Energy-Balanced Distributed Clustering Algorithm in Wireless Sensor Networks

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***Abstract*—In order to prolong the wireless sensor network lifetime, an novel energy balanced distributed clustering (EBDC) algorithm based on virtual grid is proposed. EBDC has three obvious features: Firstly, it adopts virtual grid ideas to divide each cluster into M×N square area and select a working node in each grid to reduce redundant information and save energy. Secondly, cluster head is distributed generated according to the probability which includes the residual energy, history sending packets and so on among the working nodes in each grid. Last, it improves energy utility by changing the activity of wireless communication module of sensor nodes, energy model and state transition of sensor nodes. Simulation results show that, compared with UVDC and LEACH, EBDC significantly balances the node's average energy consumption and prolong the network lifetime.**

***Index Terms*—Wireless sensor networks (WSNs), Energy balanced, Network lifetime, Distributed clustering, Virtual grid.**

I. INTRODUCTION

The availability of cheap, low power, and miniature embedded processors, radios, sensors, and actuators, often integrated on a single chip, is leading to the use of wireless Communications and computing for interacting with the physical world in applications such as security and surveillance applications, smart classroom, monitoring of natural habitats and ecosystems, and medical monitoring. The resulting systems, often called wireless sensor networks, differ considerably from current networked and embedded systems. They combine the large scale and distributed nature of networked systems such as the Internet with the extreme energy constraints and physically coupled nature of embedded control systems [1].

A wireless sensor network (WSN) consists of a large number of nodes which collaborate amongst themselves to accomplish a common task [2]. Sensor nodes are quasi-stationary, densely deployed and with limited capabilities. Nodes sense and send their signals towards a data center which is called the information sink. The design of protocols and applications for such networks has to be energy aware in order to prolong the lifetime of the network because it is quite difficult to recharge node batteries. Additionally, it has to take into account the multi-hop communication nature. Communication in a WSN between any two nodes that are out of one another's transmission range is achieved through intermediate nodes, which relay messages to set up a communication channel between the two nodes [3, 4].

The WSNs are deployed in a target area in order to facilitate many applications like habitat monitoring [5], disaster relief [6], target tracking [7] and so on. Many of these applications require simply an aggregate value to be reported to the information sink (observer, base station, etc.). In these cases, sensors in different regions of the field can collaborate to aggregate the information that they gathered. For instance, in habitat monitoring applications the sink may require the average of temperature; in military applications the existence or not of high levels of radiation may be the target information that is being sought. Grouping nodes into clusters has been widely pursued by there search community in order to achieve the network scalability objective. Clustering not only allows aggregation, but also limits data transmission primarily with in the cluster [8], there by reducing both the traffic and the contention for the channel.

The fundamental notion of clustering scheme is to divide a network into several segments which are generally called by cluster, and all sensors in WSNs are organized into the clusters where each sensor has its own CH. The key advantage of clustering scheme is to reduce the distance of transmission by communicating with CHs over relatively short distances. The formation procedure involves the election of a cluster head (CH) node in each cluster, in order to coordinate the cluster nodes. The cluster head is responsible for getting the measured values from its clusters nodes, aggregating them and sending the aggregates to the sink(s) through other cluster heads. Many studies indicate that clustering increases the network lifetime. Although the definition of the network lifetime depends on the applications semantics, a widely accepted definition is the time until the first/last node of the network depletes its energy .

In this paper, we present an energy-balanced distributed clustering (EBDC) algorithm based on virtual grid for wireless sensor network. It has three obvious features: Firstly, it divides each cluster into M×N square area called virtual grid and only selects a working node in each virtual grid. Second, head is distributed generated according the probability among the working nodes which includes the residual energy, historical sending packets. Last, it improves energy utility by changing the activity of wireless communication module of sensor

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nodes, energy model and state transition of sensor nodes. Simulation results show that, compared with EBDC, UVDC and LEACH, EBDC significantly balances nodes average energy consumption and prolong the network lifetime.

