METHODOLOGY FOR ATTAINING SCALABILITY AND ENERGY EFFICIENCY IN DENSE WIRELESS SENSOR NETWORKS

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Abstract

Each sensor node has a microprocessor and a petite amount of memory. Also every sensor node is equipped with one or more sensing devices such as acoustic sensors, microphone arrays, video cameras, infrared, seismic or magnetic sensors. But it is difficult to replace the deceased batteries of the sensor nodes. A distinctive sensor node consumes much of its energy during wireless communication. This research work suggests the development of a hierarchical distributed clustering mechanism, which gives improved performance over the existing clustering algorithm LEACH. The two hiding concepts behind the proposed scheme are the hierarchical distributed clustering mechanism and the concept of threshold. Energy utilization is significantly reduced, thereby greatly prolonging the lifetime of the sensor nodes.

Index Terms: Wireless sensor network, sensor node, cluster head, base station, residual energy, energy utilization, network lifetime.

I. INTRODUCTION

The energy consumption when transmitting one bit of data corresponds to thousands of cycles of CPU operations. These wireless sensor nodes assemble data from a sensing area which is possibly inaccessible for humans. Data gathered from the sensing field are usually reported to a remotely located base station (BS). This high redundancy of sensing power can greatly improve the sensing resolution and make sensor networks robust to swiftly changing environment. Some budding applications of wireless sensor networks are wildlife habit study, environment observation and health care monitoring. Since wireless sensor nodes are power-constrained devices, long-haul transmissions should be kept to minimum in order to expand the network lifetime. Thus, direct communications between nodes and the base station are not intensely encouraged. An effective methodology to perk up efficiency is to arrange the network into several clusters, with each cluster electing one node as its leader or cluster head (CH). A cluster head collects data from other sensor nodes in its cluster, directly or hopping through other nearby nodes. The data collected from nodes of the same cluster are extremely correlated. Data can be amalgamated during the data aggregation process. The fused data will then be transmitted to the base station directly or by multi-hop fashion. In such an arrangement, only cluster heads are required to transmit data over larger distances. Figure 1 displays typical sensor node components.

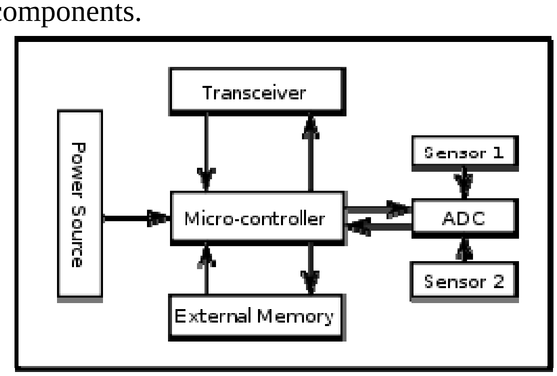

Figure 1: A typical sensor node components

This paper gives a profound description about energy efficient hierarchical distributed clustering algorithm. The remaining nodes will need to do only short-distance transmission. To distribute the workload of the cluster heads amidst the wireless sensor nodes, cluster heads will be reelected from time to time. Clustering follows some projected advantages like network scalability, localizing route setup within the cluster, uses communication bandwidth efficiently and makes best use of network lifetime. Since clustering makes use of the mechanism of data aggregation, unnecessary communication between the sensor nodes, CH and BS is avoided. Energy consumption of wireless sensor nodes is greatly trimmed down and the overall network lifetime can thus be prolonged. The rest of the paper is organized as follows. A review of existing distributed clustering algorithms is given in Section II. The hierarchical distributed clustering algorithm giving inspiration to this work is described in Section III. Section IV elaborates he details of the simulation results. Finally the last section gives the conclusion.

