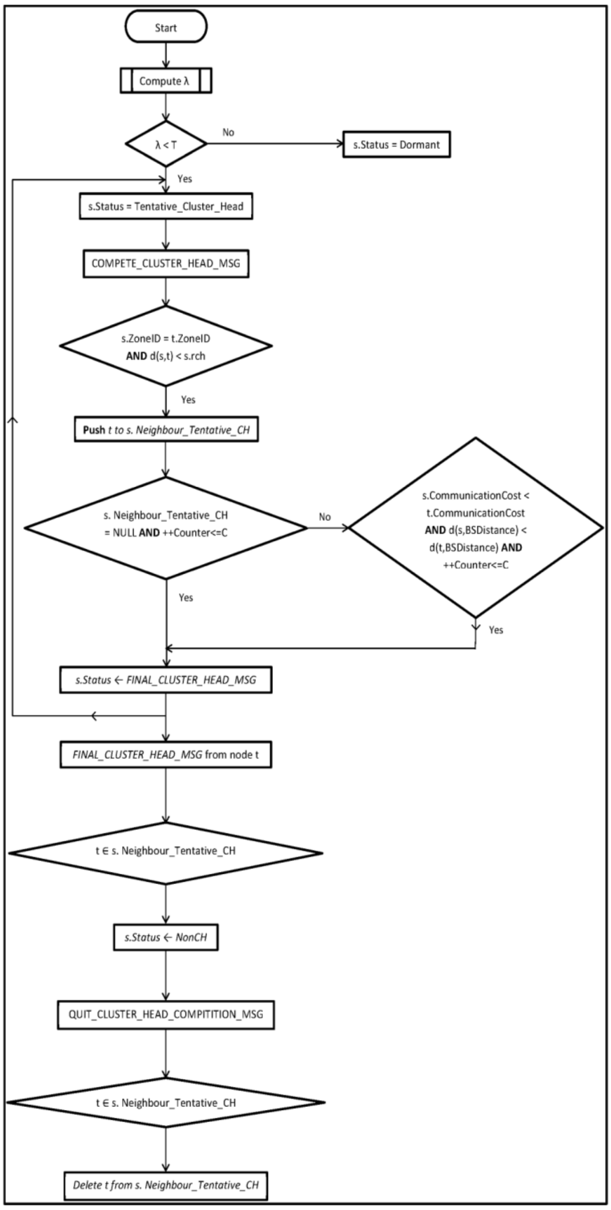

Fig. 7. Flow chart for cluster head selection process

Data Transmission Phase

After cluster formation phase, cluster members start sensing information from the phenomenon and send sensed data to its cluster head. The cluster head aggregates this information as a single length-fixed data packet and forwards it to its neighboring cluster head close to base station. The packet reaches sink node in the direction of descendant order using multi-hop data forwarding mechanism, this process is explained in the following section.

B. Multi-hop Routing Mechanism

Cluster heads use multi-hop data forwarding scheme explained in this section for data transmission process. Whereas sensor nodes from first level deliver sensed information directly to sink node to avoid heavy relay traffic burden. Once clusters are formed, the cluster members start sending their data to their cluster head. Each cluster head aggregates the received data from its members and forwards it to next cluster head in the downstream. To select forwarding node for each data transmission round, cluster heads broad-casts RELAY CLUSTER HEAD MSG which consist NodeId, LevelNumber, ResidualEnergy and DistanceBS. Cluster heads from upstream use this information to find their relay node for data transmission from the following relation.

Cluster head from downstream with greater Rch is selected as relay cluster head for a upstream data forwarding cluster head. Incase if there is a tie, the node with lower NodeId is selected as a relay node.

$$R_{ch} = \frac{(F_{RE}-D_{RE})^2}{d(F_{ch},D_{ch})^2+d(D_{ch},BS)} \qquad (14)$$

where R_{ch} is relay cluster head, F_{RE} is forwarding cluster head residual energy, D_{RE} downstream cluster head residual energy, $d(F_{ch}, D_{ch})$ is distance between forwarding and downstream cluster head and $d(D_{ch}, BS)$ is distance between downstream cluster head and base station.