II. RELATED WORK

Clustering of nodes in wireless networks has been addressed by a number of researchers. Most of the existing works for clustering base the selection of cluster heads on various factors which include cluster ID, degree of connectivity, or randomization [1].

However, most of the published clustering protocols do not consider any energy balancing among clusters due to variable density of nodes in the system. In LEACH [9], an energy efficient protocol was proposed for sensor networks which using continuous data delivery mechanism and no-mobility, it can minimize energy dissipation in sensor networks through cluster constructing. It has two phases: a set up phase and a steady state phase. First, a node randomly generates number between 0 and 1. If this number is less than the threshold T(n), the node becomes a CH. T(n) is computed as

$$T(n) = \begin{cases} \dfrac{p}{1 - p \times (r \bmod \frac{1}{p})} & if \quad n \in G \\ 0 & otherwise \end{cases} \qquad (1)$$

where r is the current round; p is the desired percentage for becoming CH; and G is the set of nodes which is not elected as a CH in the last 1/p rounds, then every CH broadcasts to inform all sensor nodes that it is the new CH head. When each node receives this message, it joins in a cluster by the signal strength of the announcement. The sensor nodes then inform their appropriate CH to join them. Then, the CHs assign a time slot by TDMA approach to each node which its data can be sent to its CH during this period. In the second phase, the sensor nodes can transmit the sensing data to the CHs. The CHs also aggregate the received data from the nodes in their cluster before sending these data on to the BS. After a certain period of time, the network goes into the set up phase again and enters the next round. The limitations of the LEACH protocol are as follows [10]: Energy consumption is a important problem in WSNs, but it does not consider the remaining energy of nodes when generating CHs; LEACH uses a probabilistic method to select a CH, although a node has very low energy, it maybe has a chance of becoming a CH. When this node dies, the entire cluster is rendered dysfunctional; it is possible that some CHs are located with in close proximity of each other. This indicates that CHs are not well distributed in the network; it is assumed that CHs have a long communication range which can enable them to directly send data to the BS. Because of signal propagation problems, this assumption is not always realistic, such as the obstacle, the BS is often directly unreachable to all nodes. On the other hand, the CHs have the capabilities of regular sensor nodes. Consequently, LEACH is not applicable to networks deployed in large networks.

The LEACH's probabilistic CH selection algorithm was proposed in [11]. They adjusted the threshold T(n) denoted in (1), relative to the nodes residual energy. Each node decides whether to become a CH in a round or not by applying this threshold. Recently, Guptaetal.[12] introduced a CH election method using fuzzy logic to overcome the drawbacks of LEACH, it use three fuzzy variables (node degree, node residual energy and nod e centrality) to efficiently increase the network lifetime, but this centralized approach is not suitable for large networks because BS must ensure much time and information to collect information about the status and location of all nodes. An improved LEACH protocol was proposed in LEACH-FL [13], which employs a similar approach to [12].This method uses three parameters (node residual energy, node degree and distance from BS) for computing the probability. The BS selects nodes with higher chance as CHs, using 27 fuzzy if-then rules. Although this algorithm has the same drawback of Group's method, it presents a better performance than LEAC protocol. Bandyopadhyay and Coyle [14] using the multi-hop routing to improve the LEACH protocol. Similar to LEACH, every CH informs it self to the neighboring sensor nodes through multi-hop method. The advertisement is forwarded to sensor nodes in at most h hops away. Cluster members (CMs) elect the closest CH in terms of hop count through multiple CH message. On the other hand, if a sensor node is neither a CH nor receives any CH announcement, it becomes a forced CH. Using multi-hop fashion, sensor nodes can reduce more energy conservation in communications than single hop missions, especially in large networks. In addition, the overhead in the setup phase increases considerably, because CH messages have to be forwarded via multiple hops.

