Energy Efficient Two Hop Clustering for Wireless Sensor Networks

Babu N V[1], Puttamadappa. C [2], Bore Gowda S B[3]

[1]Department of E & EE, SJB Institute of Technology, Bangalore, India
[2]Department of E & CE, Principal, Sapthagiri College of Engg. Bangalore, India
[3]Department of E & CE, Manipal Institute of Technology, Manipal, India

Abstract
A wireless sensor network (WSN) can be described as a collection of sensor nodes which co-ordinate to perform some specific action. Unlike traditional mobile and ad-hoc networks, WSNs depend on battery, dense deployment of nodes in a given physical space and co-ordination to carry out their tasks. In the past few years, there has been lot of research work took place in the area of routing in WSNs and it is proved that the cluster based routing is the one of the best approach to improve the lifetime of the network. The proposed THC protocol makes some assumptions for efficient data routing and network lifetime longevity. The THC protocol transmits its aggregated data to the collecting base station using multipath communication compared to direct communication in LEACH. The results show that THC protocol performs very well and increases the network lifetime.

1. Introduction

Recent advances in the invention of micro sensor, the communication technology and VLSI technology leads to the development of tiny, inexpensive, low-power, distributed devices, which are capable of local processing and wireless communication. These devices are called as sensor nodes. Each sensor node is capable of only a limited amount of processing, communication range and storage space. But they cab able to coordinate the information from a large number of other nodes and they have the ability to measure a given physical environment in great detail. Thus, a wireless sensor network (WSN) can be described as a collection of sensor nodes which co-ordinate to perform some specific action. The demand for smart energy management applications and the abundance of inexpensive, standards-based wireless microcontroller units are stimulating the growth of WSN across diverse markets, including home and building automation, telemedicine, and lighting [1]. Unlike traditional mobile and ad-hoc networks, WSNs depend on dense deployment of nodes in a given physical space and co-ordination to carry out their tasks. The sensor nodes depend the battery for their operation.

WSNs are typically self-organizing [2], so the networks allow a new node to join the network automatically without human intervention. They are also self-healing networks, since the nodes have the ability to reconfigure their link and find new paths around failed of powered-down nodes. These capabilities are specific to the network protocol and topology and ultimately determine the networks flexibility, scalability, cost and performance. In spite of the diverse applications, there are many factors which pose technical challenges while designing the routing protocol for the WSN, such as ad hoc deployment, unattended operation, untethered, dynamic topology changes etc.

Energy consumption is the most important factor to determine the life of a sensor network because usually sensor nodes are driven by battery and have very low energy resources [1]. The batteries cannot be replaced and recharged once after deployment, since sensor nodes are used to operate in remote conditions. This makes energy optimization more complicated in WSNs because it involved not only reduction of energy consumption but also prolonging the life of the network as much as possible. This can be done by having energy awareness in every aspect of design and protocol operation.

The sensor nodes are limited in communication range, so dense deployment of sensor nodes can improve network connectivity and fault tolerance. The main drawback of dense deployment is that considerable amount of redundant data would have to be communicated to the sink. Hence the transmission of redundant leads to the wastage of valuable node energy [3]. In order overcome this, the WSN is divided into number of clusters. The primary operation in clustering is to select a set of nodes as cluster heads (CHs) and others nodes in the cluster are called as member nodes. CHs are responsible for coordination among the member nodes within their clusters and aggregation of their data and communication with member nodes and/or with main collecting center i.e. base station (inter-cluster communication) [4]. All the sensors in the network are homogenous and have same capability of processing, memory, and power consumption. The Function of cluster head is cluster management, data collection from cluster members, and sending them to the base station (BS). In recent years, multiple algorithms

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have been presented for clustering in wireless sensor network.

2. Related work

In the past few years, there has been lot of research work took place in the area of routing in WSNs. It is proved that the cluster based routing is the best approach to improve the lifetime of the network. Proposed protocols can be classified into data-centric, hierarchical, location-based, network flow and QoS-aware routing [5]. Many energy-efficient (hierarchical) clustering algorithms have been proposed to prolong the network lifetime [6–12].

