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A Chain Structure-Based Uneven Cluster Routing Algorithm for Wireless Sensor Networks (CSBUC)

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Abstract: One of the most important goals in WSN research is to decrease energy consumption and maximize network life to meet application requirements. Therefore considering the energy efficiency of nodes in the networks has a very important theoretical and practical significance. This study presents a chain structure-based uneven cluster routing algorithm. In this algorithm, the node residual energy and regional node density are used as an ability of cluster-head competition, the nodes of big residual energy have great possibility of becoming the cluster head. The candidate cluster head calculates, according to the distance between the node and base station, the competition radius and constructs number of unequal size cluster. The size of cluster near the base station is smaller than that away from the base station. Cluster members organize into cluster by chain structure, the dynamic multi-hop routing transmit data is used by cluster-heads. The simulation results show that the new algorithm can effectively reduce network energy consumption, better balance the energy consumption of network nodes and prolong the network lifetime significantly.

Key words: Wireless sensor networks, unequal cluster, chain structure, multi-hop

INTRODUCTION

Wireless Sensor Networks (WSN) are comprised of spatially distributed sensor nodes where each node contains units for sensing, processing and transferring the data. In general, sensor nodes are assumed to have limited processing power, stringent memory capabilities and highly constrained energy resources (Pottie and Kaiser, 2000). Therefore, designing an effective communication strategy to prolong the lifetime of the network has become the core issue. One of the most important goals of designing the routing communication protocols is to reduce the energy consumption of node and prolong the lifetime of the networks.

RELATED WORK

There have been many researches for energy efficient data communication protocols in the area of sensor networks. The existed routing protocols can be divided into two categories by network structure Intanagonwiwat *et al.* (2000) Flat routing protocols, the status of all nodes are equal but its scalability and real time is poor and maintaining the dynamic changes of routing need a lot of control information; 2) Clustering routing protocols it is divided into many regions according to cluster its network do not need to maintain the complex routing information it has a good scalability and easy to adopt data fusion technology, decrease data redundancy and communication traffic in the network but the defect is that cluster head may be a bottleneck of the networks.This studies about the clustering routing protocols. In recent years, researchers have proposed a lot of clustering protocols for WSN.

LEACH Heinzelman *et al.* (2002). is a low power consumption adaptive routing algorithm which is specially designed for wireless sensor network by Wendi Heizelman in MIT electronic engineering and computer science department in 2000. Compared with direct communication way, LEACH protocol can prolong the lifetime of the networks by four to eight times. PEGASIS Lindsey and Raghavendra, 2002. protocol is established on the basis of the LEACH. PEGASIS protocol effectively avoids the additional costs caused by the LEACH frequently choosing cluster head. A node only communicates with its nearest node, so it can reduce the energy consumption and greatly improve the lifetime of the networks. But PEGASIS protocol has long time delay. So it must have big data compression ratio.

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ALGORITHM

Network model and energy model: The sensor network has the following properties:

- Sensor nodes are randomly and uniformly dispensed in the rectangular network and can not move
- Sensor nodes are all isomorphism which have the same data processing, communication ability and can direct communication with the base station
- The node has a power control function, the power of the local transceiver can be adjusted based on the distance of the receiving node
- The data collected by adjacent nodes in the network has data redundancy, so each node has data fusion function
- The node can not be charged. When the initial energy of the node is exhausted, the node is death. Each node has a unique Identity (ID)
- Sink-node has strong computing power, large storage capacity and the wireless signal can cover the entire sensor network

This study uses the radio energy model as the same of the literature Bandyopadhyay and Coyle (2003). Type (1) is the expression of energy consumption of transmitting a k-bit data to the distance of d. E_{elec} is the launch circuit energy loss, εfs and εamp were the energy power amplifier in the two channel model. Type (2) is the expression of energy consumption of receiving k-bit data. It caused only by circuit loss.

$$E_{Tx} = \begin{cases} k * E_{elec} + \varepsilon_{fs} * d^2, d < do \\ k * E_{elec} + \varepsilon_{amp} * d^4, d \geq do \end{cases} \quad (1)$$

$$E_{Rx} = k * E_{elec} \quad (2)$$

In addition, the fusion data will also consume energy. E_{DA} is a signal of energy consumption of fusing a bit data. The node will fuse the data which collected by itself and accepted from it near node into a fixed-length data package and then send to the next node of cluster. When the node fuses a k-bit data it consumes energy:

$$E_c = K \times E_{DA} \quad (3)$$

Algorithm description: Because of the limitations of energy of wireless sensor, a good clustering routing algorithm should have the following requirements.