With M number of cluster heads in each level ensures disjoint multi-hop routing paths in ideal situations from source to sink node [22] which guarantees even relay traffic burden among cluster heads in the network.

V. Protocol Analysis

This section presents the algorithmic complexity of proposed work, EUEC.

Lemma 1:

The big Oh complexity of the proposed work is O(N), where N is total number of nodes in the network.

Proof:

Let n be the number of tentative cluster heads. According to our COMPETE_CLUSTER_HEAD_MSG method, all the tentative cluster heads (n) will start sending the signal. So, there will be n signals at this point of time. Now, it is fair enough to assume that some of these n nodes will become final cluster heads and the rest will return back to their original state. Let, k be such number of nodes. At this point of time, there will be (n−k) number of FINAL_CLUSTER_HEAD_MSG signals and k QUIT_CLUSTER_HEAD_COMPITITION_MSG signals in the network.

Also, all these (n−k) final cluster head nodes, will send CH_ADV_MSG signals. After receiving advertisement, remaining k nodes reply with JOIN_CH_MSG to highest RSSI cluster head.

So, summing up all these signals in this Cluster formation phase we have a total of,

n +(n − k)+ k +(n − k)+ k number of signals per round i.e., O(N).

Lemma2:

There won't be two cluster heads if one is in the other's cluster head competition radius r_{ch}.

Proof :

Suppose s and t are two tentative cluster heads. s is located in the cluster head competition radius of t.

According to EUEC, s belongs to t.Neighbor_Tentative_CH set. If t becomes cluster head, s will be notified about its state, so s quits the competition and becomes an ordinary node; vice versa.

VI. Experimental Results

This section evaluates the performance of proposed work, Energy Efficient Unequal-in-Equal Clustering Algorithm (EUEC) through simulation. CASTALIA network simulator [23] is used to analyze EUEC behavior. An ideal MAC layer and error-free communication links are assumed for experimental work. EUEC performance is compared with well-known unequal clustering algorithm EEUC which also uses multihop routing mechanism for data transmission. Since LEACH is single-hop routing algorithm, it is not compared with EUEC. Simulation parameters considered for performance evaluation are given in Table I. Radio hardware energy dissipation model shown in [10] is used here.

Table 1. Simulation Parameters

Parameter	Value
Simulation Area	(0,0) ~ (1000,1000)
BS Location	(0,0)
Number of Nodes	200
Initial Energy	18720J
E_{elec}	50 nJ/bit
E_{amp}	10 pJ/bit/m2
E_{DA}	5 nJ/bit/signal
Data Packet Size	200 bits
Packet Rate	1/sec
Radius (R)	200m
Simulation Time	25000 sec
Number of Runs	10
Round Time	25 sec

Fig. 8 illustrates number of cluster heads formed by EUEC and EEUC. From the figure it is clear that EUEC select consistent number of cluster heads for each data forwarding round. Whereas, EEUC selects huge and different number of cluster heads from round to round. Maximum of M number of cluster heads in each level distributes EUEC cluster heads uniformly and the cluster size increases with the distance from base station.

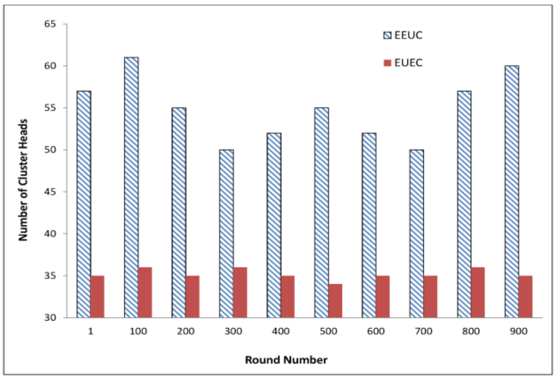

Fig. 8. Average number of CHs selected in each round

A. Energy Consumption

This section examines energy consumption behavior of EUEC.

