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Energy Efficient Routing Protocol for Cluster Based WSN with Non Uniform Node Distribution

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Abstract— Clustering is an efficient method for increasing the lifetime of wireless sensor network systems.The energy consumption associated with the cluster based wireless sensor network systems is more inconsistent. This imbalance in the energy consumption is due to the non-uniform node distribution. To avoid this problem, introduce a cluster based routing protocol with non-uniform node distribution. It consists of an energy efficient distributed clustering algorithm, EEDC and cluster based routing algorithm. EEDC helps for the clusters of even sizes. At the same time with the help of clustering algorithm, the cluster head can choose their next node which has higher residual energy and lesser number of member nodes. These helps in achieving load balance among cluster heads.Theoretical analysis and simulation results show that EEDC balance energy consumption well among the cluster heads and increase the network lifetime effectively.

Index Terms— clustering, member nodes, network lifetime, routing algorithm, wireless sensor network systems,

1 Introduction

ENERGY efficiency is one of important key factor in designing a wireless sensor network system. Large energy consumption will affect the lifetime of the sensor networks. Due to limited energy provision care must be taken while designing the topology.

Clustering is an important method for increase the scalability and lifetime of wireless sensor network system. The sensor network is divided into clusters. Each cluster consists of cluster head and member nodes. In the first step the sensor nodes sense the physical parameter under consideration and collected data are sent to the cluster head. During second phase the cluster head forwards the data to the base station in a single hop or multi-hop manner. In the case of multi-hop communication an efficient routing protocol is required for attain the energy balance.

Two types of energy consumptions are associated with a CH, inter cluster and intra cluster energy consumption. The energy reduction during receiving and aggregating the data from the cluster members is known as intra cluster energy consumption. While forwarding the aggregated data to the base station also reduce some amount of energy associated with the CH, it is termed as inter cluster energy consumption. To make a balance between the energy among nodes, most clustering algorithm uses cluster head rotation mechanism. In most cases the cluster head rotation is based on energy of the cluster head or a time basis. In time based cluster head rotation mechanism, the role of cluster head changes after particular time duration. In the case of energy based CH rotation mechanism, the role of CH changes when the residual energy of cluster head is less than a threshold value. In both cases the size of clusters are almost equal due to equal radio range

In clustering networks, the imbalanced energy consumption among nodes is the key factor affecting the network lifetime. In order to balance the energy consumption among nodes, clustering algorithms for networks with uniform node distribution tend to construct uniformly distributed cluster heads, so that the clusters have the approximate number of members and coverage areas. Thus, the intra-cluster energy consumption of cluster heads is approximate and the energy consumption of cluster heads can be balanced. For cluster members, the maximum communicate distances of cluster members are approximate, because of the uniform cluster sizes. Thus, the energy consumption of cluster members can be balanced too. Therefore, the uniformly distributed cluster head set can balance the energy consumption among nodes and finally prolong the network lifetime. In networks with non-uniform node distribution, the mechanisms used to balance the energy consumption and prolong the network lifetime are not always effective. The uniformly distributed cluster heads enable the clusters have the uniform cluster sizes, so that the energy consumption among cluster members can be balanced. However, the imbalanced energy consumption still exists among cluster heads due to the Nonuniform node distribution.

In this paper, propose a cluster-based routing protocol for wireless sensor networks with non-uniform node distribution whose cores are an energy-efficient distributed clustering algorithm EEDC and a cluster-based routing algorithm. EEDC constructs clusters of even sizes using competition range in order to balance the energy consumption among cluster members. To solve the imbalanced energy consumption among cluster heads caused by the non-uniform node distribution, a cluster-based routing algorithm is proposed, which balance the energy consumption among cluster heads by adjusting the intra-cluster and inter-cluster energy consumption of cluster heads. Therefore, it can achieve the balance of energy consumption among nodes and prolong the network lifetime.

2 Related Works

LEACH: It is a clustering based routing protocol that utilizes random rotation of cluster heads with a probability. Base sta-

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tion receives and aggregates information from member nodes and sends the aggregated data to the base station, which is located outside the sensor field in a single hop communication. In order to balance the energy dissipation, the role of cluster head is periodically rotated among the nodes. While considering the performance of LEACH in heterogeneous environment, is not very good, because the election of the cluster head is not based on the residual energy.

EADEEG: It is a distributed clustering algorithm. The selection of cluster head is based on the ratio between the average residual energy of residual node and residual energy of node its self EADEEG provides a very well cluster head distribution and increases the network lifetime. EADEEG cause "isolate point" problem.

EEUC: Energy Efficient Unequal Clustering uses a probabilistic method to elect the tentative cluster head. Tentative cluster head nodes participate in the CH competition. This protocol considers the residual energy of node for CH election.

