International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org Volume 2 Issue 4 ǁ April. 2013 ǁ PP.25-30

Energy Efficient Clustering of Wireless Sensor Networks with Virtual Backbone Scheduling

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ABSTRACT*:* *Energy efficiency is a key issue in wireless sensor networks because of battery powered sensor nodes. Clustering with minimum energy dissipation is an effective method to prolong network lifetime. Cluster heads form communicating backbone using Connected Dominating Set (CDS) algorithm. Virtual Backbone Scheduling (VBS) schedules multiple backbones to work alternatively and the backbones get their energy using duty cycle. Non backbone nodes turn off their radios to save energy. VBS minimises energy consumption and increases throughput. Clustering generates minimum CDS (MCDS) and also achieves good performance with the decentralised approach for cluster formation.*

Keywords - *clustering, node localisation, scheduling, virtual backbone, wireless sensor networks*

I. INTRODUCTION

Wireless Sensor Network (WSN) suffers from energy constraints. The key reason is because sensor node operates using battery and this determines the lifetime of networks. Sensor nodes in field are expected to work for several months to a few years where replacing or recharging the battery may not be practical. Energy efficiency becomes a critical issue in WSNs.

In a clustered network, network is divided into several clusters and one node is selected as the cluster head in each cluster. Each cluster head needs to schedule inter cluster and intra cluster communication. Individual sensor nodes transfer data their corresponding cluster head, which in turn forwards data to the next cluster head after segmentation/fragmentation through single/multi hop transmission. Ideally we expect a network to have very few clusters, cluster head spend more time listening or sending data and therefore consume more energy. Cluster heads will exhaust their batteries more rapidly than other nodes, possibly causing network partition. Energy efficiency can be maintained using clustering architecture. Several algorithms proposes different methods to form cluster and for rotating cluster head QoS is important for WSNs because of the extended use in surveillance and health care monitoring [1].

Most of the protocols have assumed all nodes in a network to follow same schedule, or assume that border nodes would follow multiple schedules. Global schedule algorithm (GSA) [2] control and exploit the presence of multiple schedules and converge all the nodes to work on a single schedule. WSNs don't have a physical backbone, so a virtual backbone can be formed. It is possible to save energy by constructing communicating backbones. Backbone is a set of active nodes used for increasing the bandwidth and decreasing energy consumption and thereby increasing network lifetime. We use Connected Dominating Set (CDS) algorithm to construct backbones. Creating a single backbone to increase the network lifetime is not conservative; hence it is desirable to construct multiple disjointed CDS.

CDS forms a temporary infrastructure, derived from Graph Theory [3]. It ensures routing, broadcasting, scalability and network connectivity. For a graph, G = (V, E), CDS is a dominating set $V' \subseteq V$ such that each node in V-V' is adjacent to some nodes dominating in V' and the sub graph induced by V' is connected. It is desirable to construct a Minimum CDS (MCDS) to reduce traffic and the overhead involved in maintaining the backbone and also to increase the network lifetime. Unfortunately computing an MCDS of a Unit Disk Graph (UDG) and Disk Graphs with Bidirectional links (DGB) are proved to be NP – hard [4][5].

Several clustering protocols have been proposed for WSN [6]-[10]. Location based [7] and Non location based routing protocols can be considered for clustered wireless sensor network. LEACH is one of the popular single hop clustering protocol[9].In this cluster head is periodically rotated among the sensor nodes, to balance the energy consumption. Communication between cluster head and sink is single hop and this is insufficient in a large sensor network. Provision for real time assurance in sensor networks must be addressed carefully. Cluster formation depends on geographic location of sensor nodes, number of sensor nodes deployed and their communication range. Success of any real time application depends on factors like jitter, delay and data rate.

This paper proposes a substantial energy saving method in cluster formation. Clusters are formed only once during a sensor network's lifetime with a decentralized approach in cluster formation. Cluster formation doesn't require any radio communication with sink.

Our contributions are

1) Proposes a protocol for simultaneous selection of cluster head and creation of balanced size clusters to prolong the sensor network lifetime, data aggregation/fusion, routing of data to the sink node.