Balance node energy consumption and avoid single node energy exhaustion early. The dispersion of cluster head must be good. The election of cluster head should be fast convergence. Reduce the protocol control information quantity as far as possible.

The CSBUC algorithm improves the cluster head election mechanism for the LEACH weakness of cluster head uneven distribution and the small surplus energy node may be elected the cluster head. Presenting a new local cluster head competition methods which based on weights. When cluster head nodes is elected, we should consider the information of the regional nodes intensity and the node surplus energy comprehensively. Its cluster weight values is defined as the following expression:

$$W_i = a\frac{E_i}{E_n} + (1-a)(N_{nbr} * P_{int}) \quad (4)$$

where, W_i is the cluster weights of competition, E_i is the current residual energy of node N_i , E_n is the initial energy of nodes, Pint is the most optimal cluster head node numbers for Wireless Sensor Networks, N_{nbr} is the number of its neighbor nodes, α is a constant which less than 1, this paper takes α as 0.85 in following simulations.

CSBUC algorithm has changed the traditional method of fixed cluster size and calculated the size of the campaigned radius according to its distance to the Bs. Competition radius is defined as follows:

$$R_i = (1 - c\frac{d_{max} - d_{(N_i,Bs)}}{d_{max} - d_{min}}) * R_c \quad (5)$$

where, R_i is node N_i campaigned radius, R_c is a constant, In this article ,we select c as 0.5, d_{max} is the maximum distance of regional node to the Bs, d_{min} is the minimum distance of regional node to the Bs, d(N_i, Bs) is distance of node between N_i and Bs.

We can see from the last two expressions that the nodes are more likely to become a cluster head which in the area of higher node intensity and have larger surplus energy and near the base station cluster radius is smaller, partitions of the region are more.

In order to determine the number of optimal cluster head node in the network, we introduce the expression of the number of cluster head nodes it is proposed in literature. Where Pint is the optimal numbers of cluster head nodes which the wireless sensor networks required. N denotes the total number of nodes in the network, ε_{fs} and ε_{amp}, respectively denote the power amplifier loss of energy consumption in the free space model and multi-path attenuation model, the M is length of the node coverage area, d(N_i, Bs) is node distance between N_i and Bs.

$$P_{int} = \sqrt{\frac{N}{2\pi}}\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}}\sqrt{\frac{M}{d^2_{(N_i,Bs)}}} \quad (6)$$

Algorithm implementation steps: To better describe algorithm, the definition of the symbols in this study is as follows:

- **Node_nbr:** Neighbor nodes set is defined that nodes within the area of this node as the center and R as the radius, the initial value is empty. Node_higher: Node Ni's neighbor nodes which the weights is higher than its owns and not covered ,the initial value is empty. Node_ch: Candidate cluster head node which in node Ni's neighbor set, the initial value is empty. Node_covered: The set is that candidate cluster head covered nodes, the initial value is empty. Node_next: It stores the ID number of the next hop node in the data transfer. Is_covered: The signs of the node whether or not is covered, the initial value is zero. "Coverage" is defined that at least one cluster head node among its neighbor set. Is_ch: The sign of the node whether or not is a cluster head node, the initial value is zero

The operation of CSBUC is broken up into rounds as the same as LEACH protocol, each round divided into two periods, one is the cluster establishment period, another is the stable working period. Clustering algorithm timing was inspired, we assume that clustering is completed over time of Tsetup and then come into stable working period, T_{work} is defined the time length. Allocation of the time shows in Fig. 1:

In the network deployment phase, the Bs with a certain transmit power broadcast messages within the network, each node calculates the approximate distance to the Bs according to the received strength of the signal, the distance is an important information to construct cluster of unequal size.