II. REVIEW OF EXISTING CLUSTERING ALGORITHMS

Bandyopadhyay and Coyle anticipated EEHC, which is a randomized clustering algorithm which organizes the sensor nodes into hierarchy of clusters with an objective of minimizing the total energy spent in the system to communicate the information gathered by the sensors to the information processing center. It has variable cluster count, the immobile CH aggregates and relays the data to the BS. It is applicable for extensive large scale networks. The peculiar drawback of this algorithm is that, some nodes remain un-clustered during the clustering process. Barker, Ephremides and Flynn proposed LCA [2], which is mainly developed to avoid the communication collisions among the nodes by using a TDMA time-slot. It makes use of single-hop scheme, attains high degree of connectivity when CH is selected randomly. The updated version of LCA, the LCA2 was implemented to decrease the number of nodes compared to the original LCA algorithm. The main drawback of this algorithm is, the single-hop clustering results in the formation of many clusters and hence much energy is wasted. Nagpal and Coore proposed CLUBS, which is implemented with an idea to form overlapping clusters with maximum cluster diameter of two hops. The clusters are formed by local broadcasting and its convergence depends on the local density of the wireless sensor nodes. This algorithm can be implemented in asynchronous environment without reducing efficiency. The main problem is the overlapping of clusters, clusters having their CHs within one hop range of each other, thereby both clusters will collapse and CH election process will restart.

Demirbas, Arora and Mittal brought out FLOC, which exhibits double-band nature of wireless radio-model for communication. The nodes can commune reliably with the nodes in the inner-band range and unreliably with the nodes that are in the outer-band range. It is fast, scalable and exhibits self-healing capabilities [3]. It achieves re-clustering in constant time and in a local manner, thereby finds valid in large scale networks. The chief drawback of the algorithm is, the nodes in the outer band use unreliable communication and the messages have the maximum probability of getting lost during communication. Ye, Li, Chen and Wu proposed EECS, which is based on an guessing that all CHs can communicate directly with BS. The clusters have variable size, such that those closer to the CH are larger in size and those farther from CH are smaller in size. It is greatly energy efficient in intra-cluster communication and excellent improvement network lifetime. EEUC [4] is proposed for uniform energy consumption within the network. It forms dissimilar clusters, with an assumption that each cluster can have variable sizes. Probabilistic selection of CH is the focal drawback of this algorithm. Few nodes may be gone without being part of any cluster, thereby no guarantee that every node takes part in clustering mechanism. Yu, Li and Levy [5] proposed DECA, which selects CH based on residual energy, connectivity and a unique node identifier. It is greatly energy efficient, as it uses fewer messages for CH selection. The main trouble with this algorithm is that high possibility of wrong CH selection which leads to discarding of all the packets sent by the sensor node.

Ding, Holliday and Celik proposed DWEHC [6], which elects CH based on weight, a combination of nodes’ residual energy and its distance to neighboring nodes. It generates well balanced clusters, independent on network topology. A node possessing largest weight in a cluster is nominated as CH. The algorithm constructs multilevel clusters and nodes in every cluster reach CH by relaying through other intermediate nodes. It shows a enormous improvement in intra-cluster and inter-cluster energy consumption. The major problem occurs due to much energy utilization by several iterations until the nodes settle in most energy efficient topology. HEED is a well distributed clustering algorithm in which CH selection is done by taking into account the residual energy of the nodes and the intra-cluster communication cost leading to prolonged network lifetime. It is clear that it can have variable cluster count and supports heterogeneous sensor nodes. The CH is stationary which carries out data aggregation and relaying of the fused data to the BS. The problems with HEED are its application limited only to static networks, the employment of complex probabilistic methods and multiple clustering messages per node for CH selection even though it prevents random selection of CH. LEACH [1] is one of the most popular clustering mechanisms for WSNs and it is considered as a representative energy efficient protocol. In this protocol, sensor nodes are combined together to form a cluster [7, 8]. In each cluster, one sensor node is selected randomly to act as a cluster head (CH), which collects data from its member nodes, aggregates them and then forwards to the base station.

$$T(n) = \begin{cases} \dfrac{p}{1 - p*(r \bmod 1/p)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

