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# A Novel Unequal Cluster-Based Data Aggregation Protocol for Wireless Sensor Networks

***Abstract**. Data aggregation is an effectual approach for wireless sensor networks (WSNs) to save energy and prolong network lifetime. A novel unequal cluster-based data aggregation protocol is proposed in this paper. It divides the network into some grids with unequal sizes, and implements cluster head rotation in each grid respectively. It is able to balance energy dissipation by setting proper sizes of grids to adjust the number of nodes that participate in cluster head rotation in different grids. Furthermore, it adopts some methods to enhance usage efficiency of energy. The results of simulations show that it can achieve better performance in aspects of network lifetime, energy efficiency and balanced extent of energy dissipation.*

***Streszczenie** Efektywnym sposobem na zaoszczędzenie energii i przedłużenie czasu życia sieci, w przypadku bezprzewodowych sieci czujnikowych (WSN), jest agregacja danych. W opracowaniu zaproponowano nowy, nierównomierny klaster oparty o protokół agregacji danych. Sieć podzielono na kilka siatek o nierównych wymiarach i wprowadzono rotację głównych klastrów (węzłów) kolejno w każdej siatce. Zrównoważenie rozproszenia energii można osiągnąć przez ustalenie odpowiednich rozmiarów siatek w zależności od ilości węzłów, które uczestniczą w rotacji klastrów głównych w różnych siatkach. Ponadto zastosowano kilka metod podwyższenia sprawności energetycznej. Wyniki symulacji pokazują, że można osiągnąć lepsze parametry w zakresie czasu życia sieci, wydajności energetycznej i zrównoważonego stopnia rozproszenia energii. **Nowy nierównomierny klaster oparty o protokół agregacji danych dla bezprzewodowej sieci czujnikowej***

**Keywords:** Wireless Sensor Networks, Data Aggregation, Unequal Clustering, Balanced Energy Dissipation.
**Słowa kluczowe:** bezprzewodowe sieci czujnikowe, agregacja danych, zrównoważone rozproszenie energii

## Introduction

Recent advances in micro-electro-mechanical systems technology, embedded computing technology and wireless communications technology have enabled the development of WSNs. The existing and potential applications of WSNs are extensive both in civilian and military domains [1]. Due to the limitations of size and cost, sensor nodes of most WSNs are equipped with limited and non-rechargeable power source. Therefore, how to save energy for prolonging network lifetime turns into a vital issue in WSNs.

Data aggregation is considered as an effectual approach for WSNs to save energy. It is the process of aggregating the data from multiple sensors to eliminate redundant data and provide fused data to the base station [2]. Various data aggregation protocols have been proposed for WSNs and the cluster-based data aggregation is one of the most important kinds. In cluster-based protocols, nodes are grouped into clusters and each cluster consists of a cluster head and some members [3]. Every cluster head collects and aggregates the sensed data of its members, then, transmits the fused data to the base station directly or by the multi-hop route of cluster heads.

It is explicit that a cluster head generally consumes more energy than a member. Additionally, different cluster heads expend different energy. Therefore, the energy dissipation of nodes may be unbalanced in cluster-based WSNs. As a result, some nodes drain their energy faster than others and lead to earlier failure of the whole network.

The motivation of our work is to address the problem of unbalanced energy dissipation in cluster-based WSNs which gather data periodically and adopt multi-hop route of cluster heads. Our contribution is proposing a Balanced Energy Dissipation and Energy Efficient Cluster-based (BEDEEC) data aggregation protocol which is a novel unequal cluster-based protocol and adopts a new strategy to balance the energy dissipation of nodes.

The remainder of this paper is organized as follows: section 2 provides a brief overview of related work; section 3 describes basal models and states problem; BEDEEC protocol is proposed in detail by Section 4; section 5 presents the analysis of BEDEEC; section 6 evaluates the performance of BEDEEC; conclusion and future work are given by Section 7.

## Related work

There are mainly three kinds of cluster-based protocols proposed with the purpose of balancing energy dissipation. The first kind adopts cluster head rotation strategy. The other two kinds are equal cluster-based protocols and unequal cluster-based protocols.

