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A Kind of Energy-Efficient Clustering Algorithm for Wireless Sensor Networks

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Abstract: To solve the limited energy problem of nodes in the wireless sensor networks (WSN), a rapid Energy-efficient Clustering Algorithm (EECA) has been proposed. In the initialization stage of the system, the deployment region is rapidly divided into multiple clusters, then the node self energy consumption ratio and degree are chosen as the weigh criterion for cluster head selection, consequently the re-election of a cluster head becomes a locally triggered action. Due to the re-election of cluster head node is only proceeded within the cluster, its complexity and computation load has been greatly reduced. The theoretical analysis indicates that the information and time complexity of EECA cluster formation algorithm are O(1), which means the algorithm has nothing to do with the network size n and has a small cost. Simulation results indicate that EECA can provide better load-balancing performance and less protocol overhead of cluster head nodes. Comparing with LEACH protocol, EECA can reduce the energy consumption and prolong the network lifetime. *Copyright © 2013 IFSA.*

Keywords: Wireless sensor networks, Cluster, LEACH, Cluster head node, Energy efficiency.

1. Introduction

Wireless sensor network (WSN) consists of large number, small size, and low cost of sensor nodes deployed in monitoring area by wireless communication to form multi-hop self-organizing network [1], and comparing with other traditional wireless network (such as AdHoc network), wireless sensor network has many advantages with distributed processing, such as wide monitoring area, high monitoring precision, rapid deployment, self-organization, etc, but at the same time the sensor nodes within a network generally depend on battery power, the power energy is limited, which is a precious resource in wireless sensor network, and determines the life of WSN. Thus according to the characteristics of WSN designing appropriate routing protocol can prolong life cycle of the whole network in maximum limitation based on energy saving [1-6].

2. Related work

Due to clustering routing protocol has many advantages, people do a lot of research on the issues. Many researchers in wireless sensor network field propose many excellent clustering routing protocols. There into, some protocols do specific design to the election of cluster head nodes, the formation of clusters, and data transmission within clusters, and some protocols just do a partly detailed design. No matter what the protocol is, how to balance the load of cluster nodes to prolong the network life cycle is the problem that urgently needs to be solved. The LEACH protocol clusters the sensor nodes at first, and then selects cluster head node for each cluster randomly, averagely shares the business of data transmission to achieve evenly shared of load. Within the cluster, cluster member nodes communicate within a cluster head node directly, those nodes that are not elected as the cluster head node will be elected with the probability of $T(n)$, which is shown in expression (1) [1]:

$$T(n)=\begin{cases} \dfrac{p}{1-p*[r\bmod(1/p)]} & n=G \\ 0 & other \end{cases} \quad (1)$$

LEACH protocol has the advantages of easy implementation and strong self-adaption, at the same time, according to the round randomly electing cluster head node implements the average energy consumption of whole network nodes, so as to extend the network life time. But in LEACH protocol, the calculation formula of $T(n)$ does not consider the shortcomings of node energy factors, in order to solve this problem, Handy etc. [2] put forward the DCHS cluster routing algorithm, which takes node energy factors in account, and the calculation method of $T(n)$ is improved in expression (2):

$$T(n)_{new}=\frac{P}{1-P(r\bmod(1/P))}\times\frac{E_{current}}{E_{\max}} \quad (2)$$

In the expression (2), $E_{current}$ represents the current energy value of node; $E_{\max}$ represents the initial energy of nodes, that is, the maximum energy value. The great is the value $\frac{E_{current}}{E_{\max}}$, the slower is the energy consumption speed of the node, and otherwise, the faster is energy consumption of the node. The new $T(n)$ calculation method prefers to select the nodes with slow energy consumption speed as the cluster head nodes.