In the period of establishing cluster of each round, each node broadcasts Node_message, that contains this Node ID number and weights, as the fixed radius R and collect neighbor Node ID and weights information which stores in Node_nbr set. Then, this node stores the neighbor node ID number, that its weights is higher than this node and the two-node distance is less than Ri, in its Node_higher set. After wait time T1, T1 shall set up long enough so that the node can receive all messages which send by other nodes that within the radius R of communication, each node checks its Node_higher set. If the node's Node_higher set is still null it shows that this node is the highest weights within the neighbor nodes. Then this node stores ID Number of neighbor nodes that within the R_i of communication, then it claims it is a candidate cluster head, broadcasts Head_message as the fixed radius R distance and sets Is_covered and Is_ch sign with 1. The Head_message contains the node ID number, weights value and its node Node_covered set information. When the non-cluster head node receives Head_message it will store the ID number and weight of the sender node in Node_ch set and update Node_higher set according to the received Node_covered set information. If the received information of the Node_covered in Head_message contains its ID, sets its is_covered with 1.Then this node checks the Node_higher set. If this node Node_higher set is empty, broadcasts Head_message as the fixed radius Rc distance and repeats the above-mentioned process. The fake code shows below:

- is_head = flase
- is_covered = flase
- Broadcast Node_message (ID W)
- On receiving Node_message(ID W_i) from N_i
- If distance (N_i,N_j)< R_c
- Add N_i to N_j.Node_nbr
- If W_i>W_j
- Add N_i to N_j.Node_higher
- End if
- End if
- Wait T_1
- If Node_higher = empty
- is_head = true
- End if
- While is_head = true then do
- If is_covered = flase
- Broadcast head_message (ID, W_i, N.Node_covered)
- is_covered = true
- End if
- On receiving head_message (ID, W_i, N.Node_covered) from N_i
- Add N_i to N_j.Node_ch
- If N_j _° N_i.Node_covered
- is_covered = true
- End if
- Upate Node_higher
- If Node_higher = empty
- is_head = true
- End if
- End While

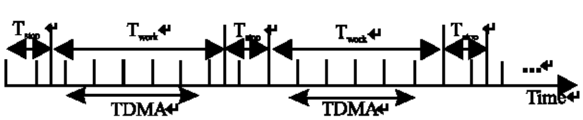

Fig. 1: Time assignment

After time T_2(T_1<<T_2), cluster head election is completed, each non-cluster head node selects the cluster head that requires the minimum communication energy and sends a JOIN (this node ID number) messages.