(1)

It separates the operation unit into many rounds and each round consists of two phases, namely the set-up phase and the steady phase. During the set-up phase, clusters are created and cluster heads are selected. All the sensor node generates a random number between 0 and 1. If the number is lesser than the threshold, then the node selects itself as a cluster head for the current round. The threshold is given as follows (equation 1)

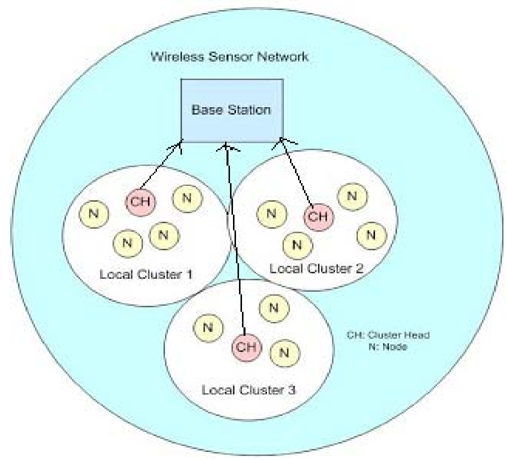

Figure 2: Evaluation of LEACH algorithm,

After the decision is made, each non-cluster head node must transmit a join- request message to the chosen cluster head to specify that it will be a member of the cluster. The cluster head creates and broadcasts a time division multiple-access (TDMA) schedule to swap the data with non-cluster sensor nodes without collision after it receives all the join-request messages. The steady phase begins after the clusters are fashioned and the TDMA schedules are broadcasted. All of the sensor nodes send their data to the cluster head once per round during their allocated transmission slot based on the TDMA schedule and in other time, they turn off the radio in order to reduce energy consumption. However, the cluster heads must remain awake all the time. Therefore, it can receive all the data from the nodes within their own clusters. On receiving all the data from the cluster, the cluster head perform data aggregation and onwards it to the base station directly. This is the complete process of steady phase. After a certain predefined duration, the network will step into the next round.

LEACH is the simplest clustering protocol which processes cluster approach and it can prolong the network lifetime when compared with multi-hop routing and static routing. However, there are still some hiding drawbacks that should be considered. LEACH does not take into account the residual energy to select cluster heads and construct clusters. As a result, nodes with lesser energy may be selected as cluster heads and then die much earlier. Moreover, since a node selects itself as a cluster head only according to the value of probability, it is hard to guarantee the number of cluster heads and their distribution. To overcome the shortcomings in LEACH, a hierarchical distributed clustering mechanism is proposed, where clusters are arranged in to hierarchical layers. Instead of cluster heads directly sending the aggregated data to the base station, sends them to their next layer cluster heads. These cluster heads send their data along with that received from lower level cluster heads to the next layer cluster heads. The cumulative process gets repeated and finally the data from all the layers reach the base station.

III. FEATURES OF PROPOSED SYSTEM

The initial step in the creation of LEACH (Low Energy Adaptive clustering of Hierarchy), is the formation of clusters. More precisely, each sensor nodes decides whether or not to turn into the cluster head for the current round. The decision is based on the priority and on the number to time the node has been a cluster head so for. The cluster nodes brings together the data and send them to the cluster head. The radio to each cluster nodes can be turned off when there is no sensing happens. When all the data have been received, the cluster head aggregates the data in to single composite signal. The composite signal is then sent to the base station directly.

