

Ad Hoc Network Routing Algorithm Based on Energy Balanced Connected Dominating Set

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Abstract

Connected Dominating Set (CDS) is an important means to alleviate the broadcast storm of wireless sensor network. Compared to non-CDS internal nodes, CDS internal nodes have faster energy consumption rates, therefore, the energy level of CDS internal nodes determines the life circle of the network. However, the current CDS algorithms only focus the scale of CDS, and the dominator node of energy level are not considered. For this, this article puts forward the Energy-balance-based Connected Dominating Set Distributed (ECDS) algorithm. CDS is built based on Weighted Coverage Cost (WCC), which contains the detected energy of neighboring nodes. The nodes with higher WCC values are selected as dominator nodes. According to simulation results, compared with current algorithms, ECDS algorithm can reduce CDS scale, improve CDS life circle by 23%, and increases the coverage by approximate 33%.

Keywords: *Wireless sensor network; Life circle; Connected dominating set; Distributed algorithm; Life circle*

1. Introduction

A large number of sensor nodes are deployed within the field of interest (FOI), then collect the data inside FOI; these sensor nodes make up the wireless sensor network (WSN). Each sensor node has the sensing and communication ability. Sensor nodes collect and process initial data from the environment, then the processed data are transmitted to the destinations. In order to collect the data inside FOI more thoroughly and leaving no blind area, the FOI coverage must be maximized. Sensor nodes may stop working, *i.e.* becoming invalid, due to interference and energy depletion. Therefore, improving the coverage has become a research focus on WSN [1-4]. When CDS is established from the perspective of CDS scale and the problem of network energy balance is ignored, some nodes with excessive residual energy become the dominator nodes. As the energy is very low, such kind of nodes will become invalid very soon, which affects the coverage and life circle of the network. For this, this article puts forward the distributed algorithm ECDS for establishing the minimum CDS from the perspective of energy balance. In ECDS algorithm, all nodes at the beginning are in initial state, and when some node works as an initiating node and become the dominating node, sending and receiving information according to its weights, and after determining itself to be a dominator node or dominatee node, it will send different information according to the different states of itself. Such circulation will continue until reaching the convergence of whole network, so that the CDS is formed. The simulation results show that the proposed ECDS algorithm effectively improves the network coverage and life cycle.

2. Constraint Conditions

It is assumed that homogeneous WSNs have N sensor nodes, which are randomly deployed inside monitoring area A . Each sensor node has an initial energy E , a communication radius R_c , a sensing radius R_s , and $R_c \geq R_s$. All sensor nodes have the same R_c and R_s . The sensing area of sensor nodes covers a circular area with the sensor node as the center and R_s as the radius, and the communication area covers a circular area with the sensor node as the center and R_c as the radius. In addition, the identifiers used in this article are listed in Table 1.

Definition 1: Coverage: Inside the 2-D plane area A , a sensor node set $S = \{s_1, s_2, \dots, s_n\}$ is given. The position coordinate of sensor node $s_i (i = 1, 2, \dots, n)$ is (x_i, y_i) . If any point x meets the condition $x \in A(s_i)$, x is covered by s_i .

Definition 2: Dominating set: A subset D inside undirected graph $G = (V, E)$, and $D \neq \emptyset$. If $v \in V - D$ and subset D is in the node neighboring to v , then D is called a subset of graph D [11].

Table 1. List of Identifiers

symbol	description
R_s	Sensing radius
R_c	Communication radius
$A(S_i)$	Sensing area of Node S_i
$N(S_i)$	1 step neighboring nodes set of Node S_i
$CR(S_i)$	Coverage redundancy set of Node S_i
$E_r(S_i)$	Residual energy of Node S_i
E_{th}	Energy threshold value
$E_{tot}(S_i)$	Sum of residual energy of neighboring nodes of Node S_i
$WCC(S_i)$	Weight value of Node S_i
$L1(S_i)$	Stored 1-step neighboring white node information of Node S_i
$L2(S_i)$	Stored 2-step neighboring white node information of Node S_i

3. ECDS Algorithm

3.1. Weights WCC

Each sensor node periodically broadcasts information packets to its neighboring nodes, and the information packet include residual energy information. In order to reduce packet collision rate, each node randomly set the backoff interval, and after timing, the information packet will be broadcasted. Once receiving the information packet from neighboring nodes, the node will compute its weighted coverage cost (WCC).