LEACH [4] is a typical cluster-based protocol which adopts the strategy of cluster head rotation. It divides the operation into rounds and selects a new set of nodes as cluster heads in every round. With the help of cluster head rotation strategy, LEACH is able to distribute the energy load of cluster heads among all nodes.

The equal cluster-based protocols try to form clusters with uniform size in each round. There are two methods to form uniform clusters, optimized clustering and fixed clustering. HEED [5] utilizes optimized clustering to periodically selects cluster heads and from uniform clusters according to a hybrid of the residual energy and a secondary parameter. A fixed clustering protocol proposed in [6] divides the network into equal square zones basing on location information, the nodes in the same zone form a fixed cluster, new cluster heads are chosen at periodic intervals.

Soro and Heinzelman have investigated the problem of unbalanced energy dissipation in cluster-based WSNs and proposed the first unequal cluster-based protocol to solve this problem [7]. By changing the number of nodes in each cluster with respect to expected relay load of cluster head, unequal cluster-based protocol has the capability to maintain balanced energy dissipation among cluster heads in each round. EEUC [8] selects some tentative cluster heads randomly to compete for cluster heads. Each tentative cluster head has a competition radius which decreases as its distance to the base station decreases, so that more clusters are produced closer to base station. Finally, each cluster head chooses another cluster head or the base station as its next hop destination based on residual energy and energy cost of relaying data to build multi-hop route. EEMR [9] employs the similar clustering algorithm in EEUC, but the multi-hop route among cluster heads in EEMR is constructed by the base station. MRPUC [10] assigns a cluster radius which decreases as the distance between node and the base station decrease to each node, and makes all nodes compete for cluster heads according to residual energy. Then, each ordinary node chooses a cluster head to form unequal clusters by considering the distance to the cluster head and the residual energy of the cluster head. Finally, each cluster head choose the cluster head which has minimum energy consumption for forwarding data and maximal residual energy as relay node to form multi-hop route of cluster heads. UCR [11] includes EEUC algorithm and a greedy geographic, energy-aware routing protocol for cluster heads.

## Problem outline

### *A. Network Model*

We consider a network model familiar in other cluster-based protocols. $N$ sensor nodes are uniformly dispersed within a rectangular deployment area with length $L$ and width $W$. The left bottom vertex of deployment area is located at ($O\_x$, $O\_y$) in Cartesian coordinate plane. The base station is located at position ($BS\_x$, $BS\_y$) which is out of the deployment area. Each node is assigned a unique ID and reports its sensed data periodically. In addition, we make some assumptions about the network as follow:

1. All nodes and the base station are stationary after deployment.
2. All nodes are homogeneous and energy constrained.
3. Every node is able to adjust its transmission power level according to the distance to the receiver.
4. All nodes and the base station are location-aware.

### *B. Energy Consumption Model*

We use a simplified energy consumption model which takes statistics of the energy dissipation whenever a node transmits or receives messages or performs data aggregation [11]. The energy spent for transmitting an $l$-bit message over distance $d$ is

(1) $$E_{Tx}(l, d)= \begin{cases} l\times E_{elec}+l\times\varepsilon_{fs}\times d^2, d< d_0 \\ l\times E_{elec}+l\times\varepsilon_{mp}\times d^4, d \geq d_0 \end{cases}$$

To receive this message, the expended energy is

(2) $$E_{Rx}(l)=l\times E_{elec}$$

The consumed energy of aggregating $m$ messages with $l$-bit is

(3) $$E_A(m, l)=m\times l\times E_{DA}$$

### *C. Problem Statement*

There are two reasons leading to unbalance energy dissipation in cluster-based WSNs. The first is that cluster heads and members consume different energy. The second is that different cluster heads expend different energy during intra-cluster and inter-cluster communication.

The protocols adopting cluster head rotation strategy distribute the energy load of cluster heads among all nodes, and the equal cluster-based protocols can balance the amount of received data of cluster heads during intra-cluster communication in each round. Although they are able to mitigate the unbalanced degree of energy consumption, they cannot outright resolve the problem.