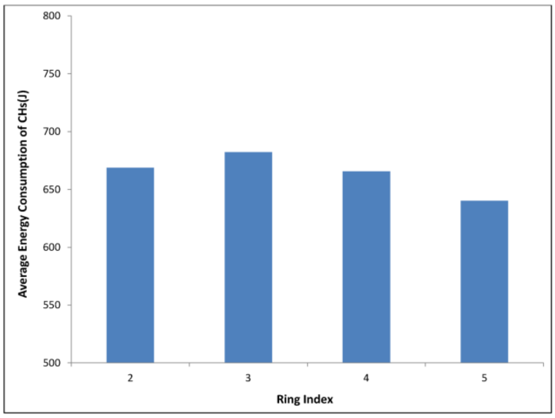

Fig. 9. Average amount of energy consumed by EUEC cluster heads in each level

Fig. 9 shows the average amount of energy consumed by EUEC Cluster Heads in each level. It is noted from the figure that the variation in energy consumption among cluster heads in different levels is minimum. This proves the EUEC achievement in balanced energy dissipation of cluster heads at various levels with its distributed cluster head selection process. Control on number of clusters formed with gradual increase in cluster size from level to level enables uniform energy dissipation among different cluster heads in the network.

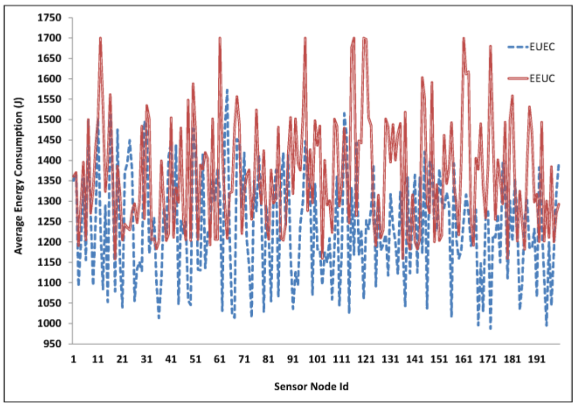

Fig. 10. Average amount of energy consumed by sensor nodes

Fig. 10 represents amount of energy consumed by sensor nodes in the network. From the figure it is observed that, EEUC sensor nodes consume more power compared to EUEC sensor nodes. Uniform distribution in cluster formation at each level allows EUEC to control cluster size across the network. This makes network load invariable on cluster members at different levels to promote reduced energy consumption in the network.

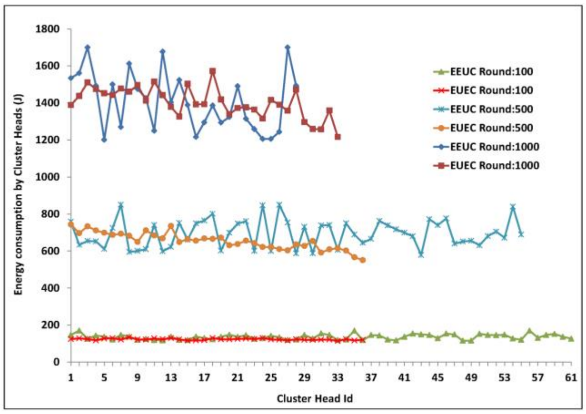

Fig. 11. Energy consumed by cluster heads in different data forwarding rounds

Fig. 11 presents energy consumed by cluster heads in various data forwarding rounds. This figure witnesses the consistency in amount of energy spent by cluster heads irrespective of data forwarding rounds. The stability in energy dissipation across different data forwarding rounds is achieved only EUEC effective cluster head distribution mechanism.

Fig. 12 presents the variance in amount of energy consumed by cluster heads in different data transmission rounds. Figure shows that the variance of EUEC algorithm is steady and proceeds towards stationary position. The steadiness in energy consumption at various data forwarding rounds makes variance to fluctuate at minimum magnitude.