2) A decentralized approach is used in cluster formation, and so no messages are exchanged between sink and sensor nodes, thereby increasing the lifetime of sensor nodes.

3) Cluster heads form communicating backbone using Connected Dominating Set (CDS) algorithm. Sink node has an unconstrained energy supply, active all the time and is implicitly included in all backbones.

4) Reducing the number of cluster heads, create Minimum Connected Dominating Set (MCDS) .This reduces traffic and overhead involved in maintaining the backbone and decreases energy consumption, thereby increases network lifetime [3].

1. Related Work

Most of the clustering protocols [6]-[10] aim at formation of stable cluster in WSN .In a stable cluster node location is mostly fixed. QBCDCP [6] considers delay, bandwidth and energy metrics for QoS route selection. Most of the proposed energy aware metrics are defined as a function of energy required for link communication and the remaining lifetime of nodes. In [8] nodes can decide whether it should join the cluster or not. This is done by comparing the signal strength of the advertisement message with a threshold value. LEACH uses randomized rotation of aggregators so that energy distribution is shared evenly among the participating sensor nodes. In LEACH [9] clusters are formed based on the received signal strength. It eliminates redundancy by data fusion. Dynamic Clustering Protocol provides energy efficiency and supports real time traffic. Cluster formation is an energy intensive task and can be done by high power base station. Based on this in LEACH centralized protocol, cluster head selection is done by base station.

CBRP is a virtual grid based clustering based routing protocol, assumes the communication radius of each node is R, and the monitoring area is divided into some virtual grids and assumes a distance d between grid and sink node. This guarantees every two node in two adjacent grids can communicate at the same time. According to [10] algorithm for cluster head selection is run independently on each grid. Each node has a probability to become the cluster head and the node with highest probability is assigned as cluster head. It limits the working of cluster members to their time slots. Members transit into sleep state only after they get a TDMA regulation message from cluster head.

Connected Dominating Set (CDS) formation, derived from Graph Theory [3] has the advantage of organizing a network in to a hierarchal structure. This cannot be achieved by any power control technique. Amount of energy required for the construction of CDS by measuring the energy dissipated in sending and receiving packet as in [9]. Various CDS algorithms [11], [12] considers this energy conservation issue. They are based on the unrealistic assumption of Global Positioning System (GPS), first each node is equipped with GPS and nodes can always communicate with neighbors without any interruption. Second nodes exchange a large number of messages to form CDS, which drains the energy of nodes and decreases network lifetime. Duty Cycle can be synchronous [13] and asynchronous [14]. Duty cycling using power saving technique in [13] does not consider the redundancy in WSN's and considers all the sensors' cycles are identical.

PACDS [15], power aware CDS algorithm addresses the energy limitation of WSNS. It construct a smaller size CDS and prolong the node's lifetime. Role of the CDS is alternated between nodes with higher residual energy. However this needs a number of message exchanges to construct CDS and drains the reserve energy. Yuanyuan [16] later presented an energy-efficient CDS (ECDS) algorithm to minimize the size of CDS.ECDS does not use any pruning rules. It constructs a dominating set called a maximal independent set (IS) and MIS is connected with gateway nodes. The ECDS algorithm is based on a coloring technique and a weight metric is used to select CDS and connector nodes. There is significant message complexity in acquiring neighbor's weight and updating nodes' status. Distributed approaches in CDS formation are preferable when compared to centralized approaches as they can deal with dynamic nature of network.

PACDS [15] proposed power aware localized routing based on transmission power related to node distance and residual battery of nodes. Greedy Routing is the popular localized routing protocol. Shortest path is calculated without any global network topology and nodes use only local information to forward the packet to the nearest destination node. Greedy Routing guarantees packet delivery. Combining greedy routing with face routing is an improvement to recover the route after greedy routing fails in local minimum.