The LEACH [6] protocol was proposed by Heinzelman et al. to meet the requirements of periodical data-gathering applications. LEACH randomly selects CHs and rotates the role of CHs to distribute energy consumption among all nodes in the network. During data transmission phase, each cluster head collects data from its member nodes and forwards an aggregated packet to the base station directly, which is a high energy consumption operation. An energy-aware variant of LEACH is proposed in [7], in which the nodes with higher energy are more likely to become cluster heads. However, the underlying routing protocol is assumed to be able to propagate node residual energy through the network. A two-phase clustering (TPC) scheme proposed by Choi et al. [8] analytically determines the optimum number of cluster heads. At the cluster head electing stage, each node in the network broadcast Cluster head advertisement message with random delay and the node who overhears others advertisement will cancel its scheduled advertisement. After completing the initial clusters, an energy-saving data relay link is setup by choosing a neighbor closer than the cluster head within the cluster.

HEED [9] introduces a variable known as cluster radius which defines the transmission power to be used for intra-cluster broad-cast. The initial probability for each node to become a tentative cluster head depends on its residual energy, and final heads are selected according to the intra-cluster communication cost. HEED terminates within a constant number of iterations, and achieves fairly uniform distribution of cluster heads across the network. VCA [10] is an improvement over HEED. Sensors vote for their neighbors to elect suitable cluster heads. The authors also propose two strategies to balance the intra-cluster workload among cluster heads. EECS [12] introduces a cluster head competitive algorithm without message exchange iterations. It extends LEACH and HEED by choosing cluster heads with more residual energy. It also achieves a uniform distribution of cluster heads. While the clustering problem has been extensively explored, researchers have only recently started to study the strategies for balancing the workload among cluster heads while considering the inter-cluster traffic. In single hop sensor networks, cluster heads use direct communication to reach the base station, and the problem of unbalanced energy consumption among cluster heads arises. Cluster heads farther away from the base station have higher energy burden due to the long-haul communication links. Consequently, they will die earlier. In EECS [12], a distance-based cluster formation method is proposed to produce clusters of unequal sizes. Clusters farther away from the base station have smaller sizes, thus some energy could be preserved for long-haul data transmission to the base station. On the other hand, the hot spot problem arises when multi-hop routing is adopted when cluster heads deliver their data to the base station.

3. Proposed network model

3.1 Assumptions: The proposed THC protocol makes some assumptions for efficient data routing and network lifetime longevity. The set of 'N' number of sensors are spread non-uniformly over the environment where the physical observation is required. The base station is located outside the sensor field and provided with the abundant computation, storage and power supply. The following assumptions are made for the proposed protocol:

- The sensor nodes in the network are homogenous
- The nodes and base station are not mobile
- Each node has a unique ID and location aware
- The activities of the nodes are coordinated by the base station
- All nodes transmit at the same transmission power except the cluster head
- The intra cluster communication is two-hop whereas the inter cluster communication is multi-hop
- Base station aware of the physical space of sensing field

3.2 Radio energy model

The attenuation of the transmitted power decreases exponentially with increasing transmission distance in wireless communication. In [7] two types of transmission models for the channels are proposed (i.e. free space model and multi-path attenuation model). The free space model is used with transmitting power decreasing exponentially by d^2 , if the distance d between transmitting and receiving node is smaller than a certain value d_0. Otherwise, the multi-path attenuation model is employed with sending power decreasing exponentially by d^4.

The protocol uses a simple radio energy model [7] for the performance evaluation of the proposed protocol as shown in Figure 1. The power required to transmits a $k-bit$ message a distance d is given by

$$E_{Tx}(k,d) = \begin{cases} E_{elec} * k + \varepsilon_{fs} * k * d^2 & d < d_0 \\ E_{elec} * k + \varepsilon_{amp} * k * d^4 & d \geq d_0 \end{cases}$$

and to receive $k-bit$ message, the radio expends

$$E_{Rx} = E_{elec} * k$$

The term d_0 is the threshold and calculated as:

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}}$$

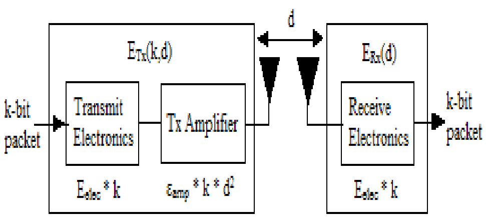

Figure 1. Radio energy model of sensor node [7]

where ε_{fs} and ε_{amp} are the energy consumption factor of amplification in two radio models, E_{elec} is the power dissipated per bit to run the transmitter or receiver circuit, d_0 is the threshold transmission distance for the amplification circuit. The E_{elec} energy depends on several factors such as digital coding, modulation, filtering and spreading of the signal. In addition, energy can also be lost during data signal processing such as aggregating, in which E_{DA} denotes energy loss for merging single data signal.