For the cluster-based WSNs adopting multi-hop inter-cluster communication, the cluster heads closer to the base station consume more energy for heavier relay load. The unequal cluster-based protocols form clusters with unequal sizes and make the clusters closer to the base station have fewer members, thereby, these cluster heads are able to expend less energy during intra-cluster communication and reserve more energy for relaying data during inter-cluster communication. Although the unequal cluster-based protocols are more effectual in balancing energy dissipation, the existing unequal cluster-based protocols have some disadvantages. Firstly, they do not consider the distribution of cluster heads, as a result, the cluster heads are randomly dispersed, and the purpose of unequal clustering will be influenced. Secondly, the multi-hop routes of cluster heads in these protocols are built basing on messages exchanging which will produce excess energy dissipation.

## BEDEEC protocol

The operation of BEDEEC is divided into rounds and every round consists of a set-up phase and a steady-state phase, particularly, there is a network-division phase before the first round.

An overview of BEDEEC is depicted by Figure 1, in which the dashed lines mark the division of swim lanes, the dotted-dashed lines denote the division of grids and the dotted lines indicate the division of clusters.

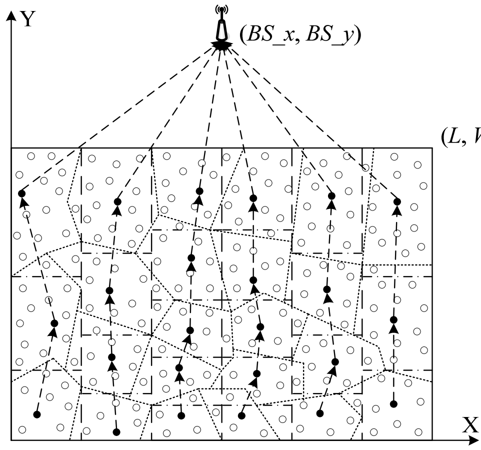


Fig.1. An overview of BEDEEC

### *A. Network-division Phase*

First, the deployment area is divided into several swim lanes. Suppose that the base station is above deployment area along Y-axis, the division is performed along X-axis. The number of swim lanes is $M$. Each swim lane has equal width $P$, and the length of each swim lane is equal to the width of deployment area. We use a sequence of integers starting from 1 as the IDs of swim lanes and the ID of the leftmost swim lane is 1. A node located at ($x$, $y$) within swim lane with ID $j$ satisfies

(4) $$O\_x+ (j-1)\times P<x\leq O\_x+j\times P$$

(5) $$O\_y<y<O\_y+W$$

Secondly, each swim lane is partitioned into several grids. Each grid has the same width with swim lane and is assigned a level. We use a sequence of integers starting from 1 as the levels of grids in each swim lane and the level of the bottommost grid in each swim lane is 1.

BEDEEC adjusts the size of each grid by setting its length. A grid with bigger size will have more nodes to take part in the rotation of cluster heads and share in the energy dissipation. For the same swim lane, the upper a node locates, the closer it is to the base station, the more data it has to relay when it serves for cluster head, for the sake of balancing energy dissipation of nodes in the same swim lane, a grid with higher level must be bigger than a grid with lower level. For different swim lanes, the further a swim lane is away from the base station, the longer transmission distances the cluster heads in its highest level grid have to use, in the interest of balancing energy dissipation of nodes in different swim lanes, the further a swim lane is away from the base station, the bigger its highest level grid must be. Therefore, it is reasonable to restrict that, for the grids in the same swim lane, a grid with higher level has a longer length, for the highest level grids in different swim lanes, the further a swim lane away from the base station the longer length its highest level grid has, for different swim lanes, the further a swim lane away from the base station the fewer grids it has.

