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Research Article

Energy-Efficient Cluster Formation in Wireless Sensor Networks

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ABSTRACT

Sensor nodes that are wireless are extremely energy-constrained devices. Due to a number of sensor node limitations, including size and cost, their battery life is limited. Furthermore, the majority of Wireless Sensor Network (WSN) applications make it impossible to recharge or swap out sensor node batteries. Thus, one of the main challenges in wireless sensor networks is making the best use of node energy. An efficient way to maximize node energy utilization and extend the lifespan of an energy-constrained wireless sensor network is to cluster sensor nodes. In order to extend the lifespan of sensor networks, we present a location-based protocol for WSNs in this paper that supports energy-efficient clustering, cluster head selection/rotation, and data routing. With the fewest transmit-receive operations, the suggested clustering technique guarantees balanced size cluster formation within the sensing field. Even though the cluster head and sensor nodes in a cluster have different energy needs, the cluster head rotation protocol guarantees balanced node energy dissipation. In order to establish balanced energy consumption across the cluster's nodes and so extend the network's lifespan, the cluster head rotation protocol has been devised. Simulation findings show that by using effective clustering, cluster head selection/rotation, and data routing, the suggested protocol extends network lifetime.

Keywords: Corona; clusters; cluster head; sink; network lifetime.

I. INTRODUCTION

Sensor nodes are tiny, inexpensive, and multipurpose devices made possible by recent developments in wireless communication and large-scale integration technologies. Sensor nodes can detect the desired environmental parameters in their immediate vicinity, including temperature, pressure, moisture, pollutants, and so on. They can then translate the sensed variable into an electrical signal and send the data to the intended location. Sensor nodes are outfitted with wireless trans-receivers, microcontrollers/microprocessors, and sensors in order to accomplish these goals.

Sensor nodes are outfitted with wireless trans-receivers, microcontrollers/microprocessors, and sensors in order to accomplish these goals. Wireless sensor networks are self-organizing cooperative wireless ad hoc networks created when these sensor nodes are widely dispersed to monitor a region. The majority of wireless sensor networks are set up in dangerous, isolated areas where manual monitoring is nearly impossible.

Wireless sensors are deployed in harsh, unattended environments, making it impossible to charge or replace their batteries. Therefore, it is crucial that wireless sensors operate efficiently in order to extend the lifespan of the entire wireless sensor network [1, 2]. In real-world deployment scenarios, multi-hop communication is crucial because wireless sensor nodes and power radios are unable to send data over long distances in a single hop. Nonetheless, in multi-hop scenarios, improper management of sensor node energy consumption could result in an energy-hole issue for the network [3]. Numerous protocols have been put forth in the literature to control and lower sensor node energy consumption [1–8].

Clustering sensor nodes has been a popular method for accomplishing this goal. One sensor node is chosen to serve as each cluster's cluster head in clustered networks. Each cluster's sensor nodes send data to the cluster head, who then aggregates and fuses the data before sending it to a sink node via single-hop or multi-hop transmission.

Among the most widely used distributed single-hop clustering protocols is LEACH [5]. Clusters are created in this protocol according to the strength of the received signals. To guarantee that each sensor node in the cluster uses the same amount of energy, the cluster head's position is alternated among the sensor nodes on a regular basis. Because cluster heads only communicate with the sink once, this algorithm becomes extremely inefficient when applied to large area sensor networks. To address the limitations of LEACH, several enhancements have been suggested in the literature [6, 15–17]. LEACH-C is one of them [6].

In order to increase the lifespan of sensor networks, we present in this paper an energy-efficient protocol that consists of clustering, cluster head selection/rotation, and data routing. The suggested protocol saves a significant amount of energy because clusters are only formed once over the course of the sensor network.The simulation experiments show that the suggested protocol significantly extends the wireless sensor network's network lifetime.

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II. RELATED WORK

For wireless sensor networks and mobile ad hoc networks, several clustering algorithms have been proposed [5–18]. One of the first attempts to extend network lifetime in mobile ad hoc networks was the linked cluster algorithm (LCA) [18, 19]. The main goal of LCA was to create an effective network topology that could manage node mobility. As a result, it was designed to optimize network connectivity. Numerous clusters were produced by the LCA. As a result, in [20], the algorithm was improved. Lin and Gerla suggested that CDMA be used to effectively support multimedia applications in multi-hop mobile networks.

