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A Clustering Protocol for a Non –Uniformly Distributed Wireless Sensor Network

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ABSTRACT
Considering the deployment of wireless sensor networks in areas of remote access to monitor them for various reasons, adapting the network for better inter- cluster and intra-cluster communication to prolong its working time is necessitated. Using optimal parameters for communication taking into account the capabilities of the sensors in the network, Energy Efficient clustering algorithm for Maximizing Network Lifetime aims to improve the traditional hierarchical protocols. But since the nodes may not be uniformly deployed over the entire area, the region under consideration also forms an important determinant of these optimal parameters. The protocol aims at merging the clusters, initially divided to from hierarchical network, so that in a non-uniform network the values of various network parameters may be adjusted to their most near optimal values. Moreover, re-clustering and re-electing the cluster heads after a threshold also helps in increasing the network lifetime.
Keywords- Cluster, Wireless, Sensor, Networks

I. INTRODUCTION

The ability to communicate over distances without any help of attached cables makes it possible for wireless sensors to be deployed at remote areas with ease. But the sole source of energy, its battery, can be charged only once that is before its deployment and thus limits the network working time. Once deployed, it's almost impossible to recharge them again. In recent years, many protocols have been aimed at utilizing this battery power in a way that network lifetime is maximized and network as a whole remains connected. Hierarchical protocols like LEACH (low-energy adaptive clustering hierarchy) algorithm, is based on gradient cluster reducing the energy consumption of nodes and enhancing the network lifetime. Clusters formed have some nodes working as ordinary sensors while others act as cluster heads working on the behalf of the entire cluster.

LEACH is one of the basic Hierarchical clustering protocol wherein nodes communicate through a series of other communicating nodes to the base station. The approach helps in providing a more fair communication overhead for the nodes situated far away from the base station in the network. But even then problems like uneven cluster sizes exist. An improvement to LEACH was the Hybrid Energy Efficient Clustering (HEED) algorithm, which made use of dynamic clustering and cluster head rotations depending upon the node proximity and the residual energy of the node. But additional energy is spent in the process.

Energy Efficient Clustering Algorithm for Maximizing Network Lifetime uses the same logic of re-clustering and reticulation in a hierarchical form but in a more static way as compared to HEED. Network is divided into static clusters based on the network optimal parameters and then in these uniform clusters the re-clustering mechanism is executed to find the new cluster heads. Since in previous networks the network clusters were not uniform, a fixed network topology was not possible. Thus, keeping the track of network with the increase in number of dead nodes became a tedious task. With the static topology of EECML such concerns were effectively addressed.

But the basic assumption that the network will be made of nodes uniformly scattered all over the area is a pitfall, as it is possible the geographical conditions may not permit so. Thus, the network will be made of some denser and some rarer areas deviating from the ideal conditions. In such case merging clusters in way that the new clusters formed deviate the least from ideal properties might prove useful. Such adaptability according to varying density across over network could prove useful maximizing the network lifetime.

II. LITERATURE SURVEY

The potential applications of wireless sensor networks (WSNs) are highly varied, such as environmental monitoring, target tracking and military. Sensors in such networks are equipped with sensing, data processing and radio transmission while the power is highly limited. This necessitates devising novel energy-efficient solutions to some of the conventional wireless networking problems, such as medium access control, routing, self-organization, bandwidth allocation, and security. Exploiting the trade-offs among energy, accuracy, and latency, and using hierarchical (tiered) architectures are important techniques for prolonging the network lifetime. Energy consumption in the network can be either useful or wasteful depending upon the data being handled while the energy is spent.

A number of protocols aim at reducing useful energy consumption. They are classified into three categories. The protocols in the first category control the transmission power level at each node by increasing the transmission power level at each node by increasing network capacity thus keeping the network connected (from HEED paper). Protocols in the second category make routing decisions based on power optimization goals. Protocols in the third category control the network topology by determining which nodes should participate in the network operation (be awake) and which should not (remain asleep).