$$E_{tot}(s_i) = \sum_{\forall x \in CR(s_i)} E_r(x), \text{ if } E_r(x) > E_{th} \quad (1)$$

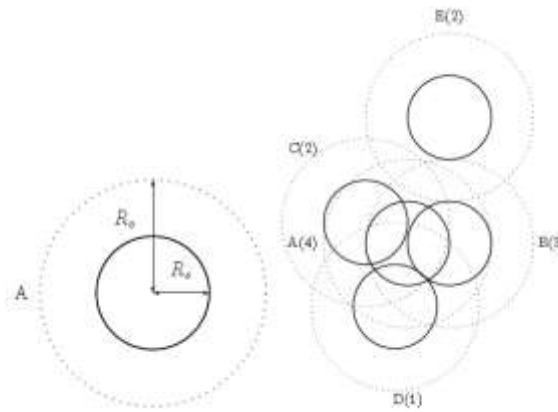
Where, $E_{tot}(s_i)$ is the residual energy s_i in neighboring nodes of node, and $E_r(x)$ is larger than the threshold value E_{th} of all nodes.

Then the WCC of sensor node s_i is:

$$WCC(s_i) = \begin{cases} 0, & \text{if } E_r(s_i) < E_{th} \\ E_r(s_i) + E_{tot}(s_i), & \text{otherwise} \end{cases} \quad (2)$$

It can be seen from Formula (2), the WCC value of the node reflects the energy levels of the nodes and neighboring nodes. In order to reduce number of nodes invalid due to energy depletion, set the WCC value of the nodes whose $E_r(s_i)$ smaller than threshold value E_{th} to zero. If residual energy is low, the working time will be short, then it will not need to add CDS set.

As shown in Figure 1, the five sensor nodes, A, B, C, D and E, are distributed inside the network area, and there are coverage and overlapping among them. Assume that their initial energy is all 5J, and Figure 1(a) describes the communication radius (dotted circle) and sensing radius (solid circle) of the node; Figure 1(b) shows the residual energy of each node, for example, the residual energy of Node C is 2 and the residual energy of Node B is 3. Assuming that $E_{th} = 1$, then the WCC values of each node can be computed according to Formula (2). For example, the sensing area of Node A are overlapped with the sensing areas of Node B, C and D, and the residual energy of these three nodes are all larger than the threshold value, therefore, $WCC(A) = E_r(A) + E_{tot}(A) = 4 + 3 + 2 + 1 = 10$. In the same way, it can be obtained that $WCC(B) = 4 + 3 = 7$, $WCC(C) = 4 + 2 = 6$, $WCC(D) = 4 + 1 = 5$ and $WCC(E) = 2$.



(a) Communication radius and sensing radius (b) Residual energy

Figure 1. Computation Example of WCC Value

3.2. CDS Building Procedures

First of all, in order to make clear and vivid description, the nodes in different states are marked by different color, as shown in Table 2.

Table 2. Status Identification

Status	Symbol	Color
Initial status	S_0	White
Dominatee status	S_1	Grey
Dominator status	S_2	Black

The core problem of ECSDS algorithm is how to select the next dominator node by using the WCC weights, *i.e.* the strategy problem for selecting dominator node. In order to make a simple description, it is assumed that Node i is the starting node. At beginning, all nodes are in initial state, and all tags are marked white. Then, Node i finds out the maximum Node v in the information packets received from neighboring nodes, and if the weight value of Node v $WCC(v)$ is larger than the weight value of

itself $WCC(i)$, Node v will broadcast the packet Mes_Dominator and declares Node v as the dominator node; otherwise Node i will broadcast packet Mes_Dominator and declares itself as the dominator node.

As shown in Figure 2, at first, each node is marked white, and the Node 14 in the graph is the Node i , namely $i=14$. In order to make the description concise, the weight of each node is their number ID. As Node i has the largest weight among neighboring nodes, it broadcasts the packet Mes_Dominator and becomes the dominator node, therefore, it is marked in black color.

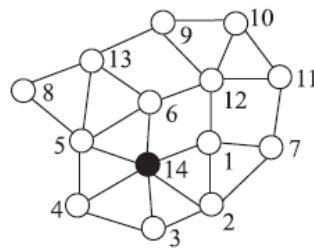


Figure 2. Generation of the First Dominator Node

After generating the first dominator node, this node will broadcast the Mes_Dominator packet. The neighboring nodes which receive this Mes_Dominator packet will temporarily become the dominatee nodes and broadcast the Mes_Dominatee packet, and they will be marked in grey color. Still take Figure 2 as an example, neighboring nodes 1, 2, 3, 4, 5 and 6 become dominatee nodes after receiving the Mes_Dominator packet, and they are marked in grey color, as shown in Figure 3.