II. PRELIMINARIES

Wireless sensor network model on a circular monitoring area of radius Z is considered. Node density, d is assumed to be uniform and there is only one sink at the centre of monitoring area. Assuming t sensor nodes are deployed in sensing area, denoted as N_1, N_2.......N_t. Such a model has been widely used in literature [10]. Each sensor node is capable of transmitting data with a low power and high power radio ranges. If R is the maximum transmission range of a node, low power R1=R/2 meters and high power R2=R meters. Maximum diameter of the cluster is assumed to be R/2 meters and low power broadcast range R1 is used for intercluster communication. Inter cluster communication is between cluster head and sensor nodes in the cluster, so that a cluster head being on cluster border can still communicate with other cluster members.R2 is used to transfer a packet between single hop cluster heads or with sink.

TDMA scheduling is used for inter cluster communication to avoid collision among the data transmitted by various sensor nodes [17]. TDMA scheduling between the cluster members is managed by cluster head. Cluster head transmit data to the next hop cluster head towards the direction of sink. To avoid collision between inter cluster data, multiple access technique of direct sequence spread spectrum (DS-SS) is assumed. It avoids collision by assigning different codes for each cluster head within the sensing area. Sensor nodes are assumed to be static and node localizability is applied to every node after their deployment [17]. Energy consumption for sensor nodes with in a sensing area is calculated based on first order energy consumption [9], [10].

2. Protocol for Clustering

Location of sink node within a network is denoted with co-ordinate (X_s, Y_s).The location of sink is referred as a signal message. After the deployment of sensor nodes, the transmission of signal message by sink node using Omni-direction antenna starts. This initiates clustering and cluster head selection phase. After receiving the signal information all sensor nodes calculate their respective Euclidian distance from sink. Assume that an ith sensor node with co-ordinates (X_i, Y_i) is at sink a distance Dsi from sink. Thus each node calculates their distance from sink.

Formation of concentric circles centered at sink starts now. Concentric circles are indexed as CCn (n=1,2,…m).Sensor nodes are assigned to these concentric circles[7] with the formula:

$$\text{CCn} = \frac{2|\text{Dsi}|}{\text{R}} \quad (1)$$

Where R denotes the radio range of sensor node. Associating sensor nodes to concentric circle is an energy efficient method as every node can itself calculate the distance from sink node and there by associate itself to a concentric circle. As each node is localized and does not need to transmit any location information to sink node, it has two advantages. Energy consumption and delay due to transmit and receive operation can be avoided. The proposed model ensures that the distance between two neighboring cluster heads is a maximum of R meters.

Concept of virtual circular band (VCB) is proposed for cluster formation and cluster head selection. Virtual circular bands are designated as VCB1, VCB2,….Node density in the sensing are is denoted as d. Value of d is made known to all sensing nodes at the time of deployment. Each virtual band has a width 2d and lies at the midway between two concentric circles. If the sensing area is sparsely populated, the value of d is kept large because the probability of finding sensor node near the centre of concentric circle is less and so we need to ensure that a cluster head is in VCB. For a densely populated sensing area, d value is small and a probable cluster head can be found near to centre. VCB index is calculated as

$$\text{VCBn} = \left\{\left(\frac{\text{R}}{2} * \text{CCn}\right) + \frac{\text{R}}{4}\right\} \pm \text{d} \quad (2)$$

All the sensor node calculate their distance from sink node Dsi , concentric circle index CCn, virtual circular band index VCBn. If the distance Dsi falls within the VCB index, the sensor node is declared as a probable candidate for cluster head selection. All the other nodes opt out from the process of cluster head selection and wait for the cluster head declaration. After the selection of probable candidates for cluster head, election of cluster head starts. The best candidate would be the one located exactly midway between two concentric circles.

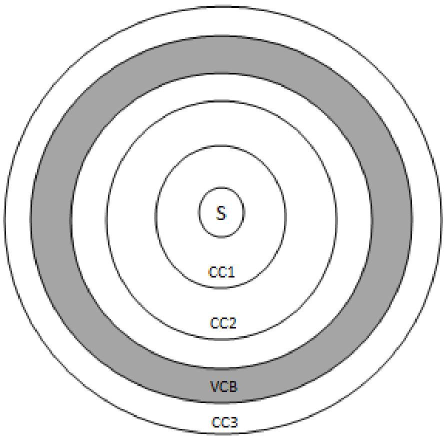

Figure 1. Formation of virtual circular band

S corresponds to sink node, located at the centre. Assuming the energy of all possible candidates for cluster head is the same, only location is considered as the criteria for cluster head selection. A decremented counter is used for the election of cluster head. The distance of cluster head candidate from the centre of VCB is calculated. Sink node initiates cluster head formation by sending a start message, so that all candidates can start their decremented counter at the same time. Decremented counter of node near to the centre of VCB will expire first. As soon as the counter becomes zero, this particular node advertises a message declaring itself as cluster head.