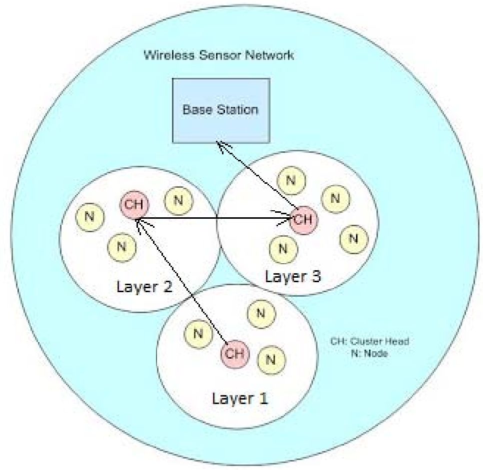

Figure 3: Evaluation of the proposed algorithm

LEACH protocol has the weakness, when periodic transmissions are unnecessary, thus causing pointless power consumption. The election of cluster head is based on priority, hence there is a possibility for weaker nodes to be drained because they are elected to be cluster heads as frequently as the stronger nodes. Moreover the protocol is based on the assumptions that all nodes commence with the same amount of energy capacity in each election round and all the nodes can transmit with enough power to reach the base station if needed. Nevertheless, in many cases these assumptions are impractical. Also the base station should keep track on the sensor nodes in order to choose which node has the highest residual energy. Hence needless transmissions occur between the base station and cluster nodes, thereby causing increased power consumption. The proposed work suggests a new idea over the existing techniques. In case of existing technique (figure 2), the aggregated data is sent to the base election directly by the CH, which leads to more energy usage. In the proposed algorithm the aggregated data is forwarded only to the next layer cluster head (figure 3), cutting down the communication distance between cluster head and base station. Two thresholds are employed namely hard threshold and soft threshold. Hard threshold is the bare minimum possible value, of an attribute to trigger a sensor node to switch on its transmitter and transmit to the cluster head. Soft threshold is a little change in the value of the sensed attribute that triggers the node to switch on its transmitter and transmit data. The hard threshold tries to trim down the number of transmission by allowing their nodes to transmit only when the sensed attribute is beyond a critical value. In a similar way, the soft threshold further lessens the number of transmissions that might have otherwise occurred when there is little or no change in the sensed attribute. At each cluster change the values of both the thresholds can be changed and thus enabling the user to control the tradeoff between energy efficiency and data accuracy. This method reduces unwanted transmissions, trimming down the energy utilization.

The main actions in the set-up phase are election of candidate nodes, selection of cluster heads, scheduling at each cluster, and discovery of cluster head for CH-to-CH data transmission. During set-up phase, every node first decides whether or not it can become a candidate node in each region for the current round. This choice is based on the value of the threshold $T(n)$ as used in LEACH protocol. As seen in equation 1, p should be given a large value in order to elect many candidate nodes. The cluster heads are elected among the candidate nodes. An advertisement message is used to elect cluster heads. For this, the candidate nodes employ a CSMA MAC protocol. Each candidate node broadcasts an advertisement message inside its transmission range. This range is dependent on the utmost distance between the levels.

In the proposed scheme, the advertisement range is given double of the maximum distance to cover other levels. When a candidate node is located within $a \times$ *Advertisement Range* where the value of a is predetermined between 0 and 1, it has to give up qualification of candidate node and has to end up joining the competition. An ordinary node, by contrast, decides the cluster to which it will belong for this round. This choice is based on the signal strength of the advertisement message. After each node has decided to which cluster it belongs, node must transmit its data to the suitable cluster head. After cluster head receives all the messages from the nodes that would like to be incorporated in the cluster and based on the number of nodes contained in the cluster, the cluster head creates a TDMA schedule and assigns each node a time slot when it can transmit.

Each cluster head broadcasts this same schedule back to the nodes in the cluster. After schedule creation, each cluster head performs cluster head discovery to discover an upward cluster head to reach the sink. For this, each cluster head uses two-way handshake technique, with REQ and ACK message. Each cluster head broadcasts REQ message within the advertisement range. Upward cluster head on receiving this REQ message transmits ACK message back to the cluster head that transmitted REQ message.