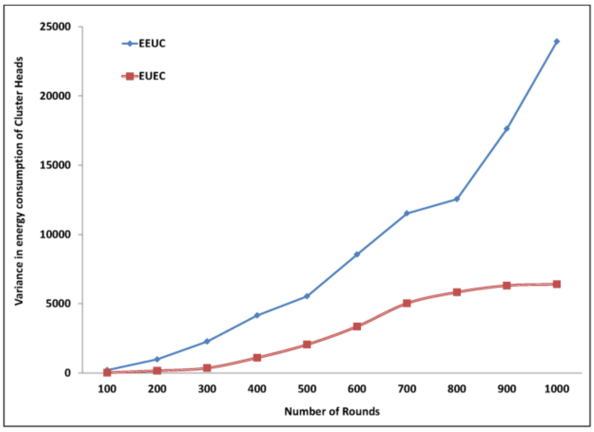

Fig. 12. Variance in amount of energy spent by CHs

B. *Life Time Computation*

Following section presents life time of sensor network with proposed EUEC algorithm.

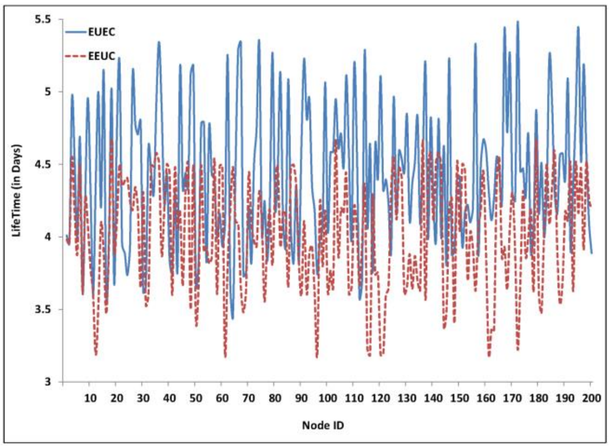

Fig. 13. Sensor nodes lifetime in the network

Fig. 13 illustrates sensor nodes lifetime in the network. EUEC shares network load in even among all the sensor nodes with uniform cluster head distribution and rotation mechanisms across the network. Fig. 13 witnesses that, EUEC is successful in enhancing sensor nodes lifetime with invariable energy consumption among sensor nodes.

Fig. 14 represents lifetime of sensor nodes in different level of the network. It is noted form the the figure that all sensor nodes start dyeing at the same point of time irrespective of level it belongs. More importantly it is observed that the nodes from first level have similar lifetime with higher level nodes witnesses the hot-spot free sensor network with EUEC mechanism. Uniform cluster distribution promotes invariable energy dissipation among sensor nodes and enhances nodes lifetime. It is also observed from the figure that the lifetime of all levels ends at same time.

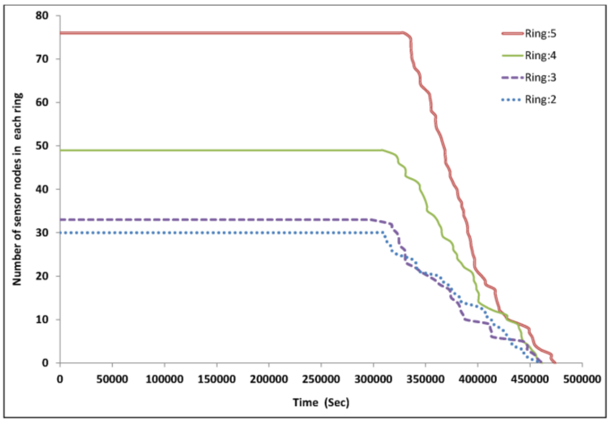

Fig. 14. Lifetime of sensor nodes at each level

Fig. 15 shows the number of sensor nodes alive over the simulation time. Here, network lifetime is calculated till first node dies in the sensor network. It is noted from the figure that, EUEC outperforms over EEUC with its enhanced network lifetime. Stabilized energy dissipation at different levels raises sensor nodes lifetime thereby networks lifetime. Also, it is observed form the figure that the EUEC network lifetime degrades gradually over time and is rapid for EEUC.

