IJCSI International Journal of Computer Science Issues, Vol. 7, Issue 4, No 1, July 2010
ISSN (Online): 1694-0784
ISSN (Print): 1694-0814

Novel Cluster Based Routing Protocol in Wireless Sensor Networks

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Abstract

In this paper, we propose a novel Cluster Based Routing Protocol (CBRP) for prolong the sensor network lifetime. CBRP achieves a good performance in terms of lifetime by balancing the energy load among all the nodes. In this protocol first we Cluster the network by using new factors and then construct a spanning tree for sending aggregated data to the base station which can better handle the heterogeneous energy capacities. Simulation results show that CBRP can remarkably extend the network lifetime and amount of data gathered.

Keywords: *Sensor Network, Network Lifetime, Spanning Tree, Energy, Data Gathering.*

1. Introduction

A wireless sensor network consists of tiny sensing devices, which normally run on battery power and randomly deployed for detecting and monitoring tasks [3]. One of the typical applications in this network, gathering and sending sensed data to the base station [3]. The main constraint of sensor nodes is their very finite battery energy, while limiting the lifetime. For this reason, the protocol running on sensor networks must efficiently reduce the node energy consumed in order to achieve a longer network lifetime [3]. Data gathering (collecting the sensed information from the sensor nodes and routing the sensed information) has to be done in an energy efficient way to ensure good lifetime for the network. Hence, data gathering protocols play an important role in wireless sensor networks keeping in view of severe power constraints of the sensor node [1]. Therefore, a major part of the research work concentrates on extending life time of networks by designing energy efficient protocols, which is the core of this paper. In this paper, we propose a distributed and energy efficient protocol, called CBRP for data gathering in wireless sensor networks. CBRP, define new algorithm for cluster head election that can better handle heterogeneous energy circumstances than existing clustering algorithms which elect the cluster head only based on a node's own residual energy. After the cluster formation phase, CBRP constructs a spanning tree over all of the cluster heads. Only the root node of this tree can communicate with the sink node by single-hop communication. Because the energy consumption for all communications in in-network can be computed by the free space model, the energy will be extremely saved, and Network lifetime is extended. The rest of this paper is organized as follows: In the next section we will introduce the related work; in section 3 we will discuss proposed algorithm; section 4 presents spanning routing tree; simulation results and performance evaluation is given in section 5; the conclusion and future works presented in sections 6.

2. Related Works

In the sensor network, sensor node can communicate with the base station directly or through the cluster head, or through other relaying nodes. In a direct communication, each node communicates directly with the base station. When the sensor network is large, the energy for communicating with the base station is correspondingly large. Hence, some nodes far apart from the base station will quickly run out of energy [2]. The other scheme is the clustering; where the nodes are grouped into clusters and one node of the cluster send all gathered data from the nodes in its cluster to the base station. The LEACH (Low-energy Adaptive Clustering Hierarchy) is a self-organizing and adaptive clustering protocol that uses randomization to distribute the energy load evenly among the sensor nodes

[2], [5]. In the LEACH scheme, the nodes organize themselves into a local cluster and one node behaves as a local cluster head. LEACH includes a randomized rotation of the high energy cluster head position such that it rotates among the sensors. This feature leads to a balanced distribution of the energy consumption to all nodes and makes it possible to have a longer lifetime for the entire network. PEGASIS (power-efficient gathering in sensor information systems) [4],[6] is an improvement over LEACH by making only one node transmit data to the base station in this protocol every node transmits it's data only to its nearest/neighbor node in the data fusion phase. PEGASIS starts with the farthest node from the base station. The chain structure is built up using greedy lookup algorithm for gathering data in each round the chain leader aggregates data and transmit it to the base station. In order to balance the overhead involved in communication between the chain leader and the base station, each node in the chain takes turn to be the leader.
So there is no centralized cluster formation mechanism in PEGASIS [4], [6] thus each node has to spend additional energy for performing data aggregation to achieve hierarchical distribution of energy. Sh. Lee et al. proposed a clustering algorithm CODA [7, 8] in order to relieve the imbalance of energy depletion caused by different distances from the sink. CODA divides the whole network into a few groups based on node's distance to the base station and the routing strategy, each group has its own number of clusters and member nodes. CODA differentiates the number of clusters in terms of the distance to the base station. The farther the distance to the base station, the more clusters are formed in case of single hop with clustering. It shows better performance in terms of the network lifetime and the dissipated energy than those protocols that apply the same probability to the whole network. However, the work of CODA relies on global information of node position, and thus it is not scalable. In HEED, author introduces a variable known as cluster radius which defines the transmission power to be used for intra-cluster broadcast [9]. 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. The authors in [10] determine the optimal cluster size in network for analyzing the problem of prolonging network lifetime. For a general clustering model, their algorithms maximize lifetime or minimize energy consumption by finding the optimal sizes of the cells. According this result, they propose a location aware hybrid transmission scheme that can further prolong network lifetime. ACE clusters the network in a constant number of iterations using the node degree as the main parameter. Soro et. al. [11] proposed an unequal clustering size model for network organization, which can lead to more uniform energy dissipation among cluster head nodes, thus increasing network lifetime.

