Energy Band Based Clustering Protocol for Wireless Sensor Networks

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Abstract

Clustering is one of the widely used techniques to prolong the lifetime of wireless sensor networks in environments where battery replacement of individual sensor nodes is not an option after their deployment. However, clustering overheads such as cluster formation, its size, cluster head selection & rotation, directly affects the lifetime of WSN. This paper introduces and analyzes a new Single Hop Energy Band Based clustering protocol (EBBCP) which tries to minimize the above said overheads resulting in a prolonged life for the WSN. EBBCP works on static clusters formed on the basis of energy band in the setup phase. The protocol reduces per round overhead of cluster formation which has been proved by the simulation result in MATLAB. The paper contains an in-depth analysis of the results obtained during simulation and compares EBBCP with LEACH. Unlike LEACH, EBBCP achieves evenly distributed Cluster Head throughout the target area. This protocol also produces evenly distributed dead nodes. EEBCP beats LEACH in total data packet received and produces better network life time. EBBCP uses the concept of grid node to eliminate the need of position finding system like GPS to estimating the transmission signal strength.

Keywords: *Clustering, WSN, Energy Band, Base Station, Grid Node, LEACH, EBBCP*

1. Introduction

Wireless Sensor Networks (WSN) is capable of data collection, aggregation and communication from a remote environment through many distributed individual sensor nodes (motes) which uses radio link to communicate [3]. WSN can be used to monitor a variety of environments for applications such as monitoring, surveillance, machine failure diagnosis, automatic warning etc. Lifetime of wireless sensor network depends on lifetime of battery of individual sensor nodes. One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation by employing aggressive energy management techniques [4]. This paper introduces and analyzes a new clustering protocol based on energy band for the wireless sensor networks which not only takes care of clustering overheads but also estimates the energy required for transmission from CH to BS with the aim of prolonging the life of the WSN. Clustering [1][2][12][13] is one of the successful techniques used for improving the life time of WSN where the target area is divided into Clusters. Each Cluster has a Cluster Head (CH) which is responsible for data collection from sensor nodes within its Cluster and transmission to Base Station (BS). The challenges in the proposed solution are Power management and reduction of CH rotation overhead. The most important part of sensor network protocol is the selection of the CH and CH to member ratio. A major challenge in wireless sensor network is when to rotate the present CH and by whom.

Rest of the paper is organized as follow. Section 2 presents related work. Next, section 3 describes proposed solution. Next, section 4 explains the simulation model and result analysis. Next, section 5 compares our protocol with LEACH. Finally, section 6 concludes this paper and proposes future work.

2. Related work

Single Hop dynamic clustering protocols like LEACH [5] (Low-Energy Adaptive Clustering Hierarchy) suffers with the problem of Cluster Head rotation overhead in each round. LEACH elects cluster heads based on randomly generated value between 0 and 1. If this randomly generated value is less than threshold value then the node becomes cluster head for the current round. ALEACH [6] tries to improve the performance of LEACH by selecting best suited node for cluster head and improves the threshold equation of LEACH by introducing two terms: General probability (Gp) and Current State probability (CSp). In ALEACH nodes make autonomous decision without any central intervention taking consideration of residual energy. Re-cluster-LEACH [7] protocol is based on nodes density, which considers the density of nodes inside the cluster for Cluster Head formation. LEACH-F [8] is an algorithm in which the number of clusters will be fixed throughout the network lifetime and the cluster heads rotated within its clusters. Steady state phase of LEACH-F is identical to that of LEACH. LEACH-B [9] is a decentralized algorithms of cluster formation in which sensor node only knows about own position and position of final receiver and not the position of all sensor nodes. E- LEACH [10] provides improvement in selection of cluster heads of LEACH protocol. It makes residual energy of the node as the main factor which decides whether these sensor nodes turn into the cluster head or not in the next round. LEACH-HPR [11] is an energy efficient cluster head election method and using the improved Prim algorithm to construct an inter-cluster routing in the heterogeneous WSN. A New Clustering Protocol Based on Energy Band for Wireless Sensor Network [2] uses energy band to form static cluster resulting in evenly distributed Cluster Head but does not give a solution for efficient Cluster Head rotation.