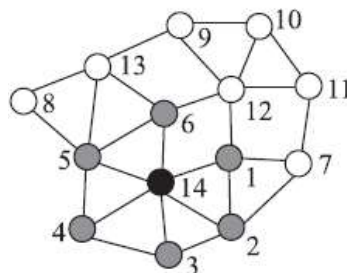


Figure 3. Generation of the Dominatee Node (First Round)

Once a white node receives the Mes_Dominatee packet, it will broadcast its packet. Take Figure 3 as an example, white nodes 8, 13, 12 and 7 will broadcast their packets. Therefore, grey nodes will broadcast receive packets broadcasted from neighboring nodes, and store these packets in List L1, then grey nodes will broadcast List L1. For example, the Node 6 in Figure 3 receives the packets broadcasted from Node 13 and 12, then it stores their weights and ID numbers in its List L1. Then it will broadcast the List L1.

Then, the first dominator node, namely the black node will receive the List L1 broadcasted by each grey nodes, and store List L1 in List L2. The black node will find out the white node with the largest weight in List L2, and this white node will be selected as the second dominator node and marked black. For example, Node 13 in Figure 3 is the white node with the biggest weight in List L2, therefore, it becomes the second dominator node.

Finally, the grey node, which is among the one step neighboring nodes $N^{(14)}$ from the first dominator node (14) and is neighboring to the second dominator node $N^{(13)}$ and

has the biggest weight, becomes the third dominator node. It can be seen from Figure 3 that Node 5 and 6 are neighboring nodes to Node 14 and 13, and Node 6 has a higher weight than Node 5, therefore, Node 6 becomes the third Node, as shown in Figure 4. Repeat the above steps until no white nodes existing in the network. Then all black nodes make up the CDS set. Still take Figure 3 as the example, the final dominator nodes are as shown in Figure 4, and Node 12 and 11 become the fourth and fifth dominator node, respectively.

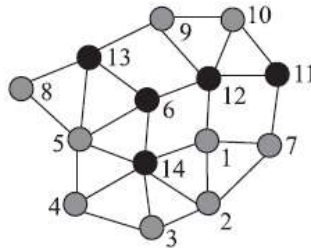


Figure 4. Generation of Dominator Nodes

The above steps for building CDS set are as shown in Figure 5.