We define an array $\boldsymbol{Q}$ with $M$ elements, $\boldsymbol{Q}=\{q_1, q_2, \ldots, q_u, \ldots, q_M\}$, where the $u$-th element is the number of grids in swim lane with ID $u$. Thus, the total number of grids in network is

$$G=\sum_{u=1}^{u\le M} q_u \tag{6}$$

Each grid is assigned a two-tuples ($i$, $j$) as its ID, which means that its swim lane ID is $i$ and its level is $j$. In addition, we define an array for each swim lane respectively to denote the lengths of its grids, the $v$-th array $\boldsymbol{H}_v$ is the lengths of grids in swim lane with ID $v$, and the $w$-th element of $\boldsymbol{H}_v$ is the length of grid ($v$, $w$). If a node located at ($x$, $y$) belongs to the grid ($v$, $w$), it has to satisfy the following relations

$$O\_x+(v-1)\times P<x\le O\_x+v\times P \tag{7}$$

$$O\_y+\sum_{k=1}^{k\le w-1} h_{vk} < y \le O\_y+\sum_{k=1}^{k\le w} h_{vk} \tag{8}$$

When the division of network is complete, the base station broadcasts a *BS_INFRMTN _MSG* ($L$, $W$, ($O\_x$, $O\_y$), ($BS\_x$, $BS\_y$), $M$, $P$, $\boldsymbol{Q}$, $\boldsymbol{H}_1$, …, $\boldsymbol{H}_M$) message to all nodes. All nodes receive this message and store the relevant information. At the end, each node calculates the ID of the grid it within by the following pseudo-code.

BEGIN
  $v\leftarrow\lceil (x-O\_x)/P \rceil$;
  $m\leftarrow y-O\_y$;
  $n\leftarrow 1$;
  While($n\le q_v$)
    If $m\le \sum_{k=1}^{k\le n} h_{vk}$
      $w\leftarrow n$;
      BREAK;
    END If;
    $n$++;
  END While
  Return ($v$, $w$);
END

***B. Set-up Phase***

For any living node in network, there are four states, i.e., *Ordinary Node*, *Member*, *Cluster Head* and *Cluster Head of Last Round*. At the beginning of the first round, each node changes its state into *Ordinary Node*.

*a. Cluster Head Selection Algorithm*

BEDEEC chooses the node with maximal residual energy of each grid as the grid's cluster head in each round. The node ID may be used to break ties.

In the first round, the cluster head of a grid is selected by the cooperative work of nodes within the grid. Firstly, each node sends a *N_INFRMTN_MSG* ($k$, ($v$, $w$), $Er$, ($x$, $y$)) message to other nodes in the same grid, where $k$ is node ID, ($v$, $w$) is node's grid ID, $Er$ is node's residual energy and ($x$, $y$) is the location of node. To save energy, the range of *N_INFRMTN_MSG* message sent by a node only has to cover the node's grid. Each node can calculate the maximal distance to the vertexes of its grid by the following pseudo-code and sets a proper transmission power level.

BEGIN
  $(A\_x, A\_y)\leftarrow((v-1)\times P+O\_x,\ \sum_{k=1}^{k\le w-1} h_{vk}+O\_y)$;
  $(B\_x, B\_y)\leftarrow(v\times P+O\_x,\ \sum_{k=1}^{k\le w-1} h_{vk}+O\_y)$;
  $(C\_x, C\_y)\leftarrow(v\times P+O\_x,\ \sum_{k=1}^{k\le w} h_{vk}+O\_y)$;
  $(D\_x, D\_y)\leftarrow((v-1)\times P+O\_x,\ \sum_{k=1}^{k\le w} h_{vk}+O\_y)$;
  $d\_A\leftarrow\sqrt{(x-A\_x)^2+(y-A\_y)^2}$;
  $d\_B\leftarrow\sqrt{(x-B\_x)^2+(y-B\_y)^2}$;
  $d\_C\leftarrow\sqrt{(x-C\_x)^2+(y-C\_y)^2}$;
  $d\_D\leftarrow\sqrt{(x-D\_x)^2+(y-D\_y)^2}$;
  $Dmax\leftarrow$MAX($d\_A$, $d\_B$, $d\_C$, $d\_D$) ;
  Return $Dmax$;
END

Each node only receives the *N_INFRMTN_MSG* messages whose grid IDs are same with node's grid ID, and adds the information of the messages into node's *Grid_Node_Info* list. By this way, every node is able to collect the information of all nodes within the same grid. Then, each node can select the cluster head of its grid, and if a node selects itself as a cluster head, it changes its state into *Cluster Head*.