3. Proposed Solution

Like LEACH, our proposed algorithm also consist of two phases (1) Setup Phase and (2) Steady Phase but unlike LEACH the setup phase runs only once. We are using a Grid Node (GN) which is placed orthogonal to BS for the creation of clusters

2.1 Setup Phase

Consider a wireless sensor network scenario as shown in Fig.1. There is a base station (BS), Grid Node (GN) and a number of sensor nodes deployed randomly in the given target area. Initially the base station broadcasts a message containing its identification at a certain power say P. This message basically makes each node aware of the base station. This process is called **base station realization** [2]. Here each node receives that message with different power because of transmission loss, fading etc. For instance, let the power received by the node n is P_{nb}. Hence, the transmission loss between the base station and the node n is ($P- P_{nb}$). So when the sensor nodes needs to send a packet to the Base Station it should transmit at ($P - P_{nb} + P_h$) where 'P_h' is the average power at which any node can receive a healthy signal for regeneration[2]. Similarly Grid Node also broadcasts a message that is received by each node with different power. For instance, let the power received by the node n is P_{ng} This process is called is called **Grid node realization process**. Now each node sends received signal strength of BS and GN along with its id i.e., (id, P_{nb}, P_{ng}) to Base station. This process is called **node realization process**. This information is used by BS to create logical band in X direction as well as in Y direction. Further, the value of P_{nb}, and P_{ng} is used by BS to calculate distance of each node from BS and GN respectively. From the value of P_{nb} of each nodes BS divides the target area into number of bands along Y axis as shown in Fig.1.Similarly the value of P_{ng} of each nodes helps partition of target area along X axis and forms a logical energy band of the complete scenario. The numbers of band X direction and Y-direction depends on size of target area so that any node within cluster can communicate with its CH in single hop and distance of that node from CH should be less than crossover distance.

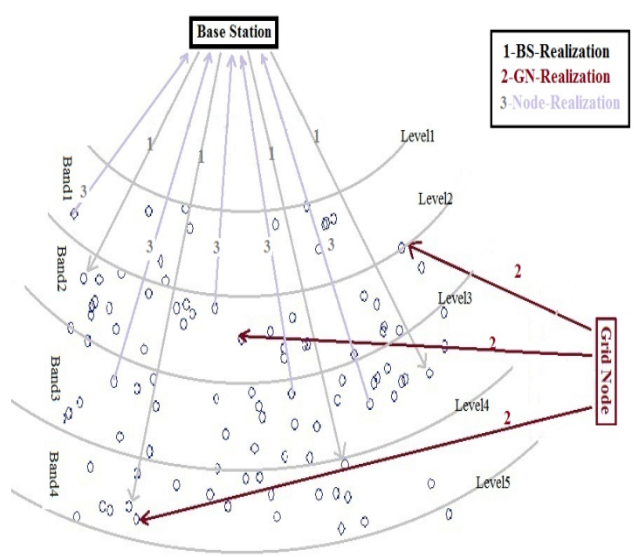

Fig. 1 Shows process of BS, GN and Node realization along with logical Distribution of target area into Bands

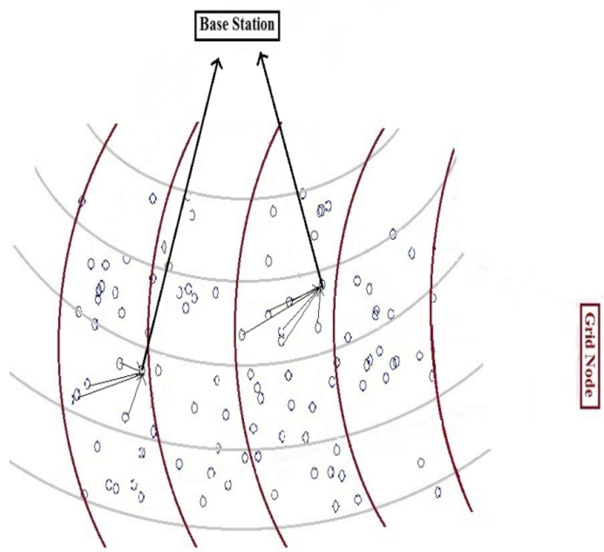

Fig. 2 Formation of cluster.