In LEACH, Energy-based LEACH and HEED protocols use a single criterion to elect cluster heads and to form clusters. LEACH protocol uses a round-robin rotation to elect its cluster head where nodes elect to become the cluster heads based on the threshold value. Each node chooses a random number between 0 and 1 and if the number is lower than the calculated probability, the node is elected to become cluster head. Nodes that have not become a cluster head in a specific round will have higher probability to become the cluster heads on the next round. Energy-based LEACH elects nodes to become a cluster head at time t with probability:

$$CHprob(t) = min(\frac{Ei(t)}{Etotal} \; X \; k, l)$$

Where Ei is residual energy of node I, $Etotal = \sum_{i=1}^{N} Ei(t)$ and k is the optimal number of cluster head. Nodes with higher energy have higher probability of becoming the cluster heads regardless whether the cluster heads are within each other's range. Energy-based LEACH protocol demonstrates the same behaviour as LEACH but elects cluster head based on node residual energy with respect to the total energy of the network. Energy-based LEACH shows better cluster heads selection and therefore has longer network lifetime. Once cluster heads announces their status, non-cluster head nodes will join a cluster based on only one criterion which is the strongest received signal strength. LEACH is a levelled hierarchical routing protocol which attempts to minimize global energy dissipation and distribute energy consumption evenly across all nodes. This is achieved by the formation of clusters with localized coordination, by rotating the high-energy cluster heads and by locally compressing data.

The model used makes the following assumptions:

1. There exists one base station with no energy constraints and a large number of sensor nodes that are mostly stationary, homogeneous and energy constrained.
2. The base station is located at some distance from the sensor nodes and the communication between a sensor node and the base station is expensive.
3. The purpose of the network is to collect data through sensing at a fixed rate (i.e. there is always something to send) and convey it to the base station.

The raw data is too much and must be locally aggregated into a small set of meaningful information. The nodes self-organize into local clusters with one node in each cluster acting as a cluster head. Once a cluster has formed, the cluster members send their data to the cluster head (low energy transmission) which in turn combines the data and sends it to the base station (high energy transmission). This organization of the nodes creates a 2-level hierarchy. The operation of the protocol is broken up into rounds, during which the clusters are dissolved and recreated. During each round, a node decides probabilistically whether to become a cluster head. This decision is based on the suggested percentage of cluster heads for the network (determined a priori) and the number of times the node has been a cluster head so far. The cluster heads advertise their intention and the rest of the nodes decide which cluster to join, usually based on signal strength. Once the clusters are formed, the cluster head creates a TDMA schedule and sends it to its cluster members.

To reduce interference, each cluster communicates using different CDMA codes. For their analysis, comparing their scheme with a direct communication protocol (each sensor sends data directly to the base station) and the minimum-energy routing protocol. In the latter, data destined for the base station is routed through many intermediate nodes that can each be reached with minimum energy transmission. A static clustering scheme is also used where cluster heads are not rotated. Their results indicate that LEACH reduces communication energy by as much as 8x. Also, the first node death in LEACH occurs over 8 times later and the last node dies over 3 times later.

HEED protocol elects the cluster heads based on node residual energy which is defined as:

$$CHprob = Cprob \; x \; \frac{Eresidual}{Emax}$$

Where Residual is the energy of the nodes, Emax is the initial energy of each node and Cprob is the initial percentage of cluster heads that is set as 5%. A number of iterations are performed before a final cluster heads are elected. HEED protocol ensures uniform distribution of cluster heads across the network. In its initialization phase, HEED protocol allows sensors to compute a probability of becoming cluster heads, proportional to its residual energy and to a pre-determined percentage of cluster heads. Then, during a repetition phase, sensor seeks the best cluster head to connect to. If no cluster heads is found, the sensor doubles its probability to become cluster head and broadcasts it again to its neighbours.

This phase stops either when this probability equals to 1 or when it finds a cluster head to connect to.EECML as described earlier divides the entire network into static clusters and then maintains this topology throughout the entire time. For this purpose it calculates various optimal parameters such as: optimal clustering angle, the angle at the network topology should be divided to form static sectors, Optimal one hop distance, optimal distance for communication between the cluster heads of the individual clusters within the sectors. The parameter also helps in dividing the sectors into clusters situated optimal distance apart. Then we have the threshold energy at which the cluster head the given cluster head should stop working and new cluster head is required to be elected. Thus using these well-defined values the network is put to a start.

III. SYSTEM ARCHITECTURE AND DESIGN ISSUES

Depending on the application, different architectures and design goals/constraints have been considered for sensor networks. Since the performance of a routing protocol is closely related to the architectural model, in this section we strive to capture architectural issues and highlight their implications.

A. Network Dynamics

There are three main components in a sensor network. These are the sensor nodes, sink and monitored events. Aside from the very few setups that utilize mobile sensors most of the network architectures assume that sensor nodes are stationary. On the other hand, supporting the mobility of sinks or cluster-heads (gateways) is sometimes deemed necessary .Routing messages from or to moving nodes is more challenging since route stability becomes an important optimization factor, in addition to energy, bandwidth etc. The sensed event can be either dynamic or static depending on the application .For instance, in a target election/tracking application, the event (phenomenon) is dynamic whereas forest monitoring for early fire prevention is an example of static events. Monitoring static events allows the network to work in a reactive mode, simply generating traffic when reporting. Dynamic events in most applications require periodic reporting and consequently generate significant traffic to be routed to the sink.