In view of the uneven distribution problem of cluster nodes in LEACH algorithm, Younis etc. proposed Hybrid Energy Efficient Distributed Clustering (HEED) [1]. In the clustering process, several iterations are used to generate the clusters with uniform distribution, and the average distribution of nodes energy consumption is used to extend network life cycle. The choice of cluster head node and cluster formation mainly depends on the two parameters of residual energy and communication costs within cluster of nodes. The node residual energy is the main parameter, and the communication cost within cluster is secondary parameter. The minimum average energy within the cluster is taken as the measurement of communication cost within clusters, when the nodes are elected as the cluster head nodes [7], the calculation is shown in expression (3).

$$AMRP=\frac{\sum_{i=1}^{m}\min power}{m} \quad (3)$$

In the expression (3), AMRP refers to the average value of the minimum power that the communication needs among all cluster member nodes within clusters and cluster head nodes, m represents the node number in the cluster.

2. EECA Description

A common characteristic of these typical layered routing protocols is that cluster range is too large, all the nodes within the network are in a cluster, this will lead to the formation of clusters, and clusters maintaining and control overhead is great in the stage of data transfer within clusters. Aiming at this problem, this paper proposes an Energy-efficient Fast Clustering Algorithm (EECA) for wireless sensor networks. At system's initialization stage, EECA divides the deployment area into multiple clusters quickly, then takes the weighing node self capacity consumption ratio and degree as the basis of cluster nodes selection, by this time the re-election of cluster head nodes changes into the behavior of local trigger. That is, every cluster is static, its node collection does not change, what will change is which member within cluster acts as cluster head node. Because the re-election of cluster head node only carries out in the cluster, this greatly reduces the complexity and computation load for the re-election of cluster head nodes.

3.1. EECA Network Model

Network is made the assumption: the network consists of N nodes which are randomly distributed in a specific area, the nodes use omni-directional antenna, and the wireless sensor network (WSN) has the features [8-11]:

1) The network is static network, nodes can be expanded after deployment. All sensor nodes in the network have only ID (node's device address or network address can be taken as the only ID);

2) The nodes have the same initial energy value;

3) The node is isomorphic with the function of data fusion;

4) Node's communication is duplex communication mode, the energy consumption of nodes that sent same amount of data is equal.

3.2. The Basic Principle of the Algorithm

Definition 1. Sensor network. The plane network is composed of n sensor nodes, which is abstracted as a connected graph $G=(V,E)$, there into, the collection node $V=\{v_1,v_2,...v_n)$, communication link set $E=\{e_1,e_2,...e_n)$ and G is always connected.

Definition 2. In $G=(V,E)$, $v_m,v_n \in G(V)$, $D(v_m,v_n)$ represents the communication link between nodes v_m,v_n. If r is the wireless communication distance among network nodes, when v_m,v_n are neighbor nodes with each other, $|D(v_m,v_n)|\le r$; Otherwise, $|D(v_m,v_n)|> r$.

Definition 3. In $G=(V,E)$, The degree of node v_i is $\deg(v_i)$ which represents the number of adjacent nodes of node v_i. $\deg(v_i)$ is a positive integer which is greater than zero. The higher is the degree value of node v_i, the more is adjacent nodes number around it.

3.2.1. The Initialization Cluster

Efficient clustering routing algorithm should meet the following requirements:

1) Cluster nodes should uniformly distribute as far as possible;

2) The rapid convergence;

3) Reduce control information among nodes in network;

4) Through balancing the load of nodes to avoid the nodes energy running out early.

Comparing with cluster member nodes, cluster head nodes need to undertake more tasks (such as the allocation of resources within the cluster, data fusion, etc.), also consume more energy, in all the nodes the cluster head nodes need to rotate the role in order to achieve load balancing. In the past clustering algorithm, the re-election of cluster head nodes is a global motion within the entire network, that is, all nodes by clustering algorithm elect a new cluster head node, the global election method of cluster head nodes will bring a lot of communication and computation load, to consume large amounts of node energy. EECA algorithm improves this and at system startup time the network is divided into several clusters, each cluster node in the network is static without change, what will change is just which member acts as cluster head node. As the re-election of cluster head node is the local action within the cluster, this greatly reduces the communication and computation load within cluster nodes.