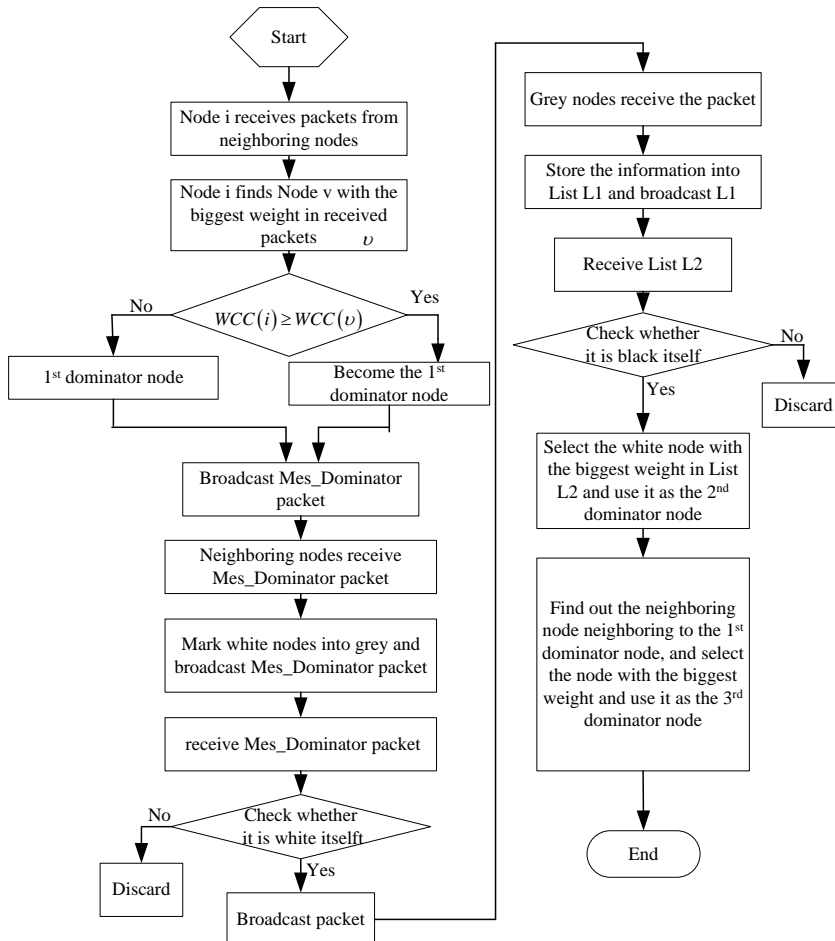


Figure 5. Flow Chart for Generating Three Dominator Nodes

4. Performance Analysis

4.1. Simulation Parameters

The simulation on ECDS algorithm is conducted in this Chapter. Assume that N sensor nodes are randomly deployed in a 2D plane, and region area is $A = 200 \times 200m^2$. Simulation parameters are shown in Table 3. Each independent simulation is repeated for 100 times, and then the mean value is used as final experimental data.

Table 3. Simulation Parameters

Parameter	Value
Simulation area	$200m \times 200m$
Node distribution	random
Number of nodes	100 ~ 400
Communication range	40 ~ 70
Residual energy of the node	1J
Data packet size	100 byte
Control packet size	25 byte

In the process of performance analysis, mean CDS scale, CDS life circle, residual energy, region coverage and CDS convergence time are used as the performance index. Both EB-CDS [9] and HMCDS [10] algorithms are used as reference.

4.2. Data Value Analysis

Figure 6 shows the mean CDS scale of three algorithms, and it can be seen from Figure 9 that, ECDS algorithm are slightly better than EB-CDS and HMCDS algorithms as ECDS algorithm can exclude the nodes whose energy are lower than threshold value from CDS set, which reduces the number of active nodes.

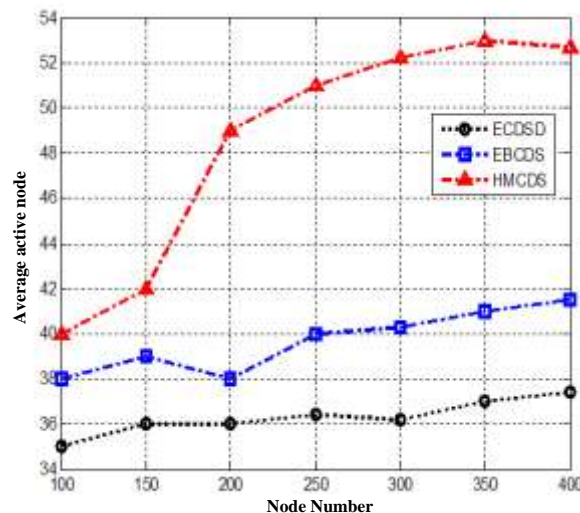


Figure 6. CDS Scale

Figure 6 shows the CDS convergence time. It can be seen from Figure 7 that, with the increasing of nodes, the convergence time of three algorithms are also increasing,

and their convergence time are similar. But when the number of nodes exceeds 300, ECDS algorithm obviously shows a better rapid convergence performance. It is because ECDS algorithm adopts simpler rules in building CDS set, which means high efficiency.