B. Node Deployment

Another consideration is the topological deployment of nodes. This is application dependent and affects the performance of the routing protocol. The deployment is either deterministic or self-organizing. In deterministic situations, the sensors are manually placed and data is routed through pre-determined paths. However in self-organizing systems, the sensor nodes are scattered randomly creating an infrastructure in an ad hoc manner. In that infrastructure, the position of the sink or the cluster-head is also crucial in terms of energy efficiency and performance. When the distribution of nodes is not uniform, optimal clustering becomes a pressing issue to enable energy efficient network operation.

C. Energy Considerations

During the creation of an infrastructure, the process of setting up the routes is greatly influenced by energy considerations. Since the transmission power of a wireless radio is proportional to distance squared or even higher order in the presence of obstacles, multi-hop routing will consume less energy than direct communication. However, multi-hop routing introduces significant overhead for topology management and medium access control. Direct routing would perform well enough if all the nodes were very close to the sink. Most of the time sensors are scattered randomly over an area of interest and multi-hop routing becomes unavoidable.

D. Data Delivery Models

Depending on the application of the sensor network, the data delivery model to the sink can be continuous, event-driven, query-driven and hybrid .In the continuous delivery model, each sensor sends data periodically. In event-driven and query-driven models, the transmission of data is triggered when an event occurs or a query is generated by the sink. Some networks apply a hybrid model using a combination of continuous, event-driven and query-driven data delivery. The routing protocol is highly influenced by the data delivery model, especially with regard to the minimization of energy consumption and route stability. For instance, it has been concluded in that for a habitat monitoring application where data is continuously transmitted to the sink, a hierarchical routing protocol is the most efficient alternative. This is due to the fact that such an application generates significant redundant data that can be aggregated on route to the sink, thus reducing traffic and saving energy.

E. Node Capabilities

In a sensor network, different functionalities can be associated with the sensor nodes. In earlier works and all sensor nodes are assumed to be homogenous, having equal capacity in terms of computation, communication and power. However, depending on the application a node can be dedicated to a particular special function such as relaying, sensing and aggregation since engaging the three functionalities at the same time on a node might quickly drain the energy of that node. Some of the hierarchical protocols proposed in the literature designate a cluster-head different from the normal sensors. While some networks have picked cluster-heads from the deployed sensors other applications a cluster-head is more powerful than the sensor nodes in terms of energy, bandwidth and memory .In such cases, the burden of transmission to the sink and aggregation is handled by the cluster-head.

Inclusion of heterogeneous set of sensors raises multiple technical issues related to data routing .For instance, some applications might require a diverse mixture of sensors for monitoring temperature, pressure and humidity of the surrounding environment, detecting motion via acoustic signatures and capturing the image or video tracking of moving objects. These special sensors either deployed independently or the functionality can be included on the normal sensors to be used on demand. Reading generated from these sensors can be at different rates, subject to diverse quality of service constraints and following multiple data delivery models, as explained earlier. Therefore, such a heterogeneous environment makes data routing more challenging.

F. Data Aggregation/Fusion

Since sensor nodes might generate significant redundant data, similar packets from multiple nodes can be aggregated so that the number of transmissions would be reduced. Data aggregation is the combination of data from different sources by using functions such as suppression (eliminating duplicates), min, max and average. Some of these functions can be performed either partially or fully in each sensor node, by allowing sensor nodes to conduct in-network data reduction .Recognizing that computation would be less energy consuming than communication substantial energy savings can be obtained through data aggregation. This technique has been used to achieve energy efficiency and traffic optimization in a number of routing protocols. In some network architectures, all aggregation functions are assigned to more powerful and specialized nodes. Data aggregation is also feasible through signal processing techniques. In that case, it is referred as data fusion where a node is capable of producing a more accurate signal by reducing the noise and using some techniques such as beam forming to combine the signals.

IV. THE PROBLEM OUTLINE

In a hierarchical protocol communication between an end node and base station takes place via a well-defined path of communicating nodes, which for the major portion is made of cluster head nodes. Cluster head nodes are no different in capabilities than any other ordinary node but they do heavy work of collecting the data from all the nodes and communication to the higher level base station in hierarchy thus in most of the protocols role of base station is rotating.