4. Proposed THC protocol

In this section, a Two Hop Clustering (THC) protocol for WSN is proposed to increase the energy saving in sensor nodes. The random deployment of the sensor nodes in the THC protocol is as shown in Figure 2. In THC, sensor nodes are selected as CH based on two parameters: remaining energy and node degree. The node degree refers to number of 1-hop and 2-hop neighbors of a node. The sensor nodes are also choose the CH, which is near to them.

THC protocol activities are divided into three phases namely: Initial, distributed node clustering and data transmit.

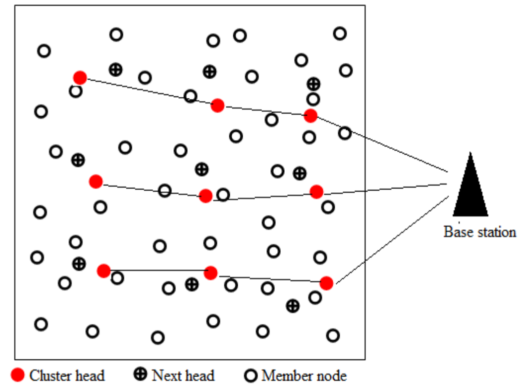

Figure 2. Network model of THC protocol

4.1 Initial phase

During this phase, the protocol allows the member nodes to create 1-hop and 2-hop neighbors table, fixes the cluster area and selects the initial CHs for the first round. This phase consist of two stages: *neighbor discovery* and *CH selection stage*

Neighbor discovery stage: The protocol performs the initial phase only in the beginning of the network operation. The base station broad cast a beacon signal into the network to initiate the neighbor discovery. Upon receiving this beacon signal, all the nodes broadcast a *START* into the network. The message has node ID, location information and hop count initialized 2 with minimum transmission power to know about their 1-hop and 2-hop neighbors. When a node receives a *START* message from its 1-hop neighbor, it decrement the hop count by 1, adds its information and the same is rebroadcasted. When a next neighbor node receives this message, the hop count reaches 0, the message is discarded and the node stores 1-hop, 2-hop neighbors information. This way each node in the network creates and maintains 1-hop and 2-hop neighbors. The neighbor discovery is terminated within the predetermined interval determined by the base station.

CH selection stage: At the end of neighbor discovery, the base station fixes the required number of clusters depending upon the physical area and initial cluster heads by randomly selecting a node from each cluster. These initial CHs node ID and center of each cluster is broadcasted into the network.

4.2 Distributed node clustering phase

During this phase, the CHs create node clustering and the current CHs selects the CH_{next}'s for the next round. This phase has *advertisement stage* and *next head selection stage*.

Advertisement stage: During this stage, the eligible CHs broadcast an *ADV_HEAD* message which contains node ID and location information to all the member nodes within its transmission range. When a member node receives more than one *ADV_HEAD* message from neighboring CHs, the node will decide which cluster it should join. In such situation, the node chooses the CH near to it. After deciding which CH node it should join, the member nodes transmit a *JOIN_CH* message to its 1-hop neighbor in the direction of CH. The *JOIN_CH* message contains the node ID, residual energy, number of neighbors (i.e. 1-hop and 2-hop neighbors) and ID of the CH to which it joins. The 1-hop neighbors add their information to the received message and finally forward it to the CH.

Next head selection stage: The CH nodes consider the *JOIN_CH* messages, which belong to them. This is simply decided by searching their ID in the *JOIN_CH* messages. Once CH node learns about the number of member nodes, it select the CH_{next}'s for the next round based on the residual energy and number of 1-hop and 2-hop neighbors. The nodes with highest residual energy and neighbor are selected as CH for the next round. These CH_{next}'s are simply behaves like normal member node during the current round. The CH_{next}'s takes the role of CH for forming the new node clustering during the next round.

4.3 Data transmit phase

In this phase, the CHs create a time slots, gather information from the member nodes and finally transmit the aggregated data to the base station. This phase has the following stages: *schedule creation stage*, *data gathering stage* and *routing stage*.