HEED [15] uses the cluster radius as a parameter to define the transmission power in cluster broadcasting. The initial probability for each node to become a tentative cluster head relays on its residual energy, and the intra cluster communication cost determines to elect the final cluster heads. It assumes that the cluster heads can communicate with each other and forma connected graph; it is trick to realize this assumption in practical deployments. In [16], a new energy efficient clustering approach (EECS) for single-hop wireless sensor networks was proposed in the periodical data gathering applications. EECS improves LEACH protocol through the dynamic size of clusters based on the distance from the BS. In the cluster head election phase, it is different from LEACH, through the localized competition to generate cluster head and its no iteration property makes it differ from HEED. This competition message includes the candidates broadcasting their residual energy to neighboring candidates. If a given node has the maximum residual energy, it becomes a cluster head. However, the EECS protocol does not consider the structural characteristics of network topology and selects the cluster head through residual energy.

A clustering-based routing protocol called base station controlled dynamic clustering protocol (BCDCP)was proposed in [17], the base station which has a high energy responsible for setting up cluster heads and performing other energy-intensive tasks, can noticeably enhance the network lifetime. In [18], a united voting dynamic cluster routing algorithm based on residual-energy in wireless sensor networks (UVDC) was introduced, it periodically depends on the residual energy among the nodes in the sensing area to elect the cluster head, the voting cost is gigantic and the large redundant nodes will waste limited energy. In order to maximize the network lifetime, a uniform balancing energy routing protocol was proposed in [19], only the nodes which their remaining energies are greater than a threshold can participate as routers for other nodes in addition to sensing the environment. In [20], the authors proposed a location-based unequal clustering algorithm (LUCA), it divides each cluster into different cluster size according to the distance between a cluster head and a sink. In LUCA, a cluster has a larger cluster size will increase the distance from sink node to minimize the energy consumption of entire network. In [21], a clustering scheme which aims to produce clusters of bounded size was proposed, in order to ensure the overall load is sufficiently balanced among all clusters in network, it require all nodes to have uniform traffic load, and this is very difficult, the unbalanced load will influence the high-density and very low-density, the high-density cluster-head will be overwhelmed with the processing and communication load and while be depleted of energy at a much faster rate than low-density cluster heads.

Besides these algorithms mentioned above, there exist several other algorithms [22], such as: Soro et al. [23] 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. Ye et al. [24] proposed a clustering algorithm, which achieves good cluster head distribution with no iteration and introduces a weighted function for the ordinary node to make a decision whether to join a proper cluster.

III. SYSTEM MODEL

Energy balanced distributed clustering is a typical application in wireless sensor networks. Our motivation is to study the problem in this kind of application. In this section, we will make some assumptions about the system model and give a statement about network model, energy model and state conversion model.

A. Network Model

We consider the wireless sensor networks where N nodes in field A are homogenous and energy constrained and the sensor network has the following properties [25]:

(1)This network is a static densely deployed network. It means a large number of sensor nodes are densely deployed in a two-dimensional geographic space, forming a network and these nodes do not move any more after deployment.

(2)There exists only one Sink node, which is deployed at stationary place outside the WSNS.

(3)The energy of sensor nodes cannot be recharged.

(4)Sensor nodes are location-aware, i.e. sensor node can get its location information through other mechanisms such as GPS or position algorithms. Each node is assigned a unique identifier [26].

(5)The radio power can be controlled, i.e., a node can vary its transmission power depending on the distance to the receiver [27].

First, the whole area has been divided into many same squares, namely, there are many clusters, and each node can directly communicate with other nodes in a cluster. Then the cluster was divided into $M\times N$ small area (the value of M, N is determine by the cluster's size, there are $M\times N$ grid in a cluster, each grid is named G_k ($k=1..\ M\times N$).