In each round after the first round, the cluster heads of current round are chosen by the cooperative work of cluster heads of last round based on the information collected in last round. At the last time of data gathering in last round, each node transmits the information of its residual energy along with its sensed data to its cluster head, then, each cluster head is able to update the information of nodes in its *Cluster_Node_Info* list.

At the beginning of current round, each last round cluster head changes its state into *Cluster Head of Last Round* and each last round member changes its state into *Ordinary Node*. Afterward, each last round cluster head checks its *Cluster_Node_Info* list and sorts all nodes including itself in the list in terms of grids, in succession, it chooses a tentative cluster head for each grid and sends a *CH_TCH_INFRMTN_MSG* (…; $k_m$, ($v_m$, $w_m$), $Er_m$, ($x_m$, $y_m$)) message which contains the information of tentative cluster heads of other grids to the last round cluster heads of corresponding grids, the transmission distance of this message is the maximal distance to the vertexes of all corresponding grids. Each last round cluster head receives the messages including tentative cluster head of its grid. After receiving all corresponding *CH_TCH_INFRMTN_MSG* messages, each last round cluster head chooses the current round cluster head of its grid from the grid's tentative cluster heads in received messages and the grid's tentative cluster head selected by the last round cluster head itself. If the last round cluster head is the selected current round cluster head, the last round cluster head changes its state into *Cluster Head*, otherwise, the last round cluster head changes its state into *Ordinary Node* and sends a *TCH_CH_INFRM_MSG* message to inform the current round cluster head, and the current round cluster head node changes its state into *Cluster Head*.

*b. Cluster Formation Algorithm*

The cluster formation algorithm is similar to LEACH. Each cluster head broadcasts a *CH_BRDCST_MSG* message to inform other nodes. The range of broadcast message of each cluster head only has to cover the cluster head's grid, by this way, BEDEEC not only guarantees that every ordinary node will be covered by at least one broadcast message, but also saves energy. Then, each ordinary node chooses the closest cluster head as its cluster head by sending a *N_JOINT_MSG* message to the selected cluster head and changes its state into *Member*. In the end, each cluster head builds a *Cluster_Node_Info* list to store the information of all nodes in its cluster, sets up a

TDMA schedule to avoid collisions among its members, and transmits the schedule to the members.

### *C. Steady-state Phase*

The operation of steady-state phase is divided into some frames, and each frame consists of an intra-cluster communication sub-phase and an inter-cluster communication sub-phase.

*a. Intra-cluster Communication Sub-phase*

In intra-cluster communication sub-phase, each member sends its sensed data to its cluster head during its allocated transmission slot according to the TDMA schedule firstly. And then, each cluster head aggregates the collected data. If current frame is the last frame of current round, each member has to transmit its residual energy information along with its sensed data to its cluster head. By this way, each cluster head is able to obtain the residual energy information of all nodes in its cluster and update its *Cluster_Node_Info* list which will be used for tentative cluster head selection in the next round.

*b. Inter-cluster Communication Sub-phase*

Different from other unequal cluster-based protocols, there is no need for BEDEEC to construct an explicit multi-hop route among cluster heads by messages exchanging. In BEDEEC, each cluster head chooses an available grid which is in the same swim lane and has adjacent higher level than the level of cluster head's grid as its next-hop destination, if such available grid does not exist, the cluster head chooses the base station as its next-hop destination. An available grid is a grid that has one or more living nodes. The information of available grids is collected by the base station basing on the received data messages and is broadcasted to the corresponding nodes. If the next-hop destination of a cluster head is a grid, the cluster head only has to guarantee that its data message is able to cover this grid, even do not have to know which or where the cluster head of this grid is. Every cluster head receives the data messages taking its grid as next-hop destination. So that there are no overhead messages exchanging among cluster heads.

## Protocol analysis

We discuss the message complexity of BEDEEC firstly.