3. Proposed Algorithm

The operation of CBRP is divided into rounds and each round contains two phases, set-up phase and steady-state phase. In the set-up phase, clusters are generated and then in the steady-state phase, routing tree constructed and aggregated data are sent to the sink node. In CBRP protocol, each node maintains a neighborhood table to store the information about its neighbors.

3.1 Cluster head election

In the set-up phase, each node broadcasts the Node_Residual_Msg within radio range r, which contains residual energy of node. All nodes within the radio range of one node as the neighbors of this node. Each node receives the Node_Residual_Msg from all neighbors in its radio range and updates the neighborhood table and generates CHSV (Cluster Head Selection Value) using formula 1.

$$CHSV_i = \frac{RE_i}{\sum_{All\ Neighbours\ j\ of\ i}(TE_j * K)} - \frac{RE_i}{\sum_{All\ Neighbours\ j\ of\ i}((Dis_j)^2 * TP * K)} \qquad (1)$$

The used parameters in formula 1 are described in table1.

Table 1: Parameters of formula 1

Parameter	Description
RE_i	Residual energy of node i
TE_j	Required energy for sending 1 bit data from node i to node j
K	Number of bits to be sent from node i to node j
Dis_j	Distance from node i to node j
TP	Transfer Power for 1 bit

For instance, see Figure 1, nodes A~D within the radio range r. As shown in figure 1 the nodes A~D within each other radio range and are neighborhood. According to the formula 1, in radio range r, node A has largest CHSV and elected as a cluster head.

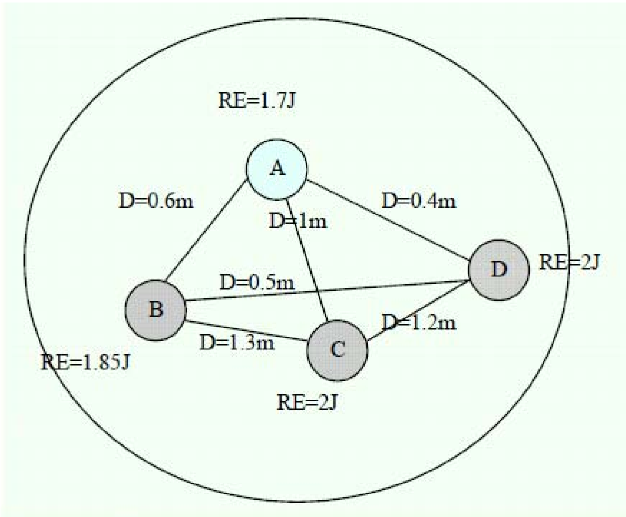

Fig. 1 Cluster head election

In the following we compute CHSV for nodes A~D. In computations, parameters K and TP are given 1.

$$CHSV_A = \frac{1.7J}{0.6^2 + 0.4^2 + 1^2} = 1.118$$

$$CHSV_B = \frac{1.85J}{0.6^2 + 1.3^2 + 0.5^2} = 0.804$$

$$CHSV_C = \frac{2J}{1^2 + 1.3^2 + 1.2^2} = 0.484$$

$$CHSV_D = \frac{1.7J}{0.4^2 + 0.5^2 + 1.2^2} = 1.081$$

Because the Cluster heads always keep rotating in whole lifetime of network, in proposed protocol we have uniform energy consumption among all nodes. Cluster formation pseudo code is shown follow.

for all nodes
1. *Set status ready*
2. *Broadcast Node_Residual_Msg to all neighbor nodes*
3. *Receive Node_Residual_Msg from all neighbor nodes*
4. *Compute distance from all neighborhood*
5. *Update neighborhood table*
6. *Compute CHSV*
7. *if CHSV > all neighborhood CHSV*
8. *Status* ***Cluster Head***
9. *else*
10. *{*
11. *Status* ***Cluster Member***
12. *if (node exist in more than one cluster head range)*
13. *Node joins to closer cluster head*
14. *}*