If a more than one cluster head candidate simultaneously declares themselves as cluster head with in the same cluster, as they are at the same distance from VCB, a random interval value can be added to restrict to a single cluster. Cluster head advertisement message is transmitted within the radio range of sensor node. All the other cluster head candidates will stop their decremented timer and associate itself with the declared cluster head. All non cluster head candidates falling within the radio range of declared cluster head will associate themselves to cluster head and forms the cluster. The same process is repeated for all concentric circles and the corresponding head and clusters are formed.

III. SCHEDULE TRANSITION GRAPH (STG)

Schedule Transition Graph (STG) is an approximation algorithm used to model a schedule in WSN. Sink is the centre node and is implicitly included in all backbones. A stable link must be established between backbone nodes. Multiple overlapped backbones are formed to increase network lifetime. Rotation of backbone ensures balanced energy consumption among the cluster heads and increases network lifetime.

Horizontal axis represents time in rounds. Each round includes states represented by ellipses. Each ellipse is a set consisting of a backbone node and energy. One to one mapping exist between state and backbone. Initial state is represented by start and is connected to all the states in first round. Connectivity is made with unidirected edges. Each edge corresponds to the energy consumption of 1 round.

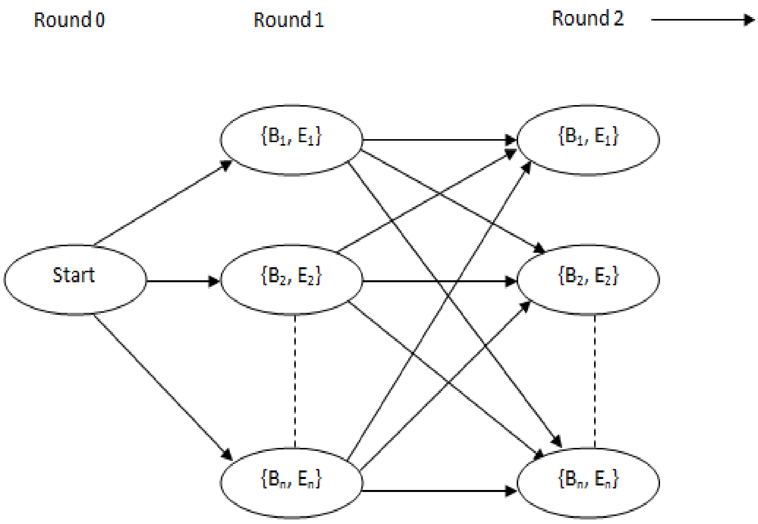

Figure 2. Scheduling in STG

5.1 Energy Efficient Routing

CDS is used for the creation of stable link between backbone nodes. Sink is implicitly included in all backbones. Cluster heads of the various cluster clusters in the monitoring area form the backbone. Each cluster head finds the nearest neighbor cluster head in the direction of destination. This ensures the energy consumption and distance travelled are less. Backbones perform inter cluster and intra cluster routing. Backbone nodes get their energy using duty cycle. Virtual backbone scheduling schedules multiple backbones to work alternatively. Lifetime of a node is the time when it starts working to the time when its energy gets depleted. Lifetime of a network is the minimum lifetime of sensor nodes in the network. Traffic is forwarded only by backbone nodes and the rest of the sensor nodes can save energy by turning off their radios. Clustering generates a minimum CDS (MCDS) and also achieves good performance with the decentralized approach for cluster formation.

IV. PERFORMANCE EVALUATION

6.1 Simulation Configuration

We simulate the proposed system using ns2 simulator with the Network Simulator (NS) 2.34 environment and Ubuntu 11.10. Parameters used to simulate the proposed system are the following. We consider a topology dimension 670m x 670m with 35 sensor nodes. MAC Type is 802.11 MAC layer and 512 byte packets are considered. Antenna used is an Omni direction antenna.