LEMMA 1. The message complexity for clustering of BEDEEC is $O(N)$ in the network.

PROOF: Since the first round only takes up very little part in the lifetime of network, we only consider the latter rounds. For each round, firstly, $G$ last round cluster heads transmit $G$ *CH_TCH_INFRMTN_MSG* messages, then, $G$ last round cluster heads send $G$ *TCH_CH_INFRM_MSG* messages, afterward, $G$ cluster heads transmit $G$ *CH_BRDCST_MSG* messages, in the end, $(N–G)$ ordinary nodes send $(N–G)$ *N_JOINT_MSG* messages. Thus the messages for clustering in each round add up to $G+G+G+N–G=N+2G$. So that the message complexity for clustering of BEDEEC is $O(N)$ in the network.

Although the message complexity for clustering of existing unequal cluster-based protocols are $O(N)$ too. The number of messages for clustering of BEDEEC is fewer than these cluster-based protocols which choose cluster heads by competition. Taking UCR for example, the number of messages for clustering per round is $N+2T\times N$, where $T$ is probability of an ordinary node becoming a tentative cluster head. The expected number of tentative cluster heads is $T\times N$, suppose that $H$ is the expected number of cluster heads, and there is

(9) $$H < T\times N$$

In BEDEEC, the expected number of cluster heads is $G$, and we assume that BEDEEC and UCR have the same expected number of cluster head per round, i.e., $H=G$, therefore,

(10) $$N+2G= N+2H< N+2T\times N$$

So that the number of messages for clustering of BEDEEC is fewer than UCR which proves that BEDEEC outperforms UCR in the aspect of message complexity.

Then, we analyze the energy dissipation of BEDEEC and summarize the following characteristics.

1. BEDEEC partitions the network into unequal grids, performs cluster head rotation in each grid respectively, and forms unequal clusters, so that it can adjust the number of nodes participating in cluster head rotation within each grid by setting the grid size to balance the energy dissipation of nodes in different grids. The grids closer to the base station are bigger, so that the clusters closer to the base station are bigger which contrary to the existing unequal cluster-based protocols, therefore, the cluster heads closer to the base station consume more energy, but the grids closer to the base station have more nodes to take part in cluster head rotation. By this way, although the energy dissipation of cluster heads in different grid is unbalanced in each round, the energy dissipation of nodes in different grids is balanced on a long view.

2. By selecting the node with the highest residual energy in each grid as cluster head, BEDEEC is able to balance the energy dissipation of nodes in individual grid.

3. BEDEEC is energy efficient. Firstly, except the first round, cluster heads are selected by the cluster heads of last round but not by the competition of more nodes. Secondly, there is no need to construct an explicit multi-hop route among cluster heads by exchanging messages. Thirdly, the necessary information of nodes for selecting cluster heads is transmitted along with sensed data. Fourthly, the transmission distances and destination nodes of messages are limited to required range.

## Simulations

We evaluate the performance of BEDEEC by simulations and choose UCR for comparison. The parameters of simulations are listed in Table 1.

Table 1. The Parameters of simulations.

| Parameter | Value |
|---|---|
| Number of nodes | 600 |
| Deployment area [m, m] | (0,0)-(300,250) |
| Location of base station [m, m] | (150,350) |
| Initial energy of each node [J] | 1 |
| $E_{elec}$ [nJ/bit] | 50 |
| $\varepsilon_{fs}$ [pJ/(bit×m$^2$)] | 10 |
| $\varepsilon_{mp}$ [pJ/(bit×m$^4$)] | 0.0013 |
| $d_0$ [m] | 86.2 |
| $E_{DA}$ [nJ/bit] | 5 |
| Size of control message [bit] | 800 |
| Size of data message [bit] | 1600 |

The division parameters of network in BEDEEC are set as: $M$=6, $P$=50, $Q$={3,4,5,5,4,3}, $\boldsymbol{H}_1=\boldsymbol{H}_6$ ={60,80,110}, $\boldsymbol{H}_2=\boldsymbol{H}_5$={40,50,70,90}, $\boldsymbol{H}_3=\boldsymbol{H}_4$={30,40,50,60,70}.