3.2 Routing tree generation

After clustering, in steady-state phase, cluster heads broadcast within a radio rang r the Cluster_Head_Residual_Msg which contains node residual energy. The cluster heads compute PSV (Parent Selection Value) by using formula 2.

$$PSV_i = \frac{RE_i}{\sum_{All\ Neighbours\ j\ of\ i}\left(\frac{Dis_j}{RE_j}\right)} \quad (2)$$

In each cluster heads range, the node has largest PSV selected as parent node and other nodes become child of it, and send the CHILD message to notify the parent node. Finally, after a specified time, a routing tree will be constructed; whose root has the largest PSV among all cluster heads.
The used parameters in formula 2 are described in table2.

Table 2: Parameters of formula 2

Parameter	Description
RE_i	Residual energy of node i
RE_j	Residual energy of node j
Dis_j	Distance from node i to node j

For Instance, assume that we have a network with cluster head nodes A~E, as shown in figure 2. For efficient energy consumption, CBRP construct a tree on cluster heads. First each cluster head broadcast Cluster_Head_Residual_Msg, which contains residual energy of cluster head. Each cluster head after receiving this massage, update its neighborhoods table and compute PSV according formula 2 and then broadcast PSV_Msg to the all neighborhoods.
According to the figure 2, nodes C, D, and E receive PSV_Msg message from another and because of node C has largest PSV rather than nodes D and E, it selected as parent node of nodes D and E. As so, nodes A, B, and C receive PSV_Msg message from another and because of node A has largest PSV rather than nodes B and C, it selected as parent node of nodes B and C.
Finally routing tree is constructed. In this tree we have one node (root node / A) that communicates directly with the base station. Routing tree formation pseudo code is shown follow.

for all Cluster Head nodes
1. *Broadcast Cluster_Head_Residual_Msg to all neighbor nodes*
2. *Receive Cluster_Head_Residual_Msg from all neighbor nodes*
3. *Compute distance from neighborhood*
4. *Update neighborhood table*
5. *Compute PSV*
6. *if (PSV > all neighborhood PSV*
7. *Status* ***Parent Node***
8. *else*
9. *Status* ***Child Node***
10. *Parent nodes broadcast TDMA to their childs*

In the following we compute PSV for nodes C, D, E and nodes A, B, C.

$$PSV_C = \frac{1.8J}{\frac{1.2}{1.0} + \frac{0.8}{1}} = 1.227 \qquad PSV_A = \frac{2J}{\frac{1.5}{1.5} + \frac{1}{1.0}} = 1.285$$

$$PSV_D = \frac{1.8J}{\frac{1.2}{1.8} + \frac{1}{1}} = 1.08 \qquad PSV_B = \frac{1.5J}{\frac{1.8}{2} + \frac{2}{1.8}} = 0.805$$

$$PSV_E = \frac{1J}{\frac{0.8}{1.8} + \frac{1}{1.8}} = 1.0 \qquad PSV_C = \frac{1.8J}{\frac{1}{2} + \frac{2}{1.5}} = 0.981$$

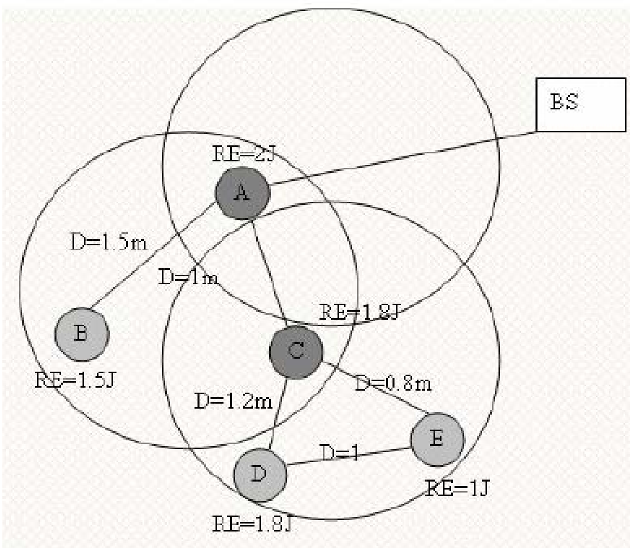

Fig. 2 Spanning tree generation

4. Simulation

In order to performance evaluation of CBRP protocol, we developed our simulator in MATLAB. Our sensor network consists of N nodes that randomly dispersed in 100 × 100 of square fields with a single base station. All parameters of simulations are shown in Table 3. Every simulation result shown below is the average of 100 independent experiments where each experiment uses a different randomly generated uniform topology of sensor nodes.