Now BS decides optimal size of cluster depending upon the value of size of target area and density of nodes in that area. The list of cluster members is arranged in ascending order according to node distance from BS. We will call this list as S-list (Sequence list) as it decides the sequence in which CH selection and CH rotation is done in a particular cluster. A control Packet is sent by BS to each node with necessary information for the working of the said protocol. The Control Packet consists of all necessary information required for steady state working of EBBCP like threshold energy value for CH change, TDMA slots for intra-cluster communication, CDMA code for communication with BS along with node id and id of other cluster members etc. This is required so that each node within its cluster is aware of the other members of its cluster, Current round CH, CH rotation sequence and sleep and wake up pattern to reduce collision and energy saving. Threshold energy is that energy up to which a CH continues working and after that sends a beep signaling CH change using a small control Packet. As S-list available with each node within a cluster is same, the nodes know their next CH and adapt accordingly as and when required. The setup phase ends after the entire target area is divided into energy band and finally into clusters based on energy band of optimal size.

2.2 Steady Phase

This phase follows the one time setup phase till the end of network. Each node is aware of the first CH within its cluster from the S-list which is part of control packet received from BS. Nodes collects data and sends it to CH with signal strength (Sd) capable of reaching the diagonal length of cluster (d) i.e. the maximum possible required distance between two nodes within a cluster. The CH checks its remaining energy after each round to see if it has reached the threshold limit for CH change (E_{th}). If current CH has reached this limit, it is required to generate a beep signal with S_d strength so that each cluster member including that member whose id is second in the S-list for that cluster know that CH has changed and start sending their packets to new CH from present round. The process continues with CH rotating as per E_{th} of individual nodes within cluster till each node within the cluster gets one chance. After the last node has reached the E_{th}, our algorithm requires that chance will be given to first node again but this time with a difference. Now the node will continue to act as CH till its death but is required to generate a beep signal just before its death so that other nodes know about it and the next node starts working as CH. This requirement of coming from last node to first node again during CH change makes circular queue data structure suitable for the work. The process continues till all the nodes within a cluster are dead and in this case the BS knows that the Cluster is no more working. Having a predefined cluster head rotation sequence within a cluster through S-list makes it possible for synchronization between BS and a cluster about the status of each node within a cluster at any given round. When all clusters die in this fashion the WSN is assumed to be dead or non-functional. However, if battery replacement of individual node is possible, the WSN can be made operational but setup phase is required again.

4. Simulation Parameter and Result

The new routing protocol was simulated under MATLAB 7.5.0. The results are based on average value taken after 20 simulations. The deployment of sensor nodes has been done at random basis. The other details of the simulation are given below in table 1.

Table 1

Parameter	***Value***
Size of Target Area	(100m*100m)
Distance of BS from Target Area (D)	10m
Distance of GN from Target Area	10m
Numbers of Nodes	1000
Initial Energy of Nodes	0.5 J
Control Packet Length	100 bit
Short Control Packet Length (For Beep Signal)	10 bit
Medium Control Packet Length (For nodes To BS communication)	20 bit
Control Packet Length	4000 bit

E_{TX}	50*10^-9
E_{RX}	50*10^-9
ξmp	0.0013 pj/bit/m^4 in ideal case
ξ_{fs}	10 pj/bit/m^4 in ideal case

A study was done before the finalization of major parameters for the said simulation. Our first major challenge was to decide the value on which a nodes decides to change its role form CH to normal node and hand over the responsibility of CH to its successor in the S-list.