In EECA, the sensor nodes are defined as three kinds of status, which are Undefined Nodes (UN), the Cluster Head (CH) nodes, and Cluster Member (CM) nodes.

1) Undefined nodes: the nodes do not belong to any cluster;

2) Cluster head nodes: at present the nodes have been selected as the cluster head nodes;

3) Cluster member nodes: the nodes have become the cluster members to join a cluster. It also defines the message format and their descriptions designed for EECA.

```
1) broadcast the message of elected cluster head node
Strcut ch_msg {
Unsignedint Message_ID;         /*Message ID*/
Unsignedchar ch_ID;        /*elected cluster head
node ID */
};

2) Undefined node cluster message
Struct joincluster_msg{
Unsignedint Message_ID;           /*message ID */
Unsignedchar ch_ID;         /*cluster head node ID */
Unsignedchar my_ID;             /*node self ID*/

3) to get the broadcast message from neighbour
nodes
Struct geteighbor_msg{
Unsignedint Message_ID;            /*message ID */
Unsignedchar rmy_ID;             /*node self ID */
};

4) the reply message from neighbor nodes
  Structneighforeply_ply{
  Unsignedint Message_ID;            /*message ID*/
Unsignedchar getneirghbor_ID;  /*source node ID */
Unsignedchar my_ID;              /*node self ID */
};

5) In cluster node rotate stage the node send message
Struct competech_msd{
Unsignedint Message_ID;             /*message ID */
Unsignedchar ch_ID;        /*cluster head node ID */
Unsignedchar my_ID;              /*node self ID */
Float Pvi_ch;                /*node weight*/
Unsignedint deg;             /*the degree of node*/
}
```

There is the EECA initial rapid cluster algorithm in the followings:

Algorithm 1. Initial rapid cluster algorithm

While (V is not empty)

select a undecided Node V_i in V;

If (V_i 's status= “UD”)

V_i 's status= “CH”;

else

goto 1;

Cluster $C = C \bigcup \{V_i\}$

clusterhead V_i broadcast(ch_msg);

on receiving (joincluster_msg) from V_i ;

if ($|C| < \delta$)

{ $C = C \bigcup \{V_j\}$;

V_j 's status= "CM";

}

else

goto 1;

endif

The execution steps of initializing rapid clustering algorithm are as follows:

1) In initial rapid clustering algorithm, at first the nodes V_i whose status is undefined from nodes set V are selected as cluster head nodes; the cluster head nodes broadcast a message ch_msg which the cluster head nodes are elected in a given sending power within the network.

2) If the other undefined nodes within the network can directly receive this message, which means they are adjacent nodes, after adjacent node receives the message of cluster nodes to send the join-cluster reply message joincluster_msg to the cluster head node, and changes their state identity into cluster member nodes.

3) Repeat the above steps until there are not undefined nodes in network node set V . Within the cluster too many member nodes will cause channel congestion, make the message collision probability to increase, generally when the node has six to eight neighbor nodes, which can ensure a optimal physical topology. In order to get the optimal cluster size, the algorithm rules within a cluster the member number is less than the threshold δ , through the limitation to the member nodes within cluster to control the clustering size. After clustering routing proceeds in the coverage area formed by the cluster nodes, EECA divides the network into multiple regions, each region is independent as clusters, coverage has been greatly reduced than the coverage originally formed by all the nodes, so that the routing maintenance information that whole network needs is greatly reduced.