Wireless sensor networks can benefit from the application of random competition-based clustering (RCC), which was created for mobile ad hoc networks [21]. Its primary goal is cluster stability so that mobile nodes can be supported. The first declare, first win principle is the foundation of RCC. According to this method, the first node to declare itself the cluster head creates a cluster within its radio coverage, and the remaining nodes within its radio coverage cede their claim to the cluster head position and become members of the cluster. Through local broadcast and coverage, the CLUBS algorithm creates clusters in a time proportional to the local node density [22].

Banerjee and Khullar [23] proposed a multi-tier hierarchical control clustering algorithm. Any node can start the cluster formation process in this process, and the clustering process is carried out in a hierarchical order. One of the most widely used clustering algorithms for wireless sensor networks is Low Energy Adaptive Clustering Hierarchy (LEACH) [5]. Clusters are created in LEACH according to the strength of the received signal.

The sensor nodes make autonomous decisions about cluster formation without any centralized control and cluster head nodes are used to route the data to the base station. The algorithm ensures the balanced energy usage of nodes by random rotation of cluster head role amongst the nodes inside cluster. LEACH creates a one-hop intra- and inter-cluster topology in which every node sends a direct message to the cluster head, which then aggregates the data before sending it in a single hop to the base station. This is a significant flaw in LEACH that reduces its practical effectiveness for networks spread across wide areas. It is also less efficient if the cluster heads are far away from the sink A distributed method called Fast Local Clustering Service (FLOC) was put forth to create roughly balanced clusters with the least amount of overlap.

The cluster head candidates in the Energy Efficient Clustering Scheme (EECS) compete with one another according to residual energy; the cluster head candidate with the highest residual energy at the end of a round is chosen as the cluster head [8]. By dynamically sizing clusters according to their distance from the sink node or base station, EECS expands on the LEACH algorithm. This enhances the network's balanced energy distribution, which prolongs the network's lifespan.

It offers improved load balancing and consistent cluster head distribution across the network. Because cluster heads near the base station must relay more data traffic, they die more quickly, which leads to the hop-spot problem, which is addressed by energy-efficient unequal clustering (EEUC) [9]. In order to save intra-cluster energy, EEUC balances the energy consumption for creating unequal clusters, where the clusters close to the sink node are smaller than the clusters farther away. The overhearing features of wireless communication serve as the foundation for the Power Efficient and Adaptive Clustering Hierarchy (PEACH) cluster formation, which facilitates adaptive multi-level clustering.

Virtual points surrounding the sink carry out the clustering process in this location-based clustering protocol. After obtaining the location data from every sensor node in the network, the sink determines the location of virtual points. In order to start the clustering process, the protocol requires that all sensor nodes send location data to the sink. Because nodes and sinks communicate via multiple hops, it raises the energy cost of clustering, particularly in large area sensor networks.

III. SYSTEM MODEL

A wireless sensor network model with a single sink node at the centre of a circular monitoring area A of radius Z and a uniform node distribution density ρ has been taken into consideration. The sensing area is equipped with T sensor nodes, which are identified by the numbers N1, N2, ... NT. The literature has made extensive use of this model [6].

For intra-cluster and inter-cluster communication, it is assumed that the transmitter electronics of every sensor node can transmit data over a multi-range using two different radio ranges: low power broadcast range R1=R/2 meters and high power range of R2=R meters, where R is a node's maximum transmission range.

A sensor node and cluster head can communicate within a cluster using the low power broadcast range R1. Data connectivity between the sensor nodes and cluster head within the cluster is maintained, even if a node is situated at the cluster's boundary. This is because the maximum diameter of any cluster is assumed to be R/2 meters.

The cluster head node uses the high-power broadcast range R2 to send data to the sink node, if the sink node is one hop away from the cluster head, or to the cluster head next hop.