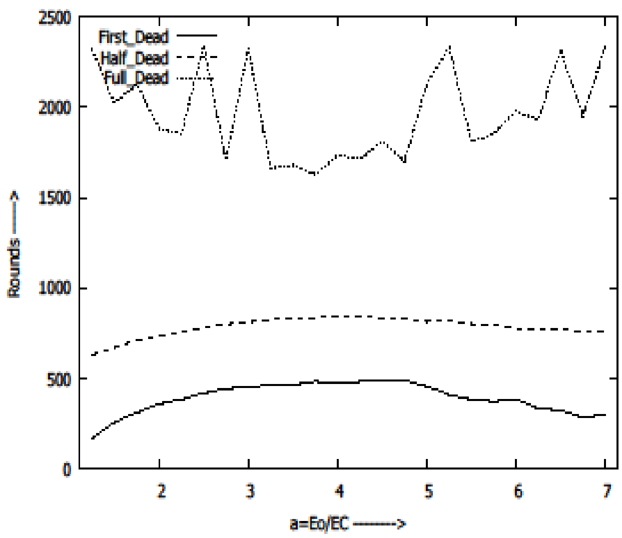

Fig. 3 Shows First Dead, Half Dead and Full Dead round position for different value of a

For selection of optimal Threshold Energy value of CH rotation we have calculated the round number for First Dead, Half Dead and Full Dead for different value of a, where $a=Eo/\ E_{th}$, Eo=Initial Energy of Nodes, E_{th} = Threshold Energy value for CH change. From Fig.3, we can deduce that round number for First Dead and Half Dead is maximum for a=4.75. we have ignored the value for Full Dead in the calculation of *a* as the results heavily depended on the nature of deployment and death of last few nodes.

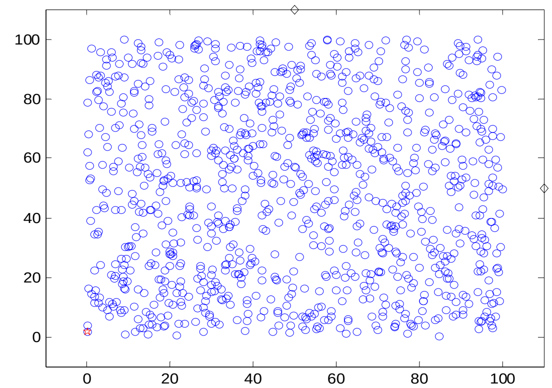

Fig. 4 Shows Random Deployment of Sensor nodes and First Dead nodes in Red Color.

In our protocol First dead nodes satisfy one of the following conditions.

A). it may be a CH of that cluster whose distance is farthest from BS

B). it may be a CH of that region where density of nodes is minimum

This has been verified by simulation and one instance of the result can be seen in Fig. 4

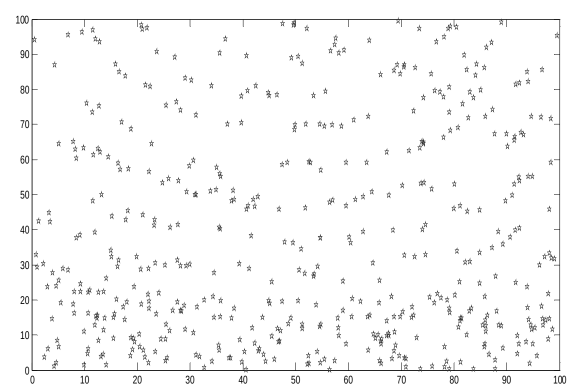

Fig. 5 Shows position of Half Dead Nodes.

The CH rotation policy of EBBCP based on S-list and the shape of cluster formation for this protocol has resulted in dead node pattern as shown in Fig.5. It shows Circular view of Dead nodes which are lying at the nearest boarder of clusters. Further, it can be visualized that number of dead nodes in a region is directly proportional to distance of the region from BS which has resulted in denser dead nodes at the lower part of Fig. 5.

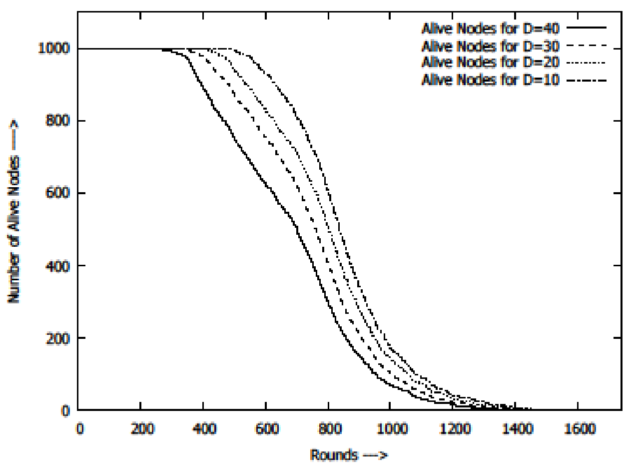

Fig. 6 Shows Number of Alive nodes in EB for Different value of D.