Table 3: Parameters used in simulations

Parameter	Value
Network Filed	(0,0)~(100,100)
Node numbers	100~500
Cluster radius *r*	40 m
Sensing radius *rs*	15 m
Sink position	(50,200)
Initial energy	3 J
Data packet size	256 Bytes
Broadcast packet size	10 Byte
Ethreshold	0.01 J
Eelec	50 nJ/bit
efs	10 nJ/bit/m2
eamp	0.0013 pJ/bit/m4
EDA	5 nJ/bit/signal
Threshold distance *d0*	80 m
Data Cycles per round(*L*)	5

Figure 3 shows the network lifetime in three protocols CBRP, HEED, LEACH with different number of nodes.
As shown in figure 3, independent of nodes density CBRP act better than other protocols. This may due to the following reasons. First, alternating the role of cluster heads can balance energy consumption among cluster members. Second, constructing spanning tree on cluster heads extremely reduce energy consumption in cluster heads. Third, CBRP considered distance and residual energies of nodes and elect optimum cluster heads that can save more energy in nodes.
Figure 4 shows the total remaining energy of the network in three protocols CBRP, HEED, LEACH for 20 rounds with 100 nodes. As shown in figure 4, CBRP balances the energy consumption among cluster heads and as a result more energy saved in network.
Figure 5 shows data delivery latency in two protocols CBRP and PEGASIS. As shown in figure 5, CBRP has less latency rather than PEGASIS.

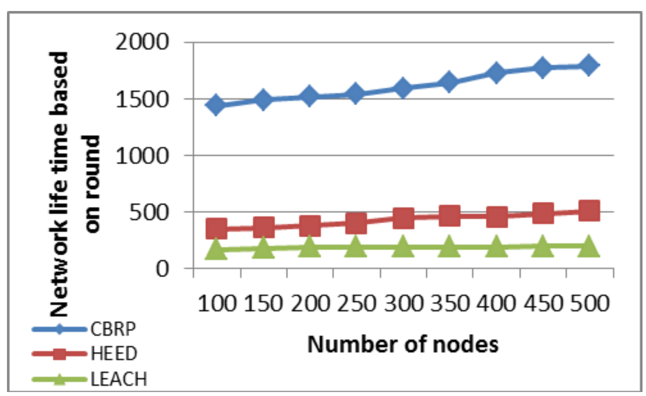

Fig.3 Network lifetime

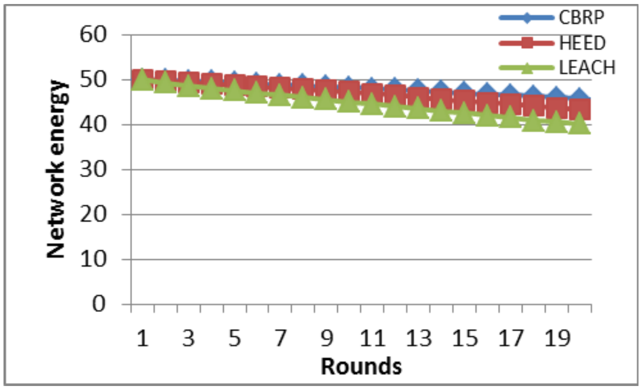

Fig. 4 The total remaining energy of the network

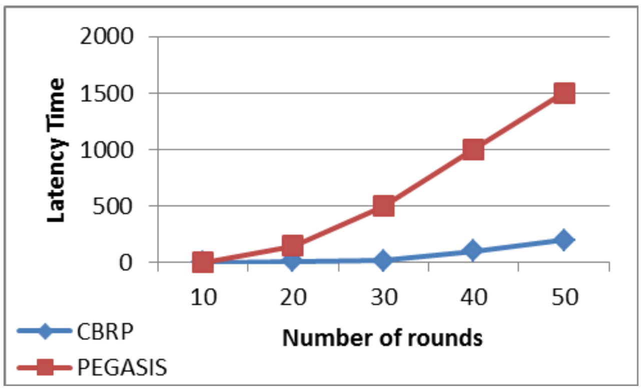

Fig. 5 Time requirement for multi hop transmission data to the base station

5. Conclusion

In this paper, we propose a novel Cluster Based Routing Protocol for prolong the sensor network lifetime. CBRP clusters sensor nodes into groups and builds routing tree among cluster heads for energy efficient communication. Simulation result shows that, CBRP act better than other protocols in terms of optimizing cluster heads energy consumption, amount of data gathered, and extending network lifetime.

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