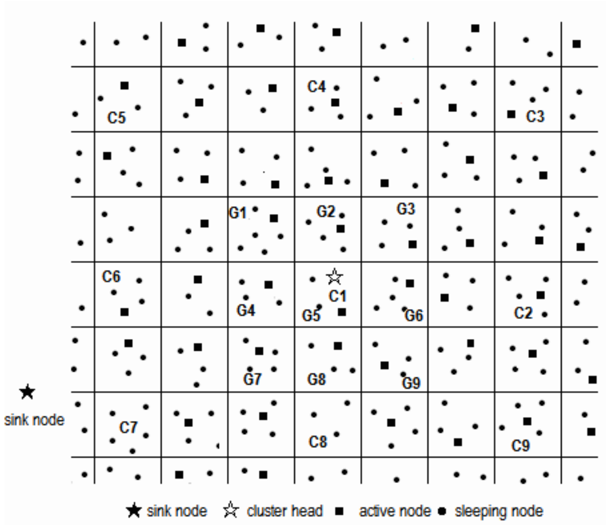

Figure 1. Network model

Fig.1 shows the virtual grid ideas, in order to describe, we suppose M=3 and N=3, each small square call as a virtual grid, node distribute into this virtual grid, C1 has 9 virtual grid such as G_1,G_2, G_3,G_4,G_5,G_6,G_7,G_8 and G_9,we suppose virtual grid G_5 as a cluster head grid, and the pentagram as the cluster head, for arbitrary adjacent virtual grid G_1 and G_2,each node in G1 can communicate with all nodes in G_2, and vice versa. In a cluster, the red dot as the working node in each grid and each node can communicate with cluster head, and we suppose the number of simultaneous working node is 1(square dot), others are sleeping(circular dots).In order to guarantee the network normal working and prolong network lifetime, one sleeping node in a virtual grid will be awaken at the right time so as to instead of the energy-exhausted node or disabled node [28].

B. Energy Model

We adopt a simplified power model of radio communication in document [29], namely, in order to send a k-bit packet information and the sending distance is d, the sending energy consumption is

$$E_{Tx}(k,d) = E_{elec} \times k + \varepsilon_{amp} \times k \times d \times d \qquad (1)$$

The distance of node I and node j is $d_{i,j}$:

$$d_{i,j} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \qquad (2)$$

The receiving energy consumption is

$$E_{Rx}(k) = E_{elec} \times k \qquad (3)$$

Where Eelec is the energy/bit consumed by the sender and receiver electronics, J/bit, Eelec=50nJj/bit,. ε_{amp} is the J/(bit × m2), ε_{amp} =100pJ/bit/m2.we commonly assume that the sending distance and d2 is directly proportional for shorter distance, while the sending distance and d4 is directly proportional for longer distance, so we can see the directly sending to long distance is consumed more energy than multi-hop sending.

But the differentiation from the document [30], we consider the processing consumption in order to proximity real scene, the energy consumption of cluster head is Ep

$$E_p(k,m) = \sum_{i=1}^{m} E_{elec} \times k_i \qquad (4)$$

So the residual energy of cluster head is:

$$E_r(i) = \sum_{w=1}^{n1} E_{TX}(k_w, d_w) - \sum_{w=1}^{n2} E_{RX}(k_w) - E_p(k,m) \qquad (5)$$

Where n1,n2 are the cluster head respectively sending and receiving times before time Ti.

The residual energy of ordinary node j is:

$$E_r(j) = E_r(j) - E_{TX}(k_n, d_n) - E_{RX}(k_l) \qquad (6)$$

C. Node State Transition Model

The energy dissipation in wireless sensor networks has three models: sensor model; procession model; wireless radio model [31]. In order to maximum lifetime and minimum routing, nodes in the EE-MLMR have various operation modes with different levels of activation and, thus, different levels of energy consumption. We put forward the new state conversion model which has flag of valve which depend on the EPGR state model. In this model, each node has six operation modes [32]: mode 1: sleeping-sensing off and radio off; mode 2: sensing -sensing on and radio off; mode 3: receiving sensing on and radio receiving; mode 4: transmitting -sensing on and radio transmitting; mode 5: listening - sensing on; mode 6:long sleeping- sensing off and radio off for ever ,no responding.

IV. Energy Balanced DISTRIBUTED Clustering Algorithm (EBDC)

At any time, only one node within a virtual grid stays active to be a coordinator, while the others fall into sleeping mode. Doing this significantly reduces the energy consumption because nodes in the idle state spend much more energy as compared with the sleeping state.