Schedule creation stage: During this stage, CHs creates time slot for each node telling when it can transmit the data. This helps in data collision from the different nodes. Based on the number of member nodes, CHs generate TDMA time slot for each node in the cluster. Finally, CHs transmit $TDMA\_CH_{next}$ message into the network. The $TDMA\_CH_{next}$ message contains the time slot for each node and their ID and also next head ID. When a node receives this message, after knowing its time slot, the node can go to sleep mode and saves energy.

Data gathering stage: The CH nodes collect the sensed data from all the member nodes during their time slot. The node which is 2-hop away sends its data to the 1-hop neighbor. The 1-hop neighbor adds its data to the received one and finally transmits it to the CH. Since nodes can wake up and send their data during their time slots and all other time they can be in sleep mode. This significantly reduces the energy consumption in nodes and greatly contributes towards maximization of network lifetime. The CH node must keep their transceiver on thought the phase and they loses more energy compared to member nodes of the cluster.

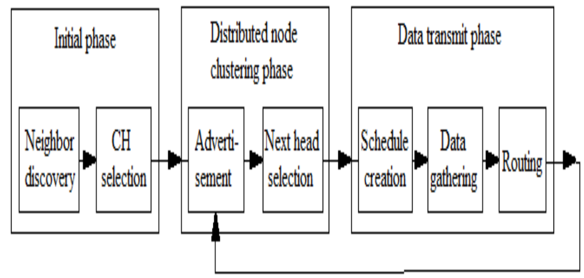

Figure 3. THC protocol operations

Routing stage: During this phase, the CH nodes aggregate the data received from the member nodes. This reduces the number of transmissions to the base station and also energy consumption. The CH nodes send their data to the base station using multi-hop communication. The faraway CHs transmit their data to the nearest CHs in the direction of base station. These CHs add their data and transmit the same to the next level CHs. This way the data finally reaches the base station. Since direct communication to the base station is more expensive than multi-hop method. The multi-hop technique also helps in distribution of energy loads among the CH nodes.

At the end of the routing stage, the network enters into new round of node clustering by the CH_{next}. The CH_{next} nodes initiates' next round of node clustering by broadcasting advertisement message as explained in the distributed node clustering. In order to synchronize the clustering process, the base station broadcast beacon signal into the network after completion of every round. The Figure 3 shows THC protocol operations.

5. Performance Evaluation

The performance of the THC protocol is evaluated by randomly deploying the 100 sensor nodes over a square area of 100m x100m. The results are compared with the 1-hop clustering and LEACH [7] protocol. The Table 1 gives the parameter used for the evaluation of THC protocol.

Lifetime is one of the important parameter in evaluating the performance of any WSN protocol. The life time of the THC protocol is evaluated by considering the parameters like death of first node, death of last node, number of alive nodes and total residual energy of the network over the simulation round. From the Table 2, it is observed that the first dead node (FDN) is reported earlier in the LEACH and 1- hop than the THC protocol. The energy efficient techniques employed in the THC protocol results in the longer network lifetime and it is shown in Table 2 that last dead node (LDN) is seen in proposed THC has longer lifetime.

Parameter	Symbol	Values
Sensor area	MXM	100m X 100m
Number of nodes	N	200
Packet size	p	500 bytes
Base station location	(x,y)	(50, 75)
T_x/R_x electronic constant	E_{elec}	50 nJ/bit
Amplifier constant	ε_{fs}	10pJ/bit/m^2
	ε_{amp}	0.0013 pJ/bit/m^4
Initial Energy	E_o	0.5 joule
Energy for Data	E_{DA}	*5 nJ/bit/signal*

Table1: Parameter set for the evaluation of THC

	FDN	LDN
LEACH	575	1125
1- hop	603	1205
THC	784	1342

Table 2: First dead node and Last dead node

The proposed THC protocol employs 2-hop clustering method, which reduces the amount of power required by the member node to communicate with the CH nodes. All the 2-hop away member nodes forward their data to the CH nodes via 1-hop nodes; this significantly reduces the amount of energy consumption. THC uses the uses next head concept, which reduces the number of negotiation messages required after every round to select the CH. The THC also uses multi-path communication to send data to the base station. This achieves almost uniform distribution of energy loads among the CHs in the network. Figure 4 shows network lifetime in terms of number of alive nodes over simulation rounds. It is observed that the sensor nodes in the THC protocol deplete their energy slowly compared to LEACH and 1-hop clustering, thus increased lifetime.