3.2.2. Rotation Mechanism of Cluster Head Nodes

Due to the number of member nodes within the cluster is not entirely the same, different cluster head nodes have different speed to consume the energy, under normal circumstances cluster head nodes with more members within the cluster have faster energy consumption speed. EECA adopts a strategy to easily implement, when the energy that cluster head nodes consumed accounts for $\frac{1}{Num(ch_i)}$ of its total energy, new cluster head nodes are re-elected, here $Num(ch_i)$ represents the cluster member nodes number with cluster node i . In order to make the energy consumption evenly distributed to all nodes within cluster, the probability of node v_i become a cluster head node can be calculated by expression (4):

$$P_{v_i-ch} = \alpha \deg(v_i) + \beta \frac{E_{v_i-current}}{E_{v_{i\_max}}} \tag{4}$$

In the expression (4), $\deg(v_i)$ is the degree of node i , if the node's degree value is higher, the more are adjacent nodes around it, so the node with higher degree value has the priority conditions as cluster head node; $E_{v_i-current}$ is the current energy value of node v_i ; $E_{v_i-\max}$ is the initial energy value of node v_i . Because in each round the energy consumption of the cluster head nodes and the cluster member nodes is different, in each round of election of cluster nodes and the cluster formation process, the nodes with lower energy consumption proportion have better chance to be selected as the cluster head nodes. α and β are the weighting factor is greater than 0 and $\alpha + \beta = 1$. The values of weight α and β is according to the different application, as the compromise between the degree value of cluster member nodes and energy consumption proportion, it's purpose is to prolong the network life cycle. Selecting the maximum value of P_{v_i-ch} as the cluster head nodes ensures each cluster node load balance. The rotation election algorithm pseudo-code of cluster nodes is given in algorithm 2.

Algorithm 2. Cluster head nodes rotation election algorithm

While (cluster C is not empty)

{ node V_i in C broadcast (getrighbor_msg);

on receiving (neighboreply_msg) from V_j ;

compute deg(V_i), $\frac{E_{vi-current}}{E_{vi\_\max}}$;

Send message (competech_msg) to clusterhead CH;

}

compute max($P_{v_i} - ch$);

broadcast (ch_msg);

on receiving join_msg from V_j ;

The execution steps of cluster node rotation algorithm are as follows:

In the rotation election algorithm of cluster head nodes, all nodes within cluster are in a given sending power to broadcast messages getneighbor_msg in network to obtain the number of their neighbor nodes; the calculated value of $\alpha \deg(v_i) + \beta \frac{E_{v_i-current}}{E_{v_i-\max}}$ through message is sent to the cluster head nodes, cluster head node through compare to calculate the node with maximum P_{v_i-ch} to be cluster head node of next round, and then broadcast the election message ch_msg of new cluster head node within the cluster.

3.2.3. EECA Analysis

Some properties analysis and explanation of EECA are given below.

Property 1. The maximum hop number of member nodes v_m and v_n within the cluster produced by EECA is two. In the network initial phase, the cluster head node in the area broadcast messages ch_msg in a given power to network , the broadcast radius can be set to r (this ensures the normal communication between the cluster head node and all adjacent nodes). This can ensure the distance is less than or equal to r between all the cluster members and cluster head nodes, the maximum distance between two cluster member nodes is $2r$ in the cluster area, so that the maximum hop of any two cluster members nodes v_m and v_n within the cluster is 2.

Property 2. The cluster node sets in different area cover all network nodes which are produced by EECA cluster algorithm.

From EECA each node status in G(V,E) is judged in network initialization phase, if this node is an undefined node, which represents this node do not belong to any cluster, this node is set as new cluster head node. Therefore, the cluster node set covers all the nodes of network from different area which is produced by EECA clustering algorithm.

Property 3. Cluster head nodes set A produced by clustering algorithm is the maximum independent set of wireless sensor network G (V, E).