A. Threshold Dynamic Setting

In our protocol, EBDC algorithm has two phases: dynamic set the threshold of cluster head and dynamic select the cluster head:

E_{r_b} (Ci) is the initial energy of cluster head C_i in a round, E_r (C_i) is the remaining energy, δ is a pre-set threshold coefficient, when E_r (C_i) meet the formula (7) conditions to begin a new head selection.

$$E_r(C_i) \le \delta \times E_{r-b}(C_i) \qquad (7)$$

The E_{r_b} () of each cluster head is different, so the different cluster head dynamic determines the time to select a new cluster head within a cluster, within the same cluster, because of the different nodes send the amount of data and moments as a cluster head are different, the E_{r_b} (C_i) is different, the time interval of the cluster head is dynamic determined by the current cluster head residual energy. This can dynamically generated cluster head in the whole network.

B. Dynamic Head Selecting based on Energy Balanced

In EBDC algorithm, each node located in the sub-clusters throughout the life cycle, so sub-cluster formation in the cluster is how to dynamically select a new cluster head, after the cluster head sent data, it computes its current residual energy, if meet the formula (6) conditions, then perform the following steps:

Step1：If one active node j meets the formula (8) condition, the active node j as the new cluster head, then go to step (5).

$$N_j == 0 \ \ and \ \ E_r(j) == Max\{E_r(v)\} \qquad (8)$$

Where v∈ [1,Q×W].

Step2: Head respectively computes the sum of the residual energy E_r (t) of all active nodes in the cluster, the average residual energy E_r (ave), and send data packets number N (t).

$$E_r(t) = \sum_{m=1}^{Q\times W} E_r(m) \qquad (9)$$

$$E_r(ave) = \frac{E_r(t)}{Q \times W} \qquad (10)$$

$$N(t) = \sum_{m=1}^{Q\times W} N_m \qquad (11)$$

Step3: Head computes the probability of active node j to be cluster head in the next round.

$$p_j = \frac{E_r(j)}{E_r(t)} \times \left(1 - \frac{N_j}{N(t)}\right) \qquad (12)$$

Step4: Old head will select the active node s as a new cluster head, which the residual energy is greater than average residual energy and p_j is maximum.

$$p_j = Max\{p_j \mid N_j \ne 0, E_r(j) > E_r(ave)\} \qquad (13)$$

Step5:End.

Figure 2. (a) is the initialization which Er(i)is the residual energy of active node, N(i) is the historical packets, Figure 2.(b) is the UVDC result which needs 40 voting packets can select $G_{1,2}$ or $G_{1,8}$ as the new head. Figure 2.(c) is the EBDC result which does not need to

send any data packets, the largest residual energy nodes are $G_{1,2}$ and $G_{1,8}$,but N8 is zero, so we can get the active $G_{1,8}$ is the new head by formula.

In figure.3 (a), the maximum remaining energy node is G_2, so G_2 is the only head. Node G_1 or G_8 are likely as the new cluster head which have the maximum number of votes using UVDC algorithm, as shown in Figure 3 (b).Using EBDC algorithm, the sum of the residual energy E_r (t) is 47,the average residual energy of active nodes E_r (ave) is 5.2222,and the total number of sending packets N (t) is 17 by formula (10) - (13), table 1 is the probability of each active node becomes head, the largest probability is 0.14894,namely, $G_{1,8}$ will be the head, although its residual energy is not the maximum, but its historical packets is zero and its residual energy is similar the maximum, EBDC selects the similar remaining energy node G_8,but not the node G_2 can optimize the whole performance, reduce the number of conversions of the cluster head and extend the life cycle of the network.