As discussed previously one of efficient algorithms for WSN communications is HEED (Hybrid Energy Efficient Distributed Clustering) which uses the dynamic approach for cluster formation. The dynamic clustering algorithm benefits HEED by electing cluster head based on its residual energy as well as on the factor of centrality of cluster head node in the cluster. But then it suffers from cost of communication in updating the cluster head information to each and every node after some period regularly. Moreover, the network topology doesn't remain stable as nodes are added and removed from the clusters as the cluster head changes

So considering a more stable algorithm in the sense of its topology, EECML (Energy Efficient Clustering for Maximizing Network Lifetime) uses clusters which are formed with calculations of several optimal parameters. EECML does not change its cluster formation throughout lifetime but it rotates role of cluster head between nodes within the cluster itself. But the EECML protocol has major fallacy that it is designed only for uniform density wireless networks. Wireless sensor networks have been proving useful in very remote areas of irregular geographical conditions ranging from hilly terrains to deep seas. So having the sensors equally distributed is quite of a job. Also to have such a uniform density is quite more than expected and sometimes even impossible. But all optimizing parameters of EECML are calculated assuming uniform density so the resultant cluster formation is suitable only for uniform density thus the efficiency of protocol drops significantly in non-uniform dense network.

V. PROPOSED APPROACH

The Network lifetime for a Wireless sensor Network is defined as the time elapsed from the point when the nodes are being deployed to the time when any sensor node in the Network dies. So it can be said that time at which the first node in the network dies, that corner of the Network is inaccessible thus making the Network unreliable.

As said about previously majority of workload is trusted upon the Cluster Head (CH) nodes. In addition to the work of ordinary node, the CH gathers data from its colleague nodes in cluster, it collects data from the CH of the cluster neighbouring to it but away from base station, it communicates this gathered data to the next CH in the hierarchy. Since there is a lot of redundancy involved, new protocols perform various aggregation techniques so as to reduce the energy spent in transmission as well as receipt. This can be explained with the power model for network

Energy consumption in a sensor node can be attributed to either "useful" or "wasteful" sources. Useful energy consumption can be due to

1. transmitting/receiving data,
2. Processing query requests, and
3. Forwarding queries/data to neighbouring nodes.

Wasteful energy consumption can be due to

1. Idle listening to the media,
2. Retransmitting due to packet collisions,
3. Overhearing, and
4. generating/handling control packets.

EECML and HEED deal with reducing the useful energy consumption. In WSN, the main energy consumption of the active node is made up of three parts: message sending,
message receiving and data processing [3, 8]. The simplified energy consumption model for each part can be defined as:

$$P_T(k) = E_{elec} \times k + E_{amp} \times d^r \times k$$

$$P_R(k) = E_{elec} \times k$$

$$P_{cpu}(k) = E_{cpu} \times k$$

Where k is the length (bits) of packets, d is the transmission distance (m). The radio dissipates Eelec (nJ/bit) per bit to run the radio circuitry. E_{amp} (nJ/bit/m2) is the power above E_{elec} needed by the transmitter for an acceptable Eb/N0 at the receiver's demodulator. E_{cpu} (nJ/bit) is the energy dissipation for processing per bit and r is the path loss exponent that is related to the transmission distance.

As it can be seen from the above equations each of the energy calculated is directly proportional to the number of bits being handled, i.e., k. Thus, any strategy that helps reduce k, keeping intact the meaning of the data, would suffice the purpose. Data aggregation techniques employ methodologies that communicate the same data with almost negligible loss of mnemonics but in a compressed way.

They achieve it mostly by redundancy in the communications. So now CH will be entrusted with this additional job. The aggregation techniques will not prove useful if the cluster doesn't have enough nodes. The CH will just then dissipate more quickly.

Owing to these problems of network non-uniformity, which might even render the aggregation techniques useless, reorganization of sectors originally formed by EECML protocol so as they can be made to work ideally as far as possible is necessitated. The approach to be presented aims at merging the clusters or if possible even dividing the clusters so as to balance the load on the object of maximum load. Finding out how much does a cluster deviate from the ideal characteristics proves a lot useful. EECML protocol defines an optimal clustering angle for dividing the network into similar sectors. The property of this clustering angle is that is independent of the area of the network or the radius of network. It depends upon the various energy attributes of the sensor nodes and the number of nodes deployed. As the energy parameters of the nodes cannot be changed once deployed they serve as constants. Thus, the clustering angle is dependent upon the number of nodes, more accurately the clustering angle varies inversely with the number of nodes in the area.

Thus, finding out the ideal number of nodes for a given clustering angle and comparing it with the actual number of the nodes present in the area we can separate out dense clusters from rarer clusters. A round for a cluster may be defined as when all the nodes from the cluster communicate for once their data with the cluster head. As we have cluster head re-election logic for maximizing lifetime after some threshold value we choose another cluster head from the same cluster. If the cluster is rarer a lot of rounds will be taking place and the ordinary nodes will deplete far sooner than the cluster head reaches its threshold limit. Thus, no re-election takes place and the cluster dies. So by merging clusters in a way that the value of number of nodes is pushed closer to the ideal value but not beyond it, we can utilize the same nodes over larger area for a longer time.