For finalizing the Distance of BS from Target Area (D), the value from D=10 meters to D=40 meters was considered with an interval of 10 meters. The result obtained for it may be seen in Fig 6 which clearly shows that the protocol works better with the value of D=10 meters as the number of alive nodes per round is better which is the foremost requirement. though the round value for full dead node is same for all the values of D, the first dead and as well as number of dead nodes at any round is comparatively better for most part of network lifetime for D= 10 meters. Hence, we have proceeded with this value of D for further simulation.

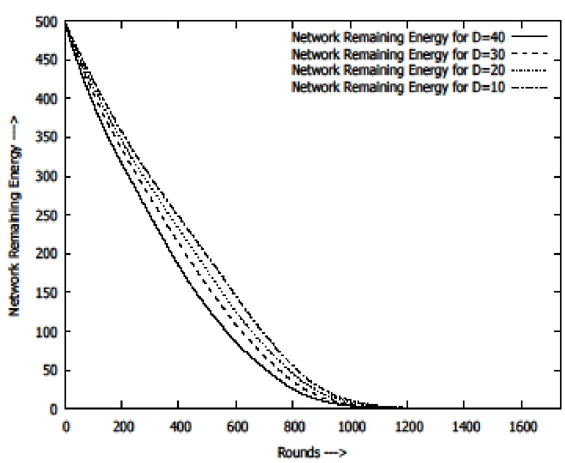

Fig. 7 Shows Network Remaining energy in EB for Different value of D.

This has been further justified by results in Fig. 7 and Fig. 8 which shows that Network remaining energy and total packet received is maximum at a value of D=10 meters out of four choices

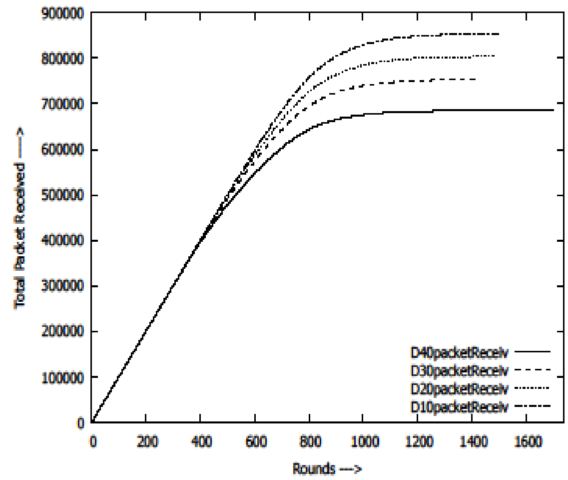

Fig. 8 Shows Total packet received by BS in EB for Different value of D.

The analysis of the above results concludes that EBBCP performance is inversely proportional to the distance D to BS. Its performance degrades when distance of BS from target area increases due to the overheads of setup phase and increase of transmission distance for each CH in steady phase

5. Comparison with LEACH

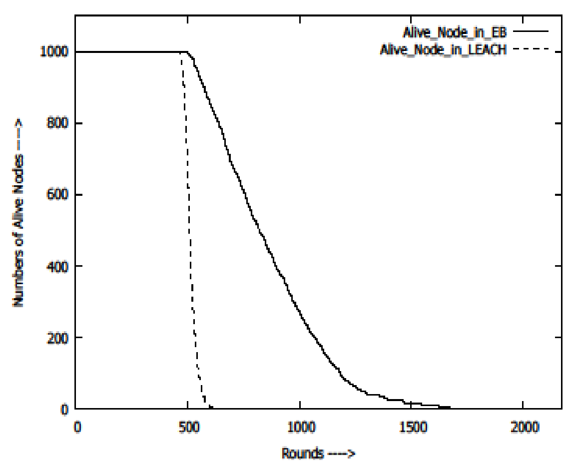

Fig. 9 Shows Numbers of Alive Nodes in EB and LEACH per round.