The Figure 5 shows the total residual energy of the nodes in the network. The total residual energy refers to the sum of energy in of all the nodes after every simulation rounds. Form the result it is observed that the energy dissipation in LEACH and 1-hop clustering is quicker compared to proposed THC protocol. So, the proposed THC protocol performs better than LEACH and 1-hop schemes energy efficiency and simplicity.

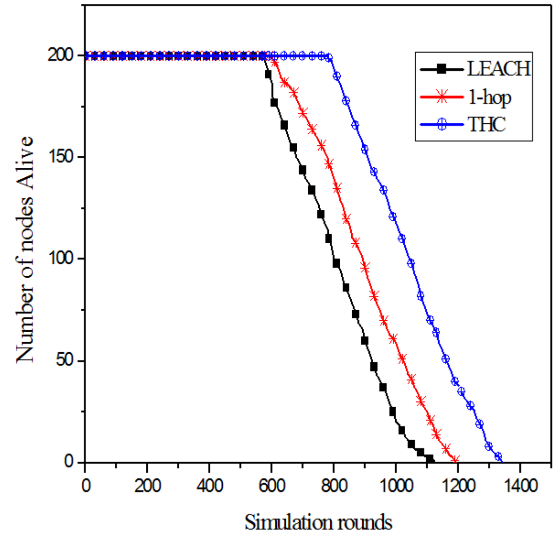

Figure 4. Network lifetime

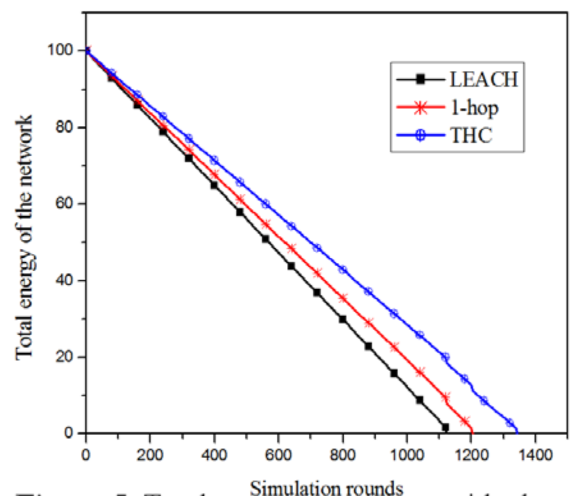

Figure 5. Total residual energy of the network

Conclusion

The novel energy efficient clustering protocol is proposed in this research work. The protocol operation starts with the initial CHs selected by the base station and rotation of these CHs performed in distributed way. The next head approach reduces the amount of negotiation required to select new CHs after every rounds. The rotation of the cluster head evenly distributes the energy load among the nodes. This considerably contributes towards maximizing the network lifetime. The THC protocol transmits its aggregated data to the collecting base station using multipath communication compared to direct communication in LEACH. The results show that THC protocol performs very well and increases the network lifetime.

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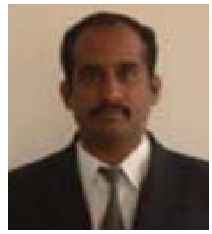

Babu N V obtained his B.E degree from Visvesvaraya Technological University, Belagum and M.Tech from Dr MGR University, Chennai. He is working as Associate Professor in EEE department, SJBIT, Bangalore. Currently he is pursuing Ph.D under the guidance of Dr Puttamadappa C from Kuvempu University, Shimoga.

C Puttamadappa obtained his B.E degree from Mysore university, PG degree from Bangalore University and Doctral Degree from Jadavpur University, Kolkatta. He is working as Professor & Principal, Sapthagiri College of Engineering, Bangalore. His research interest area is Devices & Networks.

Bore Gowda S. B received B.E. degree in Electronics and Communication from Mysore University and M.Tech from Visvesvaraya Technological University, Karnataka and Doctral Degree from Manipal University. He is currently serving as Assistant Professor (Selection Grade) in the Department of Electronics and Communication Engineering, Manipal Institute of Technology, Manipal. His main research interests include wireless sensor networks and embedded system design.