In order to maintain connectivity between such nodes, the suggested model makes sure that two neighbouring cluster heads are always at a maximum distance of R from one another. To create clusters of a balanced size, the sensor nodes employ radio range R3=R/4 during the clustering process. To lower the transmission overhead, the cluster head performs data aggregation or data fusion over the received data based on the type of sensed data as it comes in from different sensor nodes. In the direction of the sink node, the cluster head forwards the combined/aggregated data to its subsequent hop cluster head.

It is assumed that the multiple access techniques of TDMA and direct sequence spread spectrum (DS-SS) will prevent intra- and inter-cluster data collisions [10]. It is assumed that every sensing node placed in the sensing area is stationary and aware of its location. The corona, or m numbers of concentric circles of equal width, make up the sensing field [14].

In proposed model, the width of each corona is assumed to be R/2 meters, as illustrated in the Fig. 1.

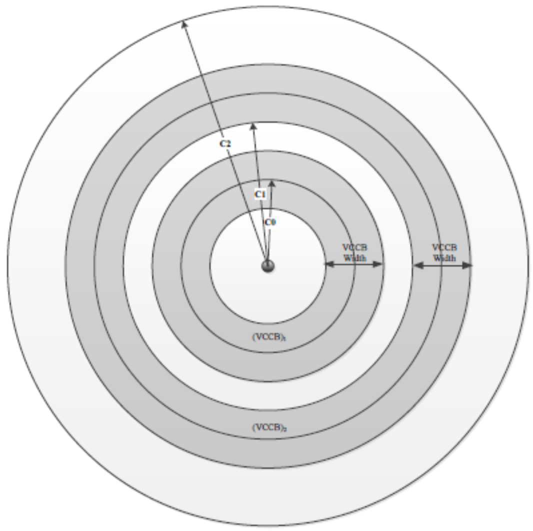

Figure 1. Corona based wireless sensor network and Assignment of concentric circles band (VCCB) to the sensor nodes.

A. Energy Model

Generalized energy consumption model based on first order radio energy consumption is used for calculation of energy consumption for sensor nodes within the sensing area [5, 6, 12, 13].The energy consumption of a sensor node for transmitting k bits of data over a distance d can be expressed as [6, 13]:

$$E_{Tx}(k,d) = E_{elect-Tx}(k) + E_{amp-Tx}(k,d) \quad (1)$$

$$E_{Tx}(k,d) = \begin{cases} kE_{elect} + k\epsilon_{fs} d^2, & d < d_0 \\ kE_{elect} + k\epsilon_{mp} d^4, & d \geq d_0 \end{cases} \quad (2)$$

$E_{elect-Tx}$ is transmission electronics energy; which is energy consumed by the sensor node for modulation, coding, spreading schemes, filtering operations, etc. $E_{amp-Tx}(k,d)$ is the power amplifier stage energy consumption of sensor node to transmit k bits of data over a distance of d meter with acceptable signal to noise ratio (SNR). E_{elect} (nJ/bit) is energy dissipation per bit to run transmitter and receiver electronic circuitry. ε_{fs} (pJ/(bit-m^{-2})) is energy coefficient of power amplifier stage of sensor node for free space energy dissipation model, when transmission distance is less than threshold i.e. $d < d_o$. ε_{mp} (pJ/(bit-m^{-4})) is energy coefficient of power amplifier stage of sensor node for multipath energy dissipation model,

Cluster Formation and Cluster Head Selection

To achieve energy balanced clustering in the network, in proposed scheme, virtual concentric circles are designated as V_1, V_2, V_3.... A virtual concentric circle band lies midway between two concentric circles and has width ± δ i.e. 2δ. The index V_j of virtual concentric bands can be calculated as:

$$V_j = \left[\left\{ \left(\frac{R}{2} * C_i \right) + \frac{R}{4} \right\} \pm \delta \right] \quad (5)$$

$$If \quad x_i = \left\{ \left(\frac{R}{2} * C_i \right) + \frac{R}{4} \right\} \quad Then \; V_j = [x_i \pm \delta] \quad (6)$$

Details about the radio range of the sensor node All sensor nodes are informed of the value of δ at the time of node deployment, and R is known apriori to all nodes. The network's node density determines the value of δ. In the network, each sensor node computes its own VCCB index, Vj, and compares it to its distance from the sink node, dsi. The sensor node is deemed a likely candidate for the cluster head (CH) election in the first round if the distance dsi is within the VCCB index [xi ± δ].