Proof: supposing A is not independent set, that is, in A there are two cluster nodes v_m , v_n which can directly communicate, and satisfy $d(v_m, v_n) \leq r$, but from EECA algorithm, there is one of v_m and v_n belonging to the cluster member nodes, this is contradictory with the supposing, therefore, set A composed of cluster head nodes will be independent set. Because in the wireless sensor network G(V, E), after the nodes implement EECA algorithm, all nodes are either belong to the cluster head nodes set A, or belong to cluster member nodes of some cluster, thus the nodes are all cluster head nodes, any node being added to A will destroy independent property of set A, therefore A is the maximum independent set.

Property 4. The message complexity of EECA cluster formation algorithm is $O(1)$. This message complexity is the message volume which transmits and stores among nodes in order to generate clusters.

Proof: in EECA cluster formation algorithm, the message complexity mainly reflects on the cluster head nodes, and the main action of cluster member nodes is sending join-cluster message joincluster_msg to cluster head nodes, due to the limitation of threshold value δ to the number of member nodes within cluster, the number has nothing to do with the size n of network, thus the message complexity of EECA cluster formation algorithm is $O(1)$, which also shows that the message overhead in algorithm is small, energy efficiency is high. From the aspect of whole wireless sensor network, because the minimum number of cluster head node is $[\frac{N}{\delta}]$, the maximum number is N (when $\delta = 1$). Therefore the message complexity of EECA in the whole sensor wireless network is $O(N)$.

4. Algorithm Simulation and Performance Analysis

4.1 The Simulation Scene Settings

In NS-2 platform, the 802.11 protocol framework is selected, the protocol module is more perfect and very suitable for being testing research platform of a self-organizing network protocol. MAC layer adopts IEEE802.11 distributed coordination function (DCF) model and RTS/CTS/DATA/ACK mechanism, which uses carrier sense multiplexed with collision avoidance (CS-MA/CA) technology to transmit data frames.

In this section the simulation is executed on EECA to evaluate its related properties, two metrics are identified to measure the performance of algorithm: number of cluster head nodes and the energy consumption of cluster head nodes. In order to verify the accuracy of experimental results, the experimental results take the average value of 20 times experiments. Comparing with the adjacent degree between the nodes and its neighbors, the node's residual energy plays a more important role in the decision whether nodes are qualified as cluster head nodes, therefore, in the node weight formulas, $\alpha = 0.4$ and $\beta = 0.6$.

4.2. The Changeable Trend Analysis of Cluster Nodes Number

In EECA algorithm, the change trend of cluster nodes is shown in Fig. 1 when the node transmission radius increases from 100 m to 600 m, the number of nodes is set to 150 and 200 respectively, it is shown:

1) The number of cluster nodes is monotonely decreased with the increase of node transmission radius. Because the node transmission radius is larger, the coverage range of node emission signal is wider, which means that in the clustering stage the clusters number is less, the number of member nodes within the cluster is more.

2) During the period of node transmission radius varying from 100 m to 400 m, the number of cluster nodes rapidly decline, and when the node transmission radius is larger, the number of cluster head nodes change is not obvious, which is consistent with the theoretical analysis. Because when the node transmission radius is small, due to the sparse node deployment, the number of member nodes within the cluster formed by EECA is less than threshold value δ, but with the increase of node transmission radius, emission signal coverage of cluster nodes increases, the number of member nodes in cluster increases, the number of cluster head nodes changes less. But because the upper limit settings of member number within the cluster is $\delta = 8$ to avoid the heavy load of cluster head nodes, even if the node transmission radius continues to increase, the number of cluster nodes changes very small.

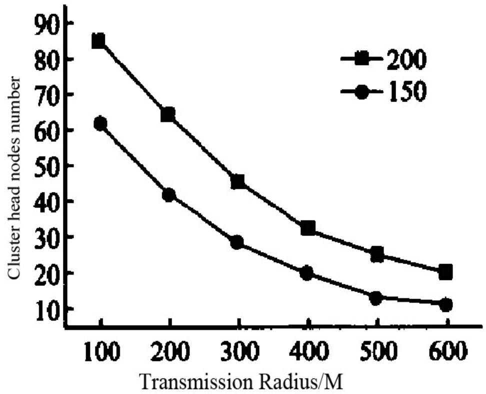

Fig. 1. Variation trend of EECA cluster heads number with transmission radius.

