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An Energy Efficient & Load Balanced Clustering Scheme in Wireless Sensor Networks

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Abstract— **In this paper, we propose an energy efficient & load balanced clustering scheme (EELBCS) for data gathering purpose over a periodic interval in WSNs which maintains a balance of energy load in between the sensor nodes. Our approach defines a novel cluster head distribution scheme which ensures more residual energy of sensor nodes and hence improves the life time of sensor network. The proposed clustering scheme is evaluated and compared with Energy Efficient Clustering Scheme (EECS). Simulation results show that the new technique for clustering outperforms EECS with prolonging the network life time over 19%.**

Keywords: Clustering, Data Gathering, Energy Efficiency, Load Balancing, Wireless Sensor Network (WSN)

I. INTRODUCTION

In Wireless Sensor Network, sensors are deployed in an area such that they remain unattended and cannot be recharged or repaired; albeit, in some cases new sensors can be deployed, probably at random locations. Therefore sensors must operate in energy saving environment. A sensor node mainly performs data sensing, data processing, and data transmission. Out of these operations, data transmission consumes most of sensor's energy as it requires radio communication and hence an energy efficient routing is required for data transmission. Owing to the advantages of hierarchical or clustering routing, it becomes an active branch of routing technology in WSNs. Hierarchical (clustering) routing provides more scalability, less energy consumption, and improved network life time [1].

LEACH [2], is a well known clustering protocol which defines a two-phase mechanism based on single-hop communication. The sensor nodes in a cluster, transmits the data to the corresponding cluster head, the cluster head collects and aggregate the data and transmits to the sink (Base Station) and provide a energy saving technique to improve longevity of network. The next protocol under discussion, the PEGASIS [3], an enhancement over the LEACH protocol increases the life time of each node by using collaborative techniques with chain topology but implemented with a significant delay. Another enhancement over LEACH is EECS [4] that elects a node as a cluster head which has highest residual energy among all the contestants of cluster head election along with a mechanism of cluster head distribution; furthermore, it introduces a novel method to balance the load among the cluster heads.

In this paper, we propose and evaluate energy efficient & load balanced clustering scheme (EELBCS) for data gathering in WSNs. The data is periodic over a time interval. The cluster setup phase uses density of last time used nodes and also unused nodes for the formation of new cluster. Cluster head is periodically changed in the cluster. A uniform distribution of cluster heads is also provided in this method. Further, a distinct approach is introduced for load balancing among cluster heads in the cluster setup phase. EELBCS is fully distributed and more energy efficient and the simulation results show that it prolongs the network lifetime as much as 19% of EECS.

II. RELATED WORK

In the last few years, lot of research work has been done in WSN clustering for different perspectives like efficient data gathering and transmission. LEACH [2], is an energy efficient clustering algorithm in which the responsibility of Cluster Head (CH) is rotated among the nodes for after a certain time period, and rotation of the CH balances the residual energy among the sensor nodes. In LEACH, each CH is responsible for directly forwarding the data to the base station (BS).

Power-efficient Gathering in Sensor Information Systems (PEGASIS) [3] is an improvement over the LEACH protocol. In PEGASIS, despite of forming multiple clusters, chains of sensor nodes are formed so that each node in the cluster transmits and receives data from a neighboring node and only one node from the chain is selected to transmit data to the base station (sink). Data from the nodes is gathered, aggregated and sent to base station in multi-hop fashion. PEGASIS provides a greedy method for chain construction. It is different from LEACH as it uses multi-hop routing by forming chains and selecting only one node to transmit the aggregated data to the sink while in LEACH, each CH directly communicates to BS.

HEED [5] improvise the LEACH by using residual energy and degree of a Node or density as a metric for cluster selection to achieve power balancing. It uses an adaptive transmission power in the inter-clustering communication and operates in multi-hop fashion.

HEED terminates in constant number of iterations, incurring low message overhead. HEED is a hybrid approach in which cluster heads are selected in a probabilistic manner of their residual energy and distributed all over the network to reduce the communication energy consumption. These algorithms are suitable for prolonging the network lifetime.

VCA [6] is a voting-based clustering algorithm that allows sensor nodes to vote for their neighbor to elect their Cluster Head. B enhances the criteria for cluster selection and y this method VCA also provide a way for balancing the load along with energy efficiency. This voting scheme is completely location unaware and distributed in nature. This method assumes a synchronization among the nodes. Like WCA [7], the voting mechanism gather information about all other nodes which required some time and this time depends on the network size. and is not constant.