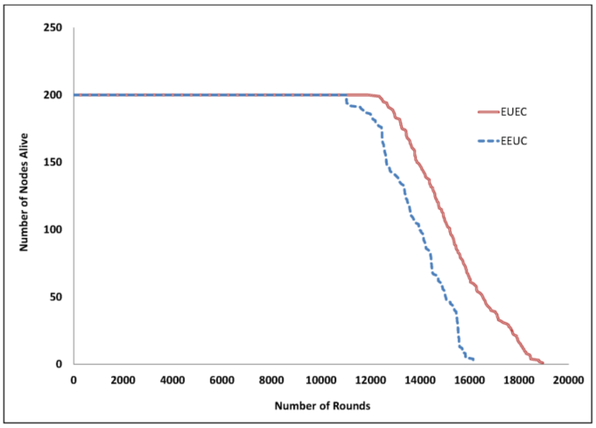

Fig. 15. Number of nodes alive in the network

Fig. 16 presents lifetime of wireless sensor network till 5% of nodes die-out in the network. From this figure it is inevitable that, EUEC produces consistent performance till last node dies in the network. Once again from the results it is evident that, EUEC out-performs on EEUC with its elevated network lifetime.

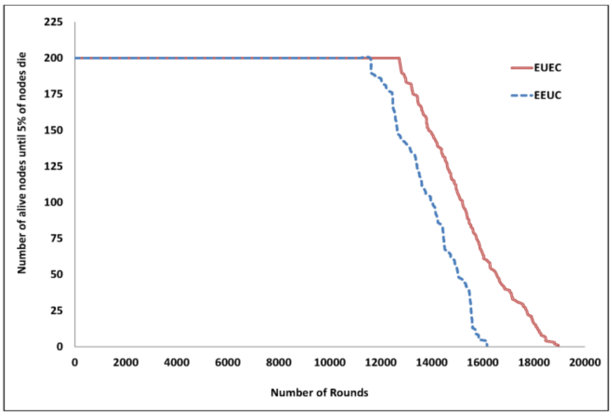

Fig. 16. Life time of sensor nodes in the network

VII. Conclusion

In multi-hop data routing model, hot-spot problem arises when employing clustering mechanism. Unequal clustering methodology is proposed to avoid hot-spot problem in the literature. But, it creates huge number of clusters with different sizes at different level of network. Though unequal clustering avoids hot-spot problem, it increases hop-count between source and destination in every data forwarding route, which causes energy wastage. Also, the irregular cluster formation causes imbalance in energy dissipation among sensor nodes in the network, leads to degrade network performance and lifetime. To overcome these issues a novel energy efficient unequal-in-equal clustering algorithm is proposed for wireless sensor networks in this paper. It creates limited and equivalent number of unequal and equal clusters at each level of the sensor network. The proposed mechanism forms small clusters near base station than those faraway. Clusters with smaller size preserves energy for inter-cluster communication. This avoids hot-spot problem and balances energy consumption among cluster heads with minimum energy wastage. This paper also propose a disjoint multi-hop routing protocol for smooth data transmission process. Limited and equivalent number of clusters in each level may employ Node-Link-Disjoint multi-path routing for data transmission. The disjoint multi-hop data forwarding guarantee's uniform network load on each data routing path. The intelligent relay node selection process helps cluster heads to choose node close to base station to forward data. Simulation results show that the proposed clustering scheme enables uniform energy dissipation with its uniform cluster head distribution in limited number across the sensor network. In addition, the proposed multihop routing scheme spreads the network load in-common to all the data forwarding nodes in the network. With its limited and distrusted cluster head selection mechanism, EUEC achieves hot-spot free network with invariable energy dissipation among sensor nodes and elevates sensor network lifetime.

References

[1] D. Bhattacharyya, T.-h. Kim, and S. Pal, "A comparative study of wireless sensor networks and their routing protocols," Sensors, vol. 10, no. 12, pp. 10 506–10 523, 2010. [Online]. Available: http://www.mdpi.com/1424-8220/10/12/10506.

[2] X. Ren and H. Yu, "Multipath disjoint routing algorithm for ad hoc wireless sensor networks," in ISORC, 2005, pp. 253–256.

[3] J. Yick, B. Mukherjee, and D. Ghosal, "Wireless sensor network survey," Computer Networks, vol. 52, no. 12, pp. 2292–2330, Aug. 2008. [Online]. Available: http://dx.doi.org/10.1016/j.comnet.2008.04.002.