BPEC: It is a distributed energy saving clustering algorithm. It elects cluster heads by the ratio between the average residual energy of neighbor nodes and the residual energy of the node itself as its primary probability and the node's degree as its subsidiary probability. BPEC can avoid the "isolate points" problem in EADEEG and keep all the cluster heads connected. The above several algorithms only have one layer of the cluster head. Therefore they are called single-level clustering algorithms. In order to further save energy in the network, adopt multi-level clustering strategy, and propose three multi-level clustering algorithms.

All the algorithms mentioned above are all based on the assumption that all the nodes are uniformly distributed in the networks. In networks with non-uniform node distribution, considering the network coverage problem, proposed some good cluster head election techniques. However, this paper focused on coverage preservation, while the energy consumption balance and network lifetime on the back burner. Considering the node distribution, propose a hierarchical architecture of sensor network with cluster formation and cluster head selection algorithm. It used various parameter metrics related to node density and indicate the deployment density variation of nodes by the edge of link lengths standard deviations.

3 Network Modal

To simplify the system model, considering few reasonable assumptions.

Let us consider a sensor network contain N number of sensor nodes, distributed randomly in an MxM square field.

1. There is a base station (data sink) fixed far away from the sensing field. All the sensor nodes and base station are stationary after deployment.
2. The sensor nodes are heterogeneous in nature and they have same capability.
3. The sensor nodes are location unaware.
4. Nodes are capable of power control to vary the power of transmission. The power control depends on the distance to base station
5. The base station is located outside the sensor field. The location of base station is known by all the sensor nodes and it has sufficient energy resource.
6. Each node is indicated by the identity (id).

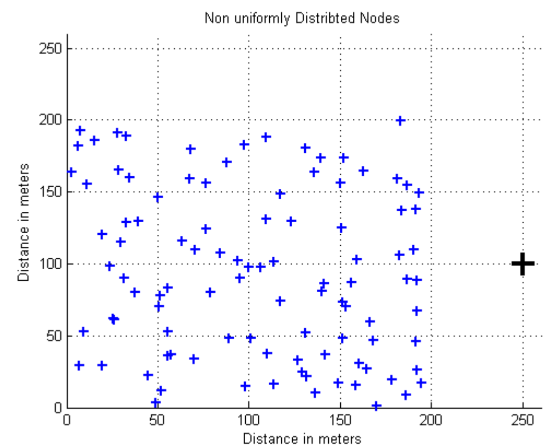

Fig. 1. Non uniformly distributed network model

4 Energy Model

We are considering the free space and multipath fading channel models. The channel model selection depends on the distance between the transmitter and receiver. The energy consumed for transmission of 'l' bit data packet over distance d is given by

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

In the above equation d is the transmission distance; the packet length is denoted by l. E_{elec}, ε_{fs} and ε_{mp} are parameters of the transmission and reception circuitry. While receiving an l-bit data, the radio expends energy

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

Here assume that the sensed data is highly correlated, thus the cluster head can aggregate the data gathered from its member nodes into a single packet having fixed length.

5 Distributed Cluster Based Routing Protocol

Cluster based Routing Protocol

The proposed protocol consists of an energy efficient varying sized clustering algorithm and unequal cluster based routing algorithm. The detailed description of the EEVSCA and routing algorithm are in the following two subsections. The descriptions of control message used in the process are shown in the table 1. To choose the cluster head which having higher energy, we consider the ratio between the average residual energy of neighbour nodes and the residual energy of the node itself. To construct the clusters of even sizes,the cluster head broadcast head message using the competition

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range.Thus the energy consumption among cluster members can be balanced well.Cluster head which are located in the congested areas have large number of member nodes,this will cause high intra cluster energy consumption. To reduce this, we introduce an inter cluster energy efficient multihop routing protocol,which helps cluster heads to elect the neighbour cluster head with higher residual energy and a lesser number of cluster members as the next hop.This will balance the energy consumption between the cluster heads.The different control messages are described in table 1.

In the network deployment stage the base station broadcasts a signal with particular energy level. Each node can calculate its approximate distance to BS based on the strength of the received signal.

TABLE 1
DESCRIPTION OF CONTROL MESSAGES

Message	Description
Node_Msg	Tuple(*selfid, selfenergy*)
Head_Msg	Tuple(*selfid*)
Join_Msg	Tuple(*selfid, headid*)
Schedule_Msg	Tuple(*scheduleorder*)
Route_Msg	Tuple(*selfid,selfenergy,membernum,disttoBS*)

5.1 EEDC details

This phase is similar to the setup phase in LEACH. The whole process is divided into three.

- Data collection phase(T_1)
- Cluster head competition phase(T_2)
- Cluster construction phase(T_3)

5.1.1 Data collection phase

During this phase each node broadcasts a node message with the following two values. One is node and the other is the residual energy of this node within radio range R_c. At the same time, it receives the *Node_Msg* messagesfrom its neighbour nodes, according to which, each node S_i calculates the average residual energy E_{ia} of its neighbor nodes by using the following formula.

$$E_{ia} = \frac{1}{d}\sum_{j=1}^{d} E_{jr} \quad (3)$$