VI. IMPLEMENTATION

The implementation of protocol is divided into phases as follows:

A. Initialization

This phase is concerned with calculating the various optimal parameters for the Network as laid down by EECML. The parameters are as follows

The optimal one hop distance:

Nodes are spread over the network each one charged with same power and having same characteristics of which one hop distance is one. One hop distance is the distance over which a sensor node can communicate. That is one hop distance is the range of the node. Now for the communication to be efficient the nodes should be situated some optimal distance apart. It is not possible for all nodes to be situated optimal distance apart. But we can use this parameter for finding the cluster heads. The cluster heads can be chosen to be optimal one hop distance apart, as they are the major source of energy dissipation. The optimal one hop distance d_{opt} is given by:

$$d_{opt} = \sqrt[\gamma]{\frac{(2E_{elec} + E_{cpu})}{E_{amp}(\gamma - 1)}}$$

The optimal clustering angle:

The clustering angle is a very important parameter, which directly affects the number of cluster heads. The optimal clustering angle is calculated taking into consideration the energy parameters of the nodes and the number of nodes in the network. It is given by:

$$\theta_{opt} = \sqrt{\frac{8\pi^3(3E_{elec} + E_{cpu})}{N(2E_{elec} + E_{cpu})}}$$

For determining the optimal time as to when a cluster head should be replaced with another node so that cluster might not die abruptly and suddenly we require some threshold value. Up until this value a CH is allowed to be working. Once the limit is crossed the it is replaced with another probable candidate from the cluster. Its value is given by:

$$f_m \approx \frac{E_{init}}{[n_m(E_{elec} + E_{cpu}) + E_{amp} \times d_0^2] \times k}$$

Base station does have all these values known in advance and hence calculates these values in the initialization phase. Then it broadcasts these values over the network. The network is divided into sectors and further into clusters. First of all the base station divides network with the help of optimal clustering angle into sectors. Then it finds out nodes optimal one hop distance away from itself in these sectors. These found are the first cluster heads for that sector. Then these cluster heads find out the next cluster heads optimal one hop distance apart. The process continues till all the clusters are formed. Now to find out clusters we have one hop distance to our help. The sectors are divided into clusters each of length one hop distance. This marks the end of initialization step as network Is divided into clusters and sensors into ordinary nodes and cluster heads.

B. Differentiation

Next phase is the finding out the density of a particular sector and comparing it with the optimal value. The term density here refers to number of nodes per sector. The ideal implementation of EECML assumes uniform network and thus uniform density for sectors to. The ideal number of nodes can be found out as:

$$Nideal = N\ x\ \frac{\theta}{360}$$

Thus if number of nodes in a sector are lesser than the N_{ideal} value then it's rarer, if it is greater than N_{ideal} then its denser.

C. Merging

After finding the density of each sector, it is required to find out the sectors which can be merged and then does their merging actually help out. The criteria for merging sectors are:

1. They should be neighbours.
2. Their merging should not lead to a density which is Greater than the ideal value.

Also the pairs chosen for merging should be either rare and rare or denser and rarer but not denser-denser. After merging the ideal density of newly formed sector can be found from the combined clustering angle. The further attributes of the sector are also found in similar way.

D. Clustering

After finding out the probable candidates for merging and re-organizing the network as per the newly formed sectors the actual working of network requires to be started. Since all the clusters in the network have similar structure, that is they have one cluster head and other ordinary nodes, they can work independent of each other. That is individual clusters can work independently. The nodes sense data and communicate it to cluster head. As cluster head serves as single point of collision the use of contention free technique for communication is required. We use a round structure, similar to TDMA, wherein a round is composed of communication by each single node one after other in order. A node can communicate only once in a round. The cluster head then aggregates this data and sends it the next cluster head in the sector hierarchy. For the communication between the cluster heads the entire network can be considered as a separate cluster made of base station as head node and cluster heads of various sectors as its constituent nodes.

Now within a cluster re-election takes place by round mechanism. A node is allowed to work as a cluster head until it reaches the threshold value as discussed above. Once it is reached another node from the cluster with sufficient energy level acts as cluster head. And all other cluster heads in the clusters of the same sector are also updated.

VII. CONCLUSION

Now as defined previously, network lifetime is the time when the first node in the network dies, whenever any cluster form any sector in the network reports death of a node we can say that network has reached its network lifetime limit.

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