[4] L. B. P. Schaffer, "Position-based aggregator node election in wireless sensor networks," International Journal of Distributed Sensor Networks, vol. 2010, pp. 1–15, 2010.

[5] K. Akkaya and M. Younis, "A survey on routing protocols for wireless sensor networks," Journal of Ad Hoc Networks, vol. 3, no. 3, pp. 325–349, May 2005.

[6] X. Liu, "A survey on clustering routing protocols in wireless sensor networks," Sensors, vol. 12, no. 8, pp. 11 113–11 153, 2012.

[7] S. Lee, H. Choe, B. Park, Y. Song, and C.-k. Kim, "Luca: An energy-efficient unequal clustering algorithm using location information for wireless sensor networks," Wireless Personal Communications, vol. 56, no. 4, pp. 715–731, 2011. [Online]. Available: http://dx.doi.org/10.1007/s11277-009-9842-9.

[8] A. Abbasi and M. Younis, "A survey on clustering algorithms for wireless sensor networks," Journal of Computer Communications, vol. 30, pp. 2826—2841, 2007.

[9] T. Liu, Q. Li, and P. Liang, "An energy-balancing clustering approach for gradient-based routing in wireless sensor networks," Computer Communications, vol. 35, no. 17, pp. 2150 – 2161, 2012. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0140366412002162.

[10] C. Li, M. Ye, G. Chen, and J. Wu, "An energy-efficient unequal clustering mechanism for wireless sensor networks," in Mobile Adhoc and Sensor Systems Conference, 2005. IEEE International Conference on, 2005, pp. 8 pp.–604.

[11] S. Lee, J. Lee, H. Sin, S. Yoo, S. Lee, J. Lee, Y. Lee, and S. Kim, "An energy-efficient distributed unequal clustering protocol for wireless sensor networks," World Academy of Science, Engineering and Technology, vol. 48, pp. 443–447, 2008.

[12] S. Soro and W. B. Heinzelman, "Prolonging the lifetime of wireless sensor networks via unequal clustering," in Proceedings of the 19^{th} IEEE International Parallel and Distributed Processing Symposium (IPDPS'05) - Workshop 12, ser. IPDPS '05, vol. 13. Washington, DC, USA: IEEE Computer Society, April 2005, pp. 236–243. [Online]. Available: http://dx.doi.org/10.1109/IPDPS.2005.365

[13] F. e. Bai, H. h. Mou, and J. Sun, "Power-efficient zoning clustering algorithm for wireless sensor networks," in International Conference on Information Engineering and Computer Science(ICIECS 2009), 2009, pp. 1–4.

[14] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy efficient communication protocol for wireless micro sensor networks," in Proceedings of the 33rd Hawaii International Conference on System Sciences, ser. HICSS '00, vol. 8. Washington, DC, USA: IEEE Computer Society, January 2000, pp. 8020–8029. [Online]. Available: http://dl.acm.org/citation.cfm?id = 820264.820485.

[15] S. Lindsey and C. Raghavendra, "PEGASIS: power-efficient gathering in sensor information systems," in Proceedings of IEEE Aerospace Conference, no. 3, March 2002, pp. 1125–1130.

[16] O. Younis and S. Fahmy, "HEED: A hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks," IEEE Transactions on Mobile Computing, vol. 3, no. 4, pp. 366–379, October 2004.

[17] S. Mao and Y. Hou, "BeamStar: An edge-based approach to routing in wireless sensor networks," IEEE Transactions on Mobile Computing, vol. 6(11), pp. 1284–1296, 2007.

[18] C. Kuong Ho, H. Jyh Ming, and H. Chieh Chuan, "CHIRON: An energy efficient chain-based hierarchical routing protocol in wireless sensor networks," in Wireless Telecommunications Symposium (WTS 2009), 2009, pp. 1–5.

[19] W. H. Li and C. Y. Yang, "A cluster-based data routing for wireless sensor networks," in Proceedings of ICA3PP, LNCS, Springer, vol. 5574, 2009, pp. 129–136.