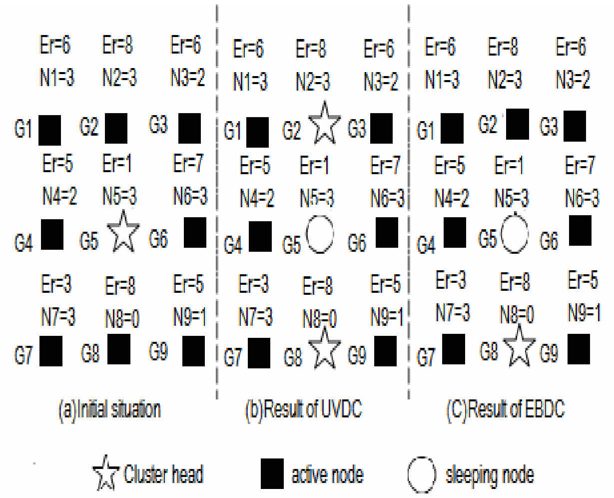

Figure 2. The results of UVDC and EBDC

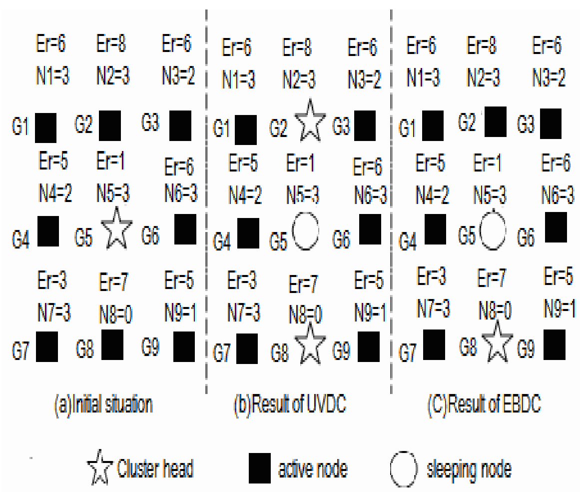

Figure 3. The results of UVDC and EBDC.

TABLE 1.
THE PROBABILITY OF ACTIVE NODES AS HEAD

ID(j)	Er(j)	N	pj
G1,1	6	3	0.1051
G1,2	8	3	0.1401
G1,3	6	2	0.1126
G1,4	5	2	0.0938
G1,5	1	0	0.02
G1,6	6	3	0.1051
G1,7	3	3	0.0525
G1,8	7	0	0.1498
G1,9	5	1	0.1001

V. SIMULATION RESULTS

A. Simulation Parameters:

We have implemented our proposed protocol in NS-2(ver. 2.31) [34]. The EBDC algorithm described in the previous section was simulated over a network of 900 nodes randomly distributed in a 450 ×450 square, 900 nodes with equal initial energy and divide into 9 cluster, each cluster divide into 3×3 virtual grid. We suppose node uniform distribute in each cluster, namely, there are about 100 nodes in each cluster. The same topology is used for all simulated protocols (or algorithms) like UVDC and LEACH. In EBDC, according to formula (1-6) to compute the residual energy and formula (7-14)to compute probability. Obviously, the first set of cluster heads are taken randomly. The initial energy of all the nodes assumed as 5 joules. The radio range is varies from 30m to 120m.Each data packet has 64 bytes, and the others are 36 bytes long. Summary of parameters and defined values are shown in Table 2.

From the figure.4, we can see that the lowest energy consumption of cluster head are EBDC and UVDC algorithm, because they use multi-hop communication to send data to the sink node and significantly reduce energy consumption, the head consumption of LEACH is maximum, not only because LEACH uses single-hop communications and constructs more cluster head number, and increases the frequency to sink node, on the other hand, the number of cluster head in LEACH is unstable and did not control the distribution of the cluster head in the network, so its heads energy consumption is more obvious; while UVDC algorithm calculated more frequently, and in the voting process need to send large amounts of data packets and consume additional energy, so its cluster head energy consumption is less than LEACH and more than EBDC. Energy consumption of EBDC algorithm is the lowest, because of selecting head is not only considered the residual energy of nodes, also taking into account the historical packets of active nodes in last round, so that the greatest probability active node will become the new cluster head, it can effectively balance the energy consumption in network and has better energy consumption performance.