EECS [4] provides a clustering mechanism which is energy efficient and prolonging network life time. EECS also increase network scalability by providing periodical data gathering. In this method, the sensor nodes communicate locally and elect a Cluster Head with more residual energy. Clusters of unequal size are formed. The size of cluster is small near to the base station while it is comparatively large for the clusters farther away from the base station. The sensors near to base station dissipate more energy and hence the clusters of comparatively smaller size helps sensor nodes in saving their energy. For large clusters, the energy consumption in transmitting data is high. EECS is fully distributed in nature in which Cluster Heads are distributed all over the network and thus balances the load among their cluster heads over the whole network.

All the hierarchal routing algorithms apply clustering to prolong the network lifetime and to balance the load among the nodes, using some metrics. The multi-hop network performance is beyond the scope of these papers. A model is described for estimating the energy consumption of a sensor node in transmission and receiving in respect of both single-hop and multi-hop wireless sensor network architectures [8].

III. SYSTEM MODEL

A. Network Model

In this paper, we have taken the same assumptions as proposed in LEACH and EECS for better comparison purposes. We have assumed a 2-D square network field with N number of sensor nodes scattered inside it. The sensor network in this protocol has the following properties:

- The sensors are mobile in nature and densely deployed in the field area in random fashion.
- Only one base station exists which is assumed to be outside the field area and 5% of total number of sensor nodes can become cluster head.
- The distance between sensor nodes can be calculated using the signal strength.
- All nodes are homogeneous in nature, the circular radius of a sensor node is assumed to be 50m and transmission energy can be varied depending on its distance to the receiver just like Berkeley Motes [9].
- Transmission Energy($Node_i \rightarrow Node_j$)= Transmission Energy($Node_j \rightarrow Node_i$)

B. Energy Model

The first order radio model [2] is used for energy equations. The energy equation for transmitting single bit over a distance **d** is given below. Here single hop transmission, is used in which energy loss is directly proportional to $\mathbf{d^2}$ and multi path transmission or multipath fading channel models is used in which energy loss is directly proportional to $\mathbf{d^4}$ [2]. A sensor node consumes E_e=50nJ/bit to run the transmitter or receiver circuitry. This energy/Power consumption in transmitting a signal can be control by setting the power amplifier. If the distance between transmitter and receiver is less than a threshold $\mathbf{d_o}$, the free space model is used; otherwise, the multipath model is used. Thus, to transmit a k-bit message a distance, the radio expends;

$$E_{TX}(k,d) = \begin{cases} k(E_e + E_s d^2), & if\ d < d_o \\ k(E_e + E_m d^4), & if d \geq d_o \end{cases} \quad (1)$$

In addition, energy consumed to receive this k bit message is given by:

$$E_{RX}(k) = kE_e \quad (2)$$

where the amplifier energy ,$\mathbf{E_s d^2}$ or $\mathbf{E_m d^4}$,depends on the distance between transmitter and receiver.

Value of threshold distance $\mathbf{d_o}$ is given by:

$$d_o = \sqrt{\frac{E_s}{E_m}} \quad (3)$$

IV. ENERGY EFFICIENT & LOAD BALANCED CLUSTERING SCHEME

The EELBCS is designed with a novel clustering scheme. The set up of clusters formation and cluster head selection for the first round is similar to LEACH using TDMA and is briefly described later in the paper. From the next round (of cluster head selection) onwards, EELBCS selects a node as the cluster head which has the highest residual energy among the corresponding cluster nodes and also surrounded by a number of nodes from other cluster regions above a threshold percentage. The threshold value for such percentage of nodes from other cluster regions can be calculated by applying some probabilistic distribution technique. (in our work we have taken it to be 50%).

When all sensor nodes are deployed in the field area, the base station broadcasts HELLO messages to all sensor nodes in the network, the distance to the base station is determined by the sensor nodes with the help of received signal strength. The EELBCS is performed in four phases including (A) Cluster Setup Phase, (B) Cluster Head Election Phase, (C) Data Transmission Phase, and (D) Re-Clustering Phase. The details of each phase are described below:

A. Cluster Setup Phase

The cluster setup phase of EELBCS guarantees to make clusters almost in the circular shape and provide an efficient load balancing of residual energy. In this phase every node having energy above a threshold value (depending on application of network) attempts for electing as cluster head with its TDMA schedule. The sensor nodes check for their residual energy; if the residual energy is more than defined threshold then the node is eligible to become cluster head, we define those nodes as Candidate Node. Now Candidate Node broadcasts a HELLO message with a low range transmission. The sensor nodes within the range of the corresponding Candidate Node receive the HELLO message and send back a REPLY message containing its cluster ID (cluster ID for initial round is NILL, as initially no sensor node is associated with any cluster), sensor ID and their residual energy. The Candidate Node check the cluster ID and calculate whether there are at least 50% of member nodes belonging to other (non self) clusters, if yes, then that particular Candidate Node announce himself as Cluster Head by sending a ACK message containing the its own cluster ID to all its associated member nodes in the cluster, otherwise this Candidate Node cannot become Cluster Head for this round and the next node in TDMA schedule will become Candidate Node. This phase is repeated after every N^{th} round where the value of N depends on application of the sensor network. For the first round (initial cluster setup) no sensor node is associated to any cluster and cluster heads for this round will be chosen according to TDMA schedule, simply by checking the residual energy above the threshold value. At the end of this phase, if a node is not associated to any cluster then it broadcasts a REQUEST_TO_JOIN message, a cluster head with in its range will send a REPLY_TO_REQUEST message back to the node. If the node receives more than one REPLY_TO_REQUEST message (i.e. there is a number of cluster heads in surrounding) then the node will decides to join the nearest cluster head by checking the signal strength of the REPLY_TO_REQUEST message and send a JOIN message to the corresponding cluster head. The cluster heads send a unique cluster ID to all its associated members in the cluster. Fig. 1 shows initial cluster formation. Fig. 2 shows re-clustering after N^{th} (N=20 in our case) rounds.

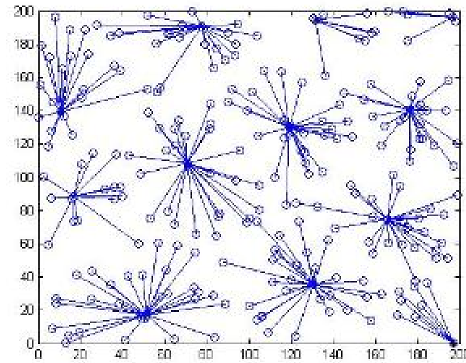

Fig. 1 Initial Cluster Setup

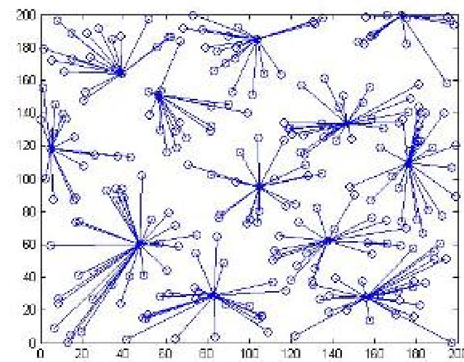

Fig. 2 Clusters after N^{th} rounds

B. Cluster Head Election Phase

Cluster head election phase starts from round 2 until the re-clustering phase comes. In cluster head election phase cluster head of previous round transfers its responsibility to another node in the cluster. When time of a round (decided based on application of the network) is complete, the cluster head of the current round check the node with highest residual energy and send a NEXT_CLUSTER_HEAD_REQUEST message to that particular node (the cluster head receives the residual energy information from data transmission phase). Now the elected node accepts the responsibility of cluster head for the next round by sending a ACCEPT message to the current cluster head and broadcasts a HELLO message including its sensor ID and cluster ID to all member nodes of the cluster. The member nodes will estimate the distance of elected cluster head by receiving signal strength. This phase continues for every round until re-clustering is done.

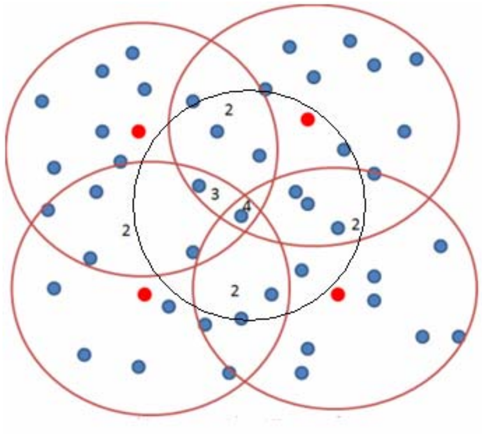

Fig. 3 Cluster Head Selection for after every N^{th} round

Fig. 3 shows that node 4 is most probable candidate node for the electing as cluster head as it is surrounded with more than 50% nodes from other clusters. The nodes in red color are the cluster heads in the previous round. Nodes marked with number 2 are the nodes, which are overlapped with two clusters and so on.

C. Data Transmission Phase

In data transmission phase, every sensor node in a cluster transmits data to the corresponding cluster head and cluster head aggregates the data and transmits aggregated data to the base station. The sensor nodes transmit their residual energy information along with the data. Each sensor node sends the sensed information to its cluster head in its exclusive time slot during data transmission phase. The cluster head then performs aggregation of the data which it has gathered from all of its member nodes into a single data packet and sends it to the base station using either single-hop or multi-hop routing protocol which depends on the network application. In our simulation framework we have used single hop mechanism.