[20] R. K. TRIPATHI, "Base station positioning, nodes' localization and clustering algorithms for wireless sensor networks," Ph.D. dissertation, IIT Kanpur, India, October 2012.

[21] K. Muni Venkateswarlu, A. Kandasamy, and K. Chandrasekaran, "Energy-efficient edge-based network partitioning scheme for wireless sensor networks," in International Conference on Advances in Computing, Communications and Informatics (ICACCI), 2013, 2013, pp. 1017–1022.

[22] A. Kandasamy, K. Muni Venkateswarlu, and K. Chandrasekaran, "Node - link disjoint multipath routing protocols for wireless sensor networks – a survey and conceptual modeling," in Advanced Computing, Networking and Security, ser. Lecture Notes in Computer Science, P. Thilagam, A. Pais, K. Chandrasekaran, and N. Balakrishnan, Eds. Berlin Heidelberg: Springer Berlin Heidelberg, 2012, vol. 7135, pp. 405–414. [Online]. Available: http://dx.doi.org/10.1007/978-3-642- 29280-4-48.

[23] A. Boulis, Castalia, A simulator for Wireless Sensor Networks and Body Area Networks, NICTA, Eveleigh, NSW, Australia, October 2013. [Online]. Available: https://github.com/boulis/Castalia.git.

Authors' Profiles

Muni Venkateswarlu K is a PhD candidate in the Department of Mathematical and Computational Sciences at National Institute of Technology Karnataka, Mangalore, India. He received master's degree in computer applications from Anna University, Chennai, India and Bachelor's degree from S V University, Tirupati, India. His current research area is wireless sensor networks.

Dr. A. Kandasamy is a professor in the Department of Mathematical and Computational Sciences of National Institute of Technology Karnataka, Surathkal, India. He has done his Doctoral Research at Indian Institute of Technology, Bombay, India and he is a Post-Doctoral Fellow of Chuo University, Tokyo, Japan. His research interests are Computational Fluid Dynamics, Rheology, Tribology, Computational Techniques, Bio-informatics and Wireless Sensor Networks. He has published more than 50 reviewed papers in the reputed international journals and international/national conference proceedings. He has given invited talks in various conferences at national and international levels including the ones held at Russia, U.K., Singapore, Malaysia, Indonesia and Hong Kong. He has guided till now fiver students at Doctoral level research work, more than 25 students at Master's level project work. He is having 23 years of teaching experience and 28 years of research experience. He is Member of Board of Studies of various universities and institutions, Reviewer for various International Journals of Elsevier, Springer, Taylor and Francis and other reputed publications. Dr. Kandasamy is a member of National Board of Accreditation of India. He is the life member of various Professional Societies at National as well as International levels. At present, he holds the position of Dean of Faculty Welfare at NITK. Mangalore, India. includes the biography here.

Dr. K. Chandrasekaran is currently Professor in the Department of Computer Science & Engineering, National Institute of Technology Karnataka, India, having 27 years of experience. He has more than 160 research papers published by various reputed and peer-reviewed International journals, and conferences. He has received best paper awards and best teacher awards. He serves as a member of various reputed professional societies including IEEE (Senior Member), ACM (Senior Member), CSI (Life Member), ISTE (Life Member) and Association of British Scholars (ABS). He is also a member in IEEE Computer Society's Cloud Computing STC (Special Technical Community). He is in the Editorial Team of IEEE Transactions on Cloud Computing, one of the recent and reputed journals of IEEE publication. He has coordinated many sponsored projects, and, some consultancy projects. He has organized numerous events such as International conferences, International Symposium, workshops and several academic short term programs at NITK. He was a visiting fellow at LMU Leeds, UK in 1995, Visiting Professor at AIT, Bangkok in 2007, and Visitor at UF, USA in 2008 and a Visitor at Univ. of Melbourne, CLOUDS LAB in 2012. He had also worked as Visiting (Professor) at DoMS, IIT Madras during Feb-Dec. 2010. His areas of interest - research include: Computer Communication Networks, Cyber Security and Distributed Computing and Business Computing & Information Systems Management.