TABLE 2.
THE PROBABILITY OF ACTIVE NODES AS HEAD

Simulation parameters	value
N(total nodes)	900nodes
A(network size)	450×450 m
Cluster size	90×90 m
Virtual grid size	30×30 m
Number of sink	1
Eelec	50nJ/bit
ε_{amp}	0.0013pJ/bit/m^2
Data packet size	64 bytes
Other packet size	32 bytes
Simulation times	150 seconds
Threshold energy	0.5w
E(initial energy)	5Joules

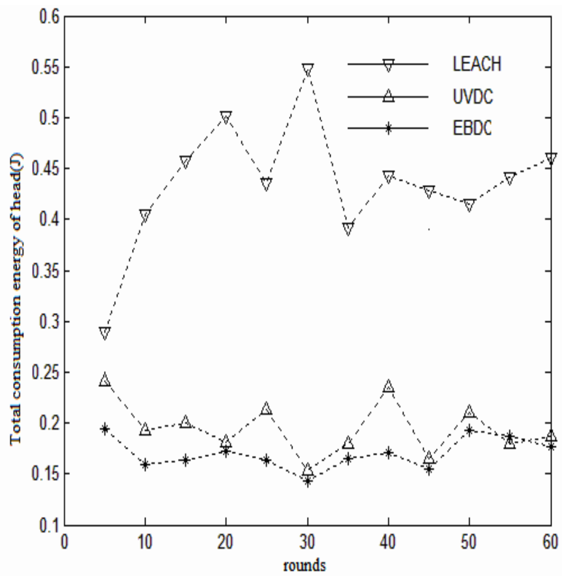

Figure 4. Energy consumption of cluster head

From figure 5, we can see that the longest network life cycle is EBDC algorithm, followed is UVDC, and LEACH is the shortest, this is because of using multi-hop way to send data to the sink node, and avoiding node of the low residual energy and the more sending packet to become new cluster head to, so the energy consumption of the node is stable reduce; followed, using data fusion scheme and consider the residual energy and distance before selecting head can significantly overhead reduce the communication overhead between the cluster head; In UVDC algorithm, only consider the residual energy of node to vote the head can reduce the amount of data transferred in the network, but the cost of voting in each cycle easily cause excessive energy consumption, and only consider the number of votes without considering the network topology and data traffic. the performance of network lifecycle is shorter than EBDC;LEACH algorithm requires nodes with higher power communications capabilities, poor scalability, and is not suitable for large-scale network, the performance will be poor with the network size changed.

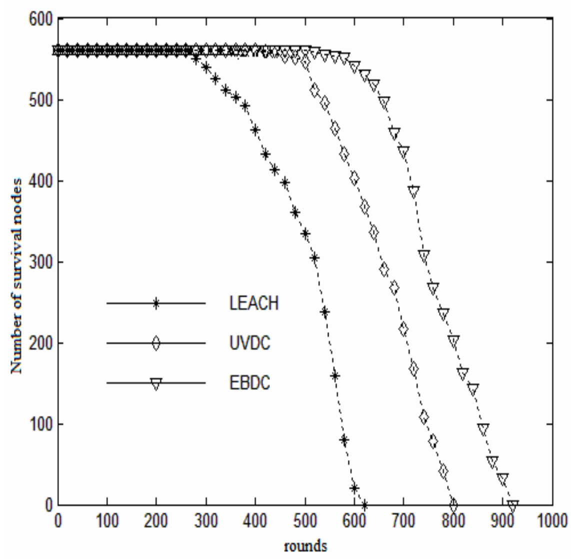

Figure 5. The weight of each active node using EEDCP

VI. CONCLUSIONS

In this paper, an energy balanced distributed clustering algorithm (EBDC) based on virtual grid for wireless sensor networks is proposed, which is bale to dramatically prolong network lifetime and achieve energy consumption. In the EBDC, we introduce the typical energy model to compute energy consume, virtual grid technology to construct the cluster and a long sleeping state to reduce energy consumption. In addition, we computes the probability of active node j to be cluster head in the next round instead of voting, which can significant reduce the computing times and the number of transmitting information. Further, simulation experiments are conducted to compare the EBDC with some well-known clustering algorithms and simulation results show that the proposed methods significantly balances the node's average energy consumption and prolong the network lifetime.

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