D. Re-clustering Phase

The phenomenon of re-clustering occurs if allocated time period (or defined number of rounds) is expired. When the clusters are formed during the setup phase, an optimum time duration (or fixed number of rounds) is fixed as the life time of current cluster setup. This time duration is the maximum time limit for which a cluster setup is valid and this may be fixed by the application based on sensor node battery specification. Thus, after N^{th} (N=20 in our case) rounds, cluster setup phase is called and clusters are formed again in a fresh manner.

V. SIMULATION RESULTS

In this section, we evaluate the performance of EELBCS protocol by simulating the algorithm in MATLAB. For simplicity, we are not considering the signal collision and interference in the wireless channel. We have taken similar setup of MAC protocols for EELBCS as suggested in EECS [4].

The parameters of simulations are taken similar to as of LEACH [2].

PARAMETERS	VALUE
Field dimension	200 x 200m
Number of Nodes	200
Location of sink	(50,175)
Data packet size	4000 bits
Control packet size	200 bits
Energy normal node	.1J
Electronic Energy, E_e	50 nJ/bit
Amplification Energy , E_s	10 nJ/bit/m^2
Aggregation Energy, E_{DA}	5 nJ/bit
Amplifier Energy , E_m	50 nJ/bit
Node Low range	20m
Node full range	50m

Table 1: Network Parameters for simulation

Fig. 4 shows the graphical representation of number of nodes alive in the network Vs number of rounds. The graph shows that in EECS, the nodes are started to die after 240^{th} round while in EELBCS, the nodes are started to die after 380^{th} round. In case of EECS, the first node is dead after 240^{th} round and around 50% of nodes are dead after 340^{th} round while in case of EELBCS, first node became dead after 380^{th} round and 50% of nodes are dead after 439^{th} rounds. The graph shows that EELBCS outperforms EECS and increases sensor nodes life.

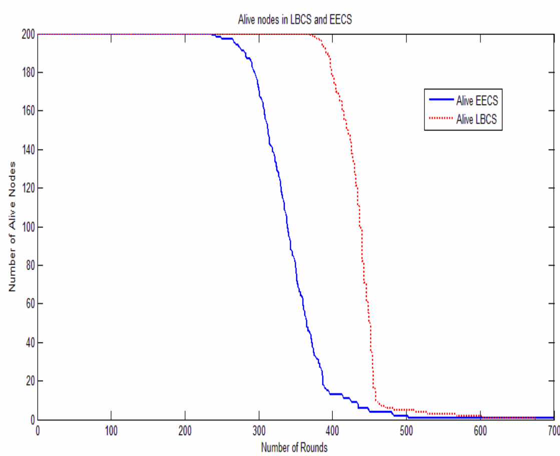

Fig. 4 Alive Nodes in the network (EECS Vs EELBCS)

Fig. 5 shows the residual energy of the network over the number of rounds. The graph specifically shows the high residual energy of network in the case of EELBCS in comparison to EECS. This is calculated to be 19% more in EELBCS in comparison to EECS.

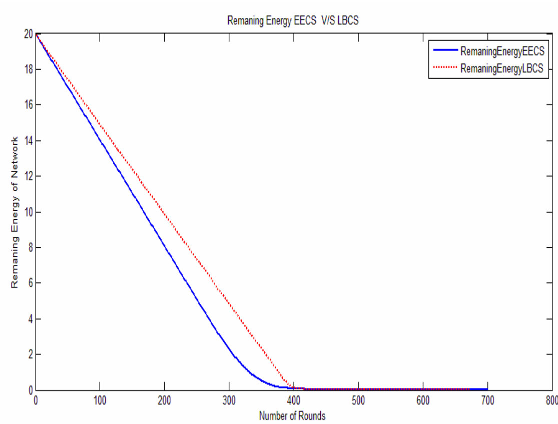

Fig 5 shows the residual energy of the network

VI. CONCLUSION AND FUTURE WORK

In this paper, we propose energy efficient & load balanced clustering scheme (EELBCS) for periodical data gathering in WSNs which maintains a balance of energy load in between the sensor nodes. EELBCS produces a uniform distribution of cluster heads across the network through localized communication with little overhead. What's more, a novel approach has been introduced to distribute the energy consumption among the sensors in the cluster formation phase. Simulation results show that EELBCS prolongs the network lifetime as much as 19% of EECS and the total energy is efficiently consumed. All of our contributions here are focused on the cluster set-up stage. There is still much space to improve the performance of data transmission. In the large scale sensor networks, multi-hop communication is a mainstream technique for energy saving. We will remove the assumption of single-hop and design an en energy efficient protocol for both intra-cluster and inter cluster data transmission in the future work.

We have taken 50% as marker but can be improve by applying probabilistic distribution model. Round 20 can be varied. We have taken one cluster head up to now but we can take more than one cluster head to balance the load in between the cluster. Reduce overlapping of clusters and provide energy efficient & load balanced clustering scheme.

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