Every other sensor node chooses not to participate in the first round of cluster head selection and waits for the first round cluster head to be announced before joining one of the designated cluster heads. The first round cluster head election process begins after the selection of likely candidates for the position is finished. The candidate who is precisely halfway between the two concentric circles would be the most qualified candidate for the first round cluster head election. It has been assumed that all likely cluster head candidates have the same level of energy for the first round of the election.

Therefore, only location of cluster head candidate has been used as sole criteria for first round cluster head selection. All the probable cluster head candidates calculate their distance from center of their respective VCCB as:

$$d_{i(vc)} = \left\| \left[\left\{ \left(\frac{R}{2} * C_i \right) + \frac{R}{4} \right\} - d_{si} \right] \right\| \quad (7)$$

Initially back-off timer value of node N_i is set to be t_i, and is given by:

$$t_i = \frac{d_{i(vc)}}{\delta} * T_{ch} \quad (8)$$

Where T_{ch} is the time allocated for the first-round cluster head election. The sink node assists the cluster head formation by sending START message, which directs all the probable cluster head candidates in the network to start their back-off timer at same time. As the back-off timer value is directly proportional to the distance of cluster head candidate from center of VCCB, the back-off timer of the node near to the center will expire first. As soon as the back-off timer of particular cluster head candidate expires, it sends advertising message CH_ADVT, declaring itself as first round cluster head. This message will be transmitted within the radio range $R_3 = (R/4)$ of sensor node. Any other probable cluster head candidate within the radio range (R/4) of the node which has declared itself as cluster head, will stop its back-off timer and associate itself with the declared cluster head for formation of cluster. Similarly all non-cluster head candidates, falling within the radio range (R/4) of declared cluster head, will also associate themselves with the cluster head and thus form a uniform cluster. Same process takes place in all the concentric circles throughout the sensing area and simultaneous cluster head selection and cluster formation takes place within the network.

IV. PERFORMANCE EVALUATION

In this section the performance of VCCBC protocol is evaluated through simulation experiments. We have implemented the simulator in MATLAB. The performance of VCCBC protocol is compared with Hausdorff [10] and ERP- SCDS [11] protocols.

TABLE I. SIMULATION PARAMETERS

Parameter	Default Value	Range
Area	(100×100) m^2	(50×50)~(400×400) m^2
Number of nodes	550	100~500
Initial Energy of node	3 Joule	
Data packet size (k)	120 byte	
Eelect	20 nJ/bit	
εfs	40 pJ/bit/m^2	
Emp	0.00134 pJ/bit/m^4	
Eaggr	5 nJ/bit/signal	
Threshold distance (d_0)	47 meters	

The performance metrics include clustering energy dissipation, and life-time of network. The probability of signal collision and signal interference is ignored, assuming TDMA scheduling for intra cluster and DS-SS for inter cluster communication. The simulation parameters are listed in Table I. For each parameter, simulation has been run many times and average result of all runs has been taken for evaluation.

A. *Clustering Energy Dissipation*

The network lifetime can be extended and the effectiveness of any clustering and routing protocol can be demonstrated by the minimum clustering energy requirement. The change in clustering energy dissipation with changes in the number of nodes and sensing field area is depicted in Fig. 3. When nodes are randomly placed within a sensing field of 100 x 100 m2, the simulation results of variations in clustering energy dissipation for the Hausdorff, ERP-SCDS, and VCCBC protocols with varying node counts from 100 to 500 are displayed in Fig. 3(a).

Hausdorff uses more control messages to form clusters, which results in the highest clustering energy dissipation. The clustering energy requirement of ERP-SCDS is higher than that of VCCBC protocol, but it is lower than that of the Hausdorff protocol. Compared to our suggested protocol VCCBC, it uses more energy because it necessitates the transmission of location data from each node to the sink, which then starts the clustering process after receiving this data. The cost of clustering energy is increased by the numerous transmit/receive operations involved in this process. With the VCCBC protocol, clustering and first-round cluster head selection are done concurrently across the network.