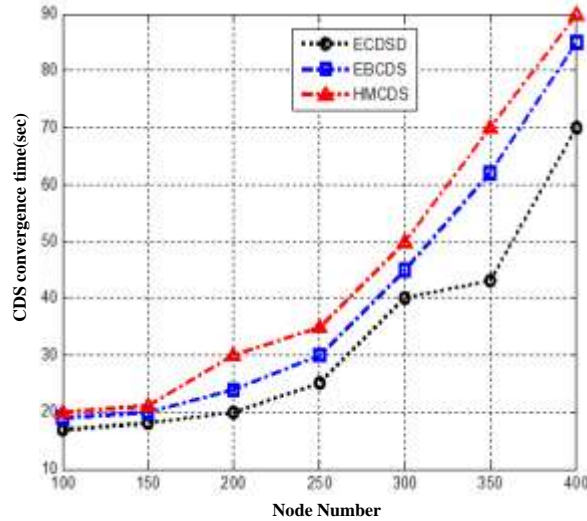


Figure 7. CDS Convergence Time

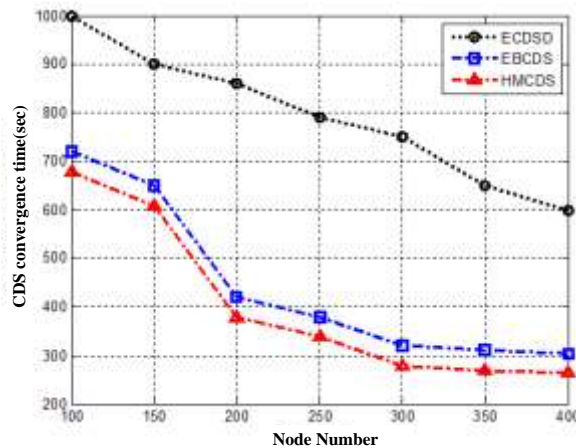


Figure 8. CDS Life Cycle

Figure 8 shows the curve of CDS life circles of three algorithms vary with the change of the number of nodes. It can be seen from Figure 8 that, with the increasing of the number of nodes, corresponding number of active nodes also increases, and more energy are consumed and CDS life circle declines. And compared with EB-CDS and HMCDS algorithms, ECDS algorithm has longer life circle as it uses weight value to select the dominator nodes, which means that only the nodes with large coverage weight values can become active nodes.

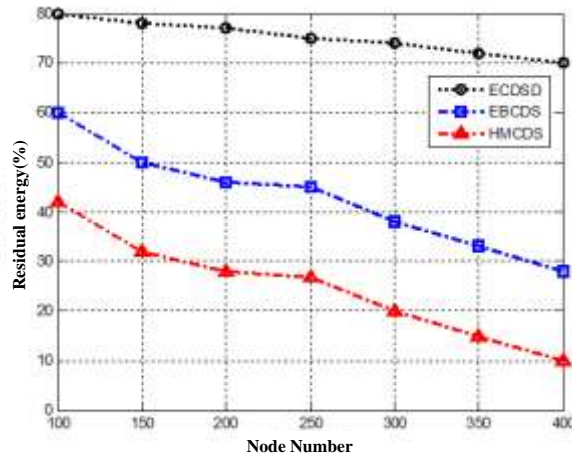


Figure 9. Residual Energy

Figure 9 shows the residual energy of the network after carrying out the simulation for 7200 seconds. It can be seen from Figure 9 that ECDS algorithm has the highest residual energy. That is because ECDS algorithm alleviates the load of active nodes, saving energy consumption of the nodes.

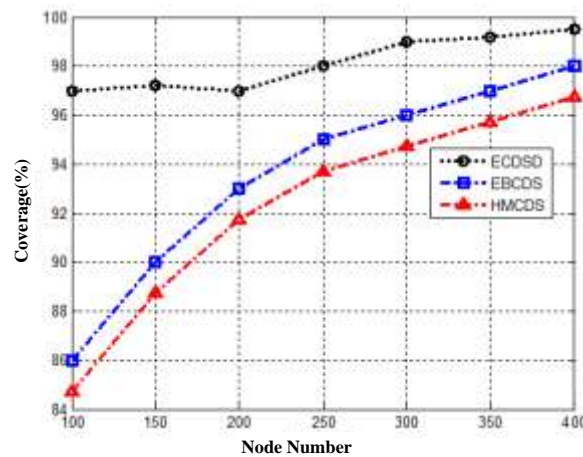


Figure 10. Coverage

At last, Figure 10 shows the curve of region coverage varying with the change of the number of nodes. With the increase of number of nodes, coverage also increases. Compared with HMCDS and EBCDS algorithms, ECDS algorithm requires less active nodes, and accordingly, it consumes less energy in the same time period, and ECDS algorithm selects the nodes with high coverage weights as the active nodes. It can be seen from Figure 10 that when there are only a few nodes, three algorithms all have low coverage, and with the increasing of the number of nodes, the coverage rates begin to rise. ECDS algorithm keeps a region coverage of 97%, which is better than those of HMCDS and EBCDS algorithms.

5. Conclusion

This article puts forward the Energy-balance-based Connected Dominating Set Distributed (ECDS) algorithm, which considers the energy distribution of nodes. It tries to include the nodes whose residual energy are higher than threshold value in the

dominator set. ECDS algorithm uses the WCC to select the dominator nodes, and as WCC contains the energy information of neighboring nodes, it can balance the energy consumption of the network. The simulation results show that the proposed ECDS algorithm effectively improves the network coverage and extends the life cycle of the network.

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