6.2 Energy Dissipation in Clustering

Minimum energy dissipation in clustering can prolong the network lifetime and increases the efficiency of clustering. Figure shows the energy dissipation in clustering with the number of nodes in sensing area. In the existing protocols, transmission of location information between the sensor nodes and sink, processing these information increases the energy dissipation. In our clustering protocol, each node is localized and they themselves assign to cluster. Cluster head selection and clustering is carried out simultaneously throughout the network. Number of nodes slightly increases the energy dissipation in clustering.

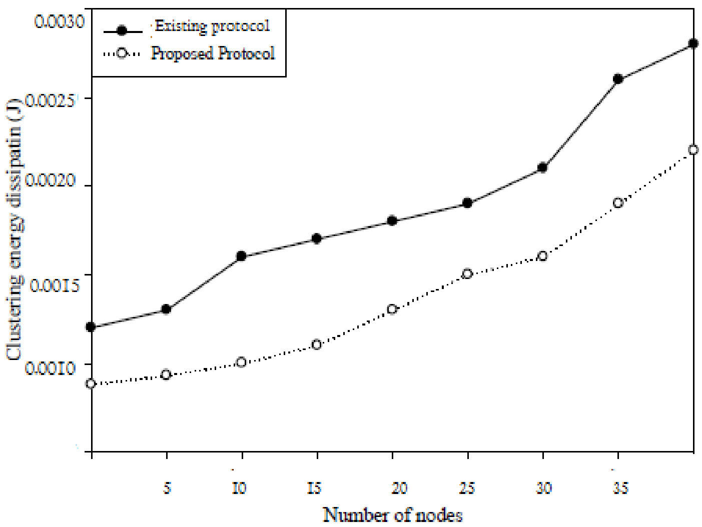

Figure 3. Energy dissipation in clustering with the number of nodes in sensing area.

6.3 Network Lifetime

The line labeled “original” is the result without any sleep scheduling. Lifetime of a network is determined by the minimum lifetime of nodes in the network. If no sleep scheduling technique is used, all the nodes work simultaneously and network lifetime decreases drastically. STG achieves longer lifetime, because CDSs in the network is smaller and disjoint.

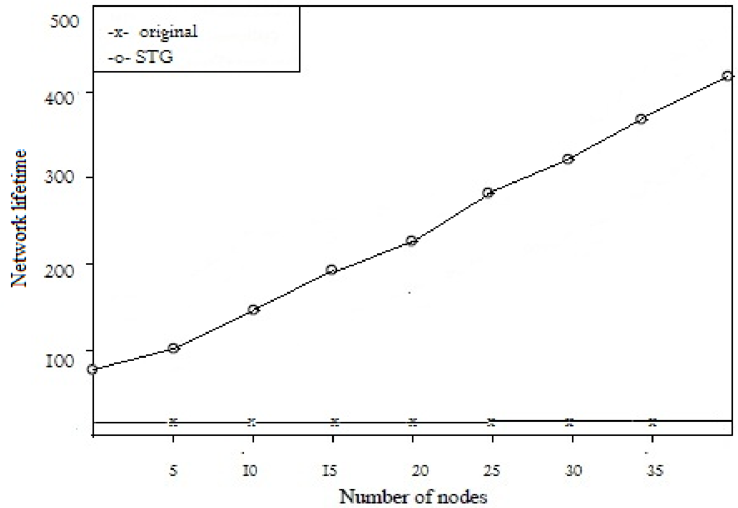

Figure 4. Network lifetime with the number of nodes

V. CONCLUSION

We propose an energy efficient clustering with balanced size clusters in virtual circular band and clusters are formed only once in network lifetime. Transmission power of cluster head is adjusted to perform intercluster and intracluster routing. Cluster heads form multiple disjoint communicating backbones. VBS combines virtual backbone and sleep scheduling, which increases the lifetime of WSNs over existing methods. Backbone nodes are tied with duty cycle to preserve network connectivity. Clustering protocol can be extended in future to a sensor network with mobile sensor nodes and to an efficient distributed implementation of VBS.

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