First, we measure the network lifetime of BEDEEC and UCR. Figure 2 plots the number of living nodes over rounds. The first node dies in 672nd round and the last node dies in 847th round of BEDEEC, while the first node dies in 386th round and the last node dies in 726th round of UCR. BEDEEC improves the network lifetime 74.09% and 16.67% over UCR respectively.

Secondly, we compare the energy efficiency of BEDEEC and UCR. We take statistics of the total residual energy of network over rounds, as shown in Figure 3. As evident from the figure, BEDEEC has more residual energy than UCR in every same round, which illuminates that BEDEEC is more energy efficient than UCR.

In the end, we estimate the performance of BEDEEC and UCR in balancing energy dissipation. Commonly, the ratio of time interval between the time until the first node dies( $FND$) and the time until the last node dies($LND$) to the full time is able to indicate the balanced extent of energy dissipation, so that we introduce an estimation criterion balanced extent of energy dissipation ($BEED$) calculated as follows

(11) $$BEED= (LND–FND)/LND$$

The value of $BEED$ is a number from 0 to 1, and the protocol with smaller $BEED$ has a better performance in aspect of balancing energy dissipation. According to formula (11), the $BEED$ of BEDEEC is 0.2066 and the $BEED$ of UCR is 0.4683, figured by Figure 4. The result of contrast shows that BEDEEC is able to achieve more balanced energy dissipation than UCR.

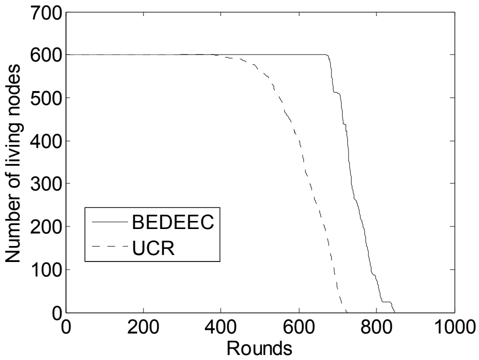

Fig.2. Number of living nodes over rounds

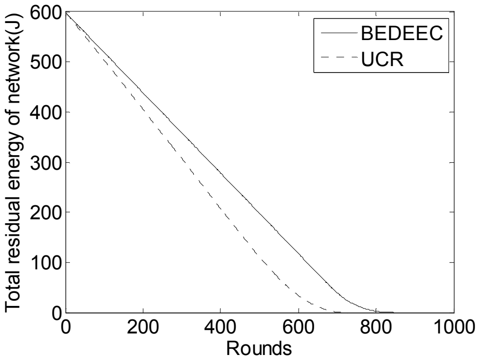

Fig.3. Total residual energy of network over rounds

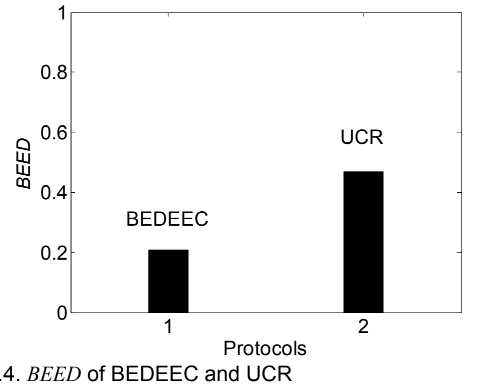

Fig.4. $BEED$ of BEDEEC and UCR

**Conclusion and future work**

In this paper, we focus on the problem of unbalanced energy dissipation in cluster-based WSNs and propose BEDEEC protocol. Unlike the existing unequal cluster-based protocols which try to balance the energy dissipation of cluster heads in each round, BEDEEC attempts to balance the energy dissipation of nodes on a long view. The results of simulations show that BEDEEC outperforms UCR in aspects of network lifetime, energy efficiency and balanced extent of energy dissipation.

The optimal division of network depends on the specific application, as a future work, we will formulate the parameters of BEDEEC to maximize the performance of network.

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