4.3. Analysis of Energy Consumption of Cluster Nodes

Energy consumption of cluster head nodes is the important parameter of grading cluster routing protocol. Compared with the ordinary node, cluster head nodes take on more tasks (such as the allocation of resources within the cluster, data fusion, etc.), also consume more energy. Fig. 2 is the diagram of cluster head nodes energy consumption curve changing with time in two clustering routing protocols of LEACH and EECA.

From Fig. 2, the energy consumption of EECA protocol nodes are uniform, at the beginning of the clustering, because EECA needs cluster nodes to send some control information to initialize clustering, the energy consumption of cluster nodes is higher than LEACH, but LEACH is centralized clustering routing protocol, the selection of the cluster head node does not take into account the current energy situation of cluster head node, the communication between cluster head nodes and cluster member nodes is the global action of entire network, and at system starting time EECA divides the network into several clusters, each cluster nodes in the network is static and without change, what changes is which member in the cluster acts as cluster head node. The member number within cluster is set an upper limit δ to avoid excessive load of cluster head nodes, this greatly reduces the communication and computation load of nodes within cluster.

Fig. 3 shows the performance comparison of node number with zero energy (death node).

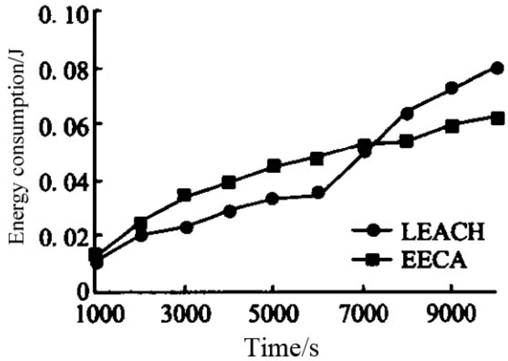

Fig. 2. The variation trend of energy consume of cluster head nodes.

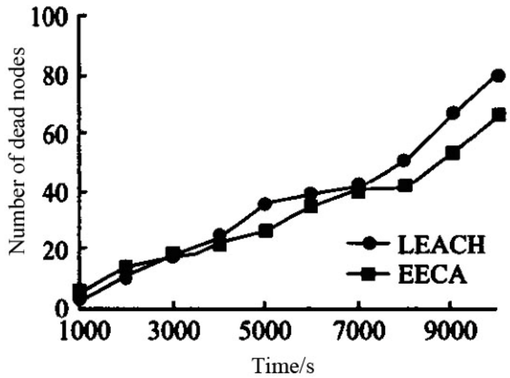

Fig. 3. Node numbers with zero energy compared between LEACH and EECA.

From Fig. 3, LEACH appears dead nodes earlier, and EECA delays a period of time than LEACH, in EECA of every round election of cluster head nodes and the cluster formation process, the nodes with lower energy consumption proportion have better chance to be selected as the cluster head nodes to ensure load balancing of each cluster head node. This also further illustrates EECA effectively balance the network energy consumption and prolong the network life cycle, achieve the design purpose of the wireless sensor network protocol reducing energy consumption and maximizing the network life.

5. Conclusion

The routing algorithm research of energy constrained sensor nodes based on wireless sensor network is a hot spot at present, this paper combines current research background in wireless sensor network environment, puts forward a fast clustering algorithm EECA based on energy efficiency, according to the theoretical analysis and simulation evaluation, which comprehensively analyze the application effect of algorithm in wireless sensor network. But due to the limitation of test environment and simulation environment, the simulation of large-scale sensor network can not implement. And in this paper, some parameter settings of the algorithm brings the impact on algorithm performance aspect, which has no further research, all of these are the continues work in the future.

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