Because fewer control messages are sent for clustering, fewer transmit/receive operations are required. The simulation results of how the clustering energy dissipation changes as the side length of the sensing area increases from 50 to 400 meters, when 400 nodes are deployed, are displayed in Fig. 3(b). For Hausdorff and ERP-SCDS, the simulation results demonstrate an increase in clustering energy dissipation. This increase can be explained by the fact that in Hausdorff, more control messages are exchanged, and in ERP-SCDS, as the distance between nodes and the sink increases, more location data is transmitted from all sensor nodes to the sink.

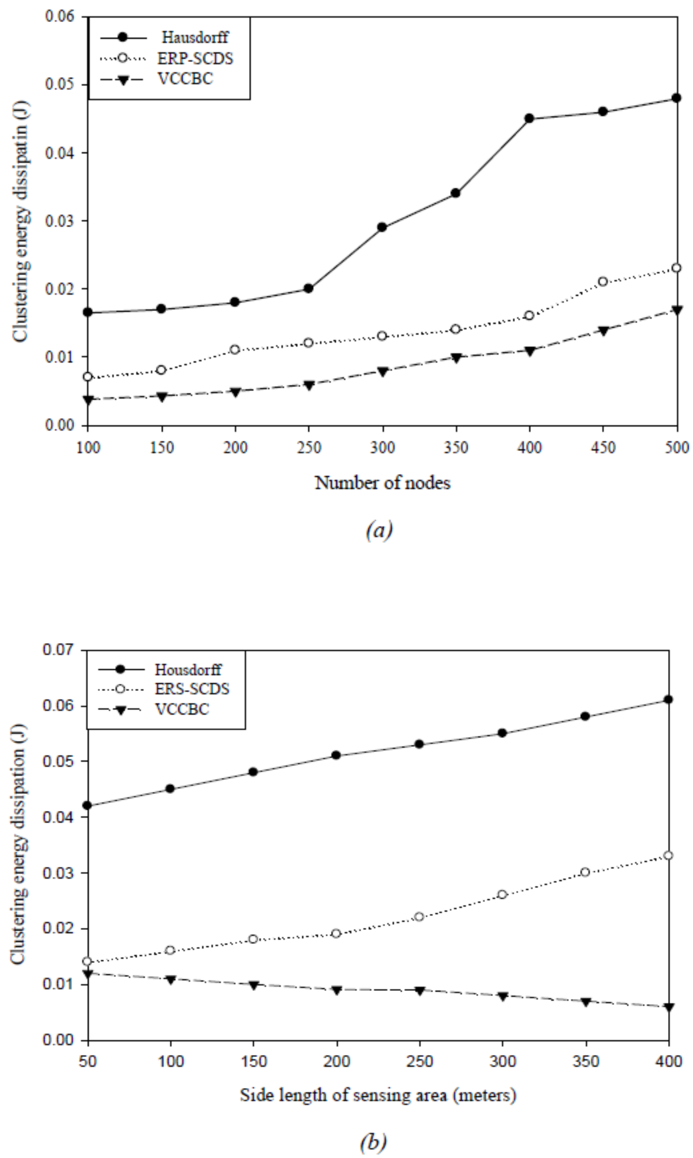

Figure 3. Variation in Clustering energy dissipation with (a) number of nodes deployed in sensing field, and (b) side length of sensing field.

V. CONCLUSIONS

An energy efficient clustering, cluster head selection/rotation and data routing protocol is proposed in this paper. The creation of homogeneous clusters in virtual concentric circular bands surrounding the sink is guaranteed by the suggested virtual concentric circle band based clustering protocol (VCCBC). The cluster formation in the suggested method only occurs once during the network lifetime, preventing the energy waste that comes with re-clustering. The energy calculation of the different tasks carried out by the sensor nodes and cluster head in a cluster forms the basis of the cluster head rotation process. Energy consumption is balanced to determine the cluster head rotation's timing and frequency. The network lifetime is increased as a result of the node's balanced energy drainage. The outcomes of the simulation show how well the suggested protocol dissipates clustering energy.

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