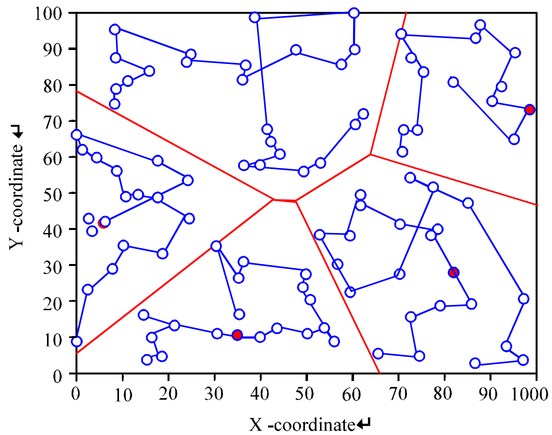

Fig. 2: Cluster structure

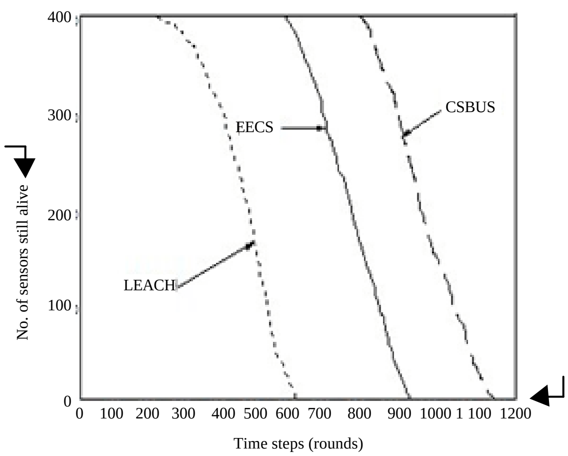

Fig. 3: System lifetime

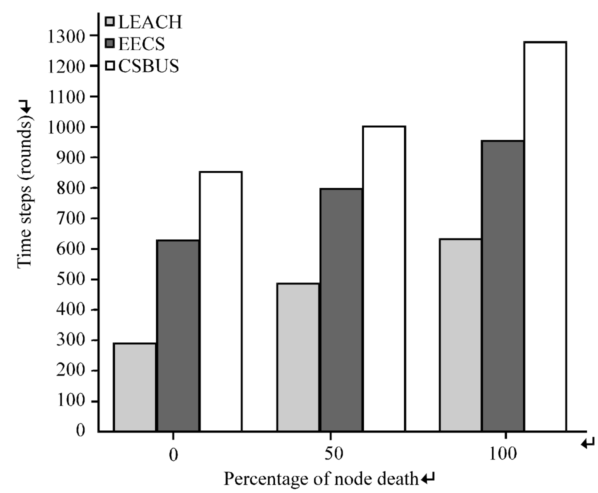

Fig. 4: System lifetime death node comparison

After the cluster head receives the all of the JOIN messages, then connects the cluster members into a chain according to distance from the Bs and broadcasts a Cluster_chain (this cluster members into chain order ID and the TDMA schedule) messages as the fixed radius R distance. After the non-cluster head node receives the Cluster_chain messages from its cluster head it will find its next jump node ID number and store in the Node_next.

After the completion of clustering, cluster head broadcasts Routing (including node ID and weights) messages as the fixed radius $2R_c$ distance. After cluster head nodes receive Routing messages, choose the weights of the minimum cluster head node as the next hop relay node. The weights of Routing messages is defined:

$$W_{ic} = \frac{E_n}{E_i} * d(N_i, Bs) \quad (7)$$

In the stable working period, nodes transmit the data to the next node according to the TDMA schedule and transmit the node to the cluster head from the both ends of the endpoint in the chain. The cluster head transmits data to the base station by multi-hop way.

SIMULATION AND CONCLUSION

In order to test the performance of the CSBUC algorithm, this paper uses MATLAB simulation of the LEACH, EECS and CSBUC protocol Qiao *et al.* (2011). In the experiment, this paper assumes that 400 sensor nodes randomly distributed within the rectangular area of 200m *200m, the initial energy of each node is 0.5J, the Bs position is in (100,250), packet size is 2000 k-bit, All nodes are static.

Figure 3 simulates the lifetime of the network nodes. From the Fig. 3 we can see that the death time of the first node of the CSBUC is greatly longer than LEACH and EECS. The network lifetime of the CSBUC prolongs about 46% compared with the LEACH and about 26% compared with the EECS. This indicates that CSBUC can effectively prolong the network lifetime. From the Fig. 4 we can see, the time that the 5 and 50% of the nodes die averagely delays 200% than LEACH and 35% than PEGASIS. This shows that in the same network survival time the death nodes of CSBUC are much fewer than LEACH and EECS. From the energy consumption figure we can find that the CSBUC energy consumption curve is gentler than EECS and LEACH. This shows that CSBUC has higher energy efficiency.

This study proposes CSBUC. Its significant features are:

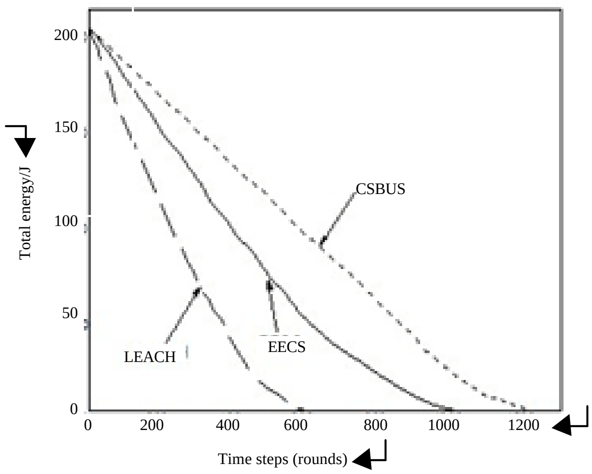

Fig. 5:Total energy consumption

- This algorithm elects cluster head by using local cluster-head competition mechanism which based on the weights, so the elected cluster head dispersion is good and it avoids more than one cluster head in the same area
- Adopt a non-uniform way clumping, cluster radius near the base station is smaller and partitions of the region are more. More cluster head nodes forwarded packets, so it can effectively avoid the impact of the "hot spots" and balance the energy consumption of the entire network nodes
- In the stage of clustering, cluster members organize into clusters by chain structure, so cluster members only communicate with the nearest cluster member and all nodes only receive and send data once. It can further reduce the distance of the node communication, reduce the burden of the cluster head and balance the energy consumption of cluster heads and ordinary nodes
- The data transfers between the clusters using multi-hop data forwarding it can reduce the number of cluster head which directly communicates with the base station
- In the design of experiments ,it is assumed in the ideal communications environment which did not given much thought of the external signal interference and data communications security

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