The new protocol EBBCP was compared with LEACH for the value of P = 0.1 where P is the probability of a node becoming CH in current round. This value of P is chosen so that the number of clusters formed for the target area is similar**.** The result obtained for the said comparison may be seen in Fig, 9 which Shows that EBBCP performs better than LEACH throughout the network lifetime. The difference in performance increases with number of rounds in the favor of EBBCP.

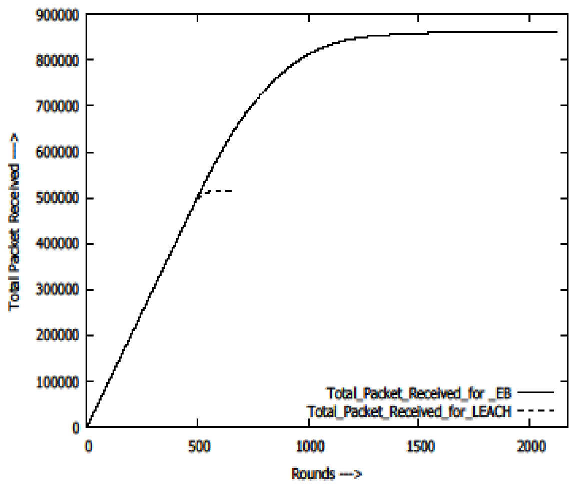

Fig. 10 Comparison of Total Packet Received by BS in EBBCP and LEACH.

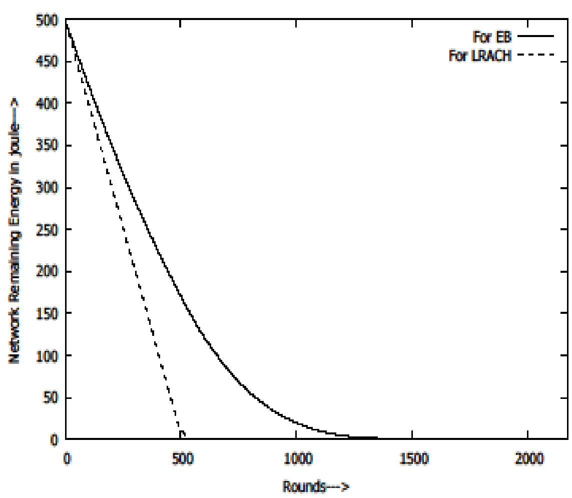

Fig. 11 Comparison of Network Remaining Energy in EBBCP and LEACH.

The results obtained using EBBCP for total packet received and network remaining energy was compared with LEACH and their comparative performance is shown in Fg. 10 and Fig. 11 respectively. The results shows that EBBCP outperforms LEACH by a ggod margin on both parameters.

The various simulation results for EBBCP and LEACH are summarized in Table 2.

Table 2: Shows First, Half and Full Dead node for EBBCP and LEACH

Energy Band Based Protocol					Low-Energy Adaptive Clustering Hierarchy			
D	First Dead	Half Dead	Full Dead	Total Packet Received	First Dead	Half Dead	Full Dead	Total Packet Received
0	483	873	2141	903217	468	527	665	530991
10	392	829	1883	861243	443	510	700	514391
20	388	769	2144	811847	432	492	621	494984
30	263	700	1583	753029	424	469	564	472646
40	226	660	1668	703453	405	445	522	447600
50	176	593	1397	637860	381	419	549	420664

2. Conclusion and Future Work

EBBCP performs better than LEACH on all parameters when BS is closer to target area which has been proved by Simulation results. The improvement of EBBCP is more with the increase of round number which is good for the network lifetime. EBBCP provides uniformly distributed CH which is far superior to LEACH as it selects CH randomly. EBBCP is successful in reducing the per round overhead in CH selection and CH rotation resulting in energy conservation and better lifetime of WSN.

Future work can be done to save energy by finding node to CH distance for intra-cluster communication. EBBCP can also be extended for Multi - hop routing protocol for larger target areas.

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