The steady-state phase of the proposed scheme is analogous to other cluster-based protocols. Main activities of this phase are sensing and transmission of the sensed data. Each sensor nodes senses and transmits the sensed data to its cluster head according to their own time schedule. When all the data has been received, the cluster head perform data aggregation in order to reduce the amount of data. Finally, each cluster head transmits data to the sink along the CH-to-CH routing path which have been fashioned during the set-up phase. After all the data is transmitted or a definite time is elapsed, the network goes back into the set-up phase again and the next round begins by electing candidate nodes.

IV. SIMULATION STUDY

All the simulations were carried using GloMoSim considering 15 sensor nodes. For the simulations, a network model similar to the one used in the conventional clustering protocols is assumed with the following properties. All sensor nodes are considered to be immobile. Each sensor node initially has identical energy level. A fixed sink node is located away from the edge of network. The sensor nodes are outfitted with power control capabilities.

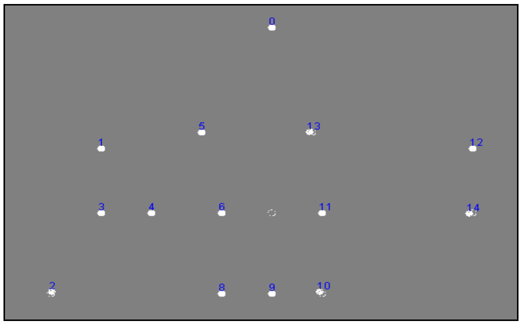

Figure 4: Nodes deployment in the proposed algorithm

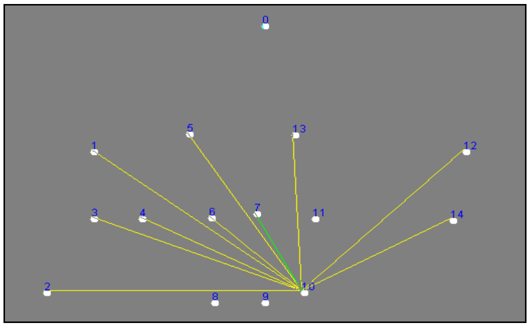

Figure 5: Cluster formation in the proposed algorithm

Table 1: Simulation parameter setup

Parameter	Acronym	Values
Cluster topology (m)	C_t	100 x 100
Tx/Rx electronics	$E_{tx/rx}$	m^2
constant Amplifier	E_{amp}	50nJ/bit
constant	E_{th}	$10pJ/bit/m^2$
CH energy threshold	p	$10^{-4}J$
Packet size	N	50 bytes
Number of nodes	R_{bc}	15
Transmission range	R_{sense}	70m
Sensing range	$R_{cluster}$	15m
Cluster range		30m

For the experiments, the network parameters and the communication energy parameters are set as shown in table 1. The deployment of wireless sensor nodes are shown in figure 4. Here the nodes are assumed to be static. The nodes organize into hierarchical group of clusters, short while after deployment (figure 5). The cluster heads starts forwarding the aggregated data to the next higher layered cluster head immediately after hierarchical layers are formed. The process gets terminated for one round when all the aggregated data reaches the base station. The radio channel is assumed to be symmetrical in manner. Thus, the energy required to transmit a message from a source to a destination node is same as the energy required to transmit the same message from the destination node back to the source node. Moreover, it is assumed that the communication medium is contention free. Hence there is no need for retransmission of data. The initial energy of each node is assumed to be the identical.

The total system energy usage is the sum total of energy consumed during communication, processing, etc., which is the total energy consumed for complete clustering mechanism by the whole sensor network. As discussed in the previous section, LEACH uses more energy for communication between the nodes and CHs. It tries to distribute the loading of CHs to all the nodes in the network by switching the cluster heads from time to time. Due to two-hop arrangement of the network, a node far from CH will have to consume more energy than a node nearer to CH. This introduces an rough distribution of energy among the cluster members, affecting the total system energy. The uneven distribution of energy among the cluster members is avoided in the proposed algorithm by the usage of hierarchical clustering mechanism.

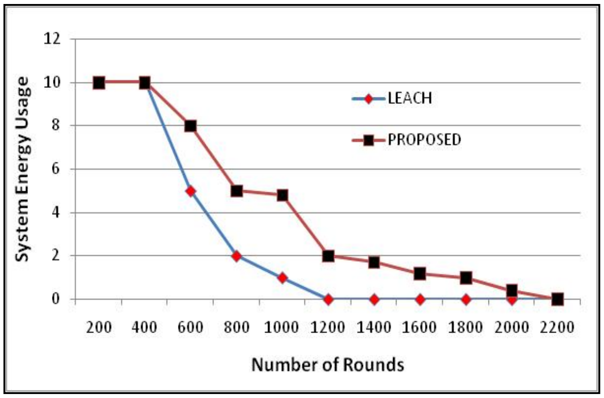

Figure 6: System energy usage versus number of rounds

In the proposed algorithm, fewer communication energy is required which could be understood from the simulations. It uses the concept of threshold to further reduce the communication energy. From the simulation, it is also clear that the slope of LEACH algorithms is maximum, hence consuming the available energy easily compared to the proposed algorithm. Also in the proposed algorithm, parting among the layers is optimized to use optimum power for each layer. From figure 6, the system energy usage of the proposed algorithm is optimum for discrete number of rounds. But in case of LEACH, the energy usage is in a gradual manner. This positive performance of the proposed algorithm is mainly by the reduction in long-haul communications between the cluster head and base station.

The node death rate is the measure of the number of nodes die over a particular number of rounds, from the initiation of the process. When the data rate increases the node death rate also increases equivalently. The networks formed by LEACH show periodical variations in data collection time. This is due to the selection function reliant on the number of data collection process. Since the CH selection of LEACH is a function of the number of completed data collection processes, the number of cluster changes periodically. This raises up the node death rate.

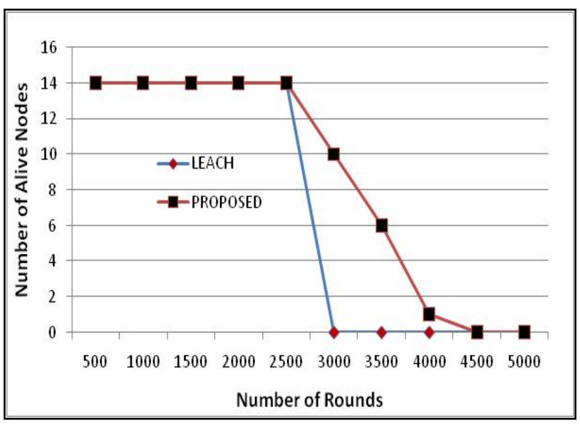

Figure 7: Node death rate versus number of rounds

The proposed algorithm uses a restricted data collection process, as the concept of hierarchical clustering is employed. Also the proposed algorithm has an excellent control over the number of connections between the cluster nodes, cluster heads and base station. In LEACH, there is no control over the number of connections, which increases the data collection time, thereby increasing the data rate and node death rate. From figure 7, all the nodes die early in 3000 rounds for LEACH algorithm. The proposed algorithm shows prolonged performance, as all the nodes die only in 4500 rounds. Hence, the proposed algorithm shows excellent reduction in the node death rate compared to LEACH. This is mainly by the usage of soft threshold and hard threshold concept to reduce the redundant aggregated data transmission from cluster head to the base station.

V. CONCLUSION

This paper is concerned with the introduction of hierarchical clustering mechanism in wireless sensor networks with the inclusion of threshold concept in the cluster head. The main feature of this proposed algorithm compared to the existing clustering mechanism (LEACH), is that the aggregated data is transmitted by the cluster head to the base station by forwarding through next higher layer cluster heads. Also soft threshold and hard threshold concepts are employed to further reduce the number of transmission from cluster head to the base station. Hence energy wastage by long distance transmission is avoided, thereby reducing energy utilization to much extent. The node death rate is reduced to a greater extent compared to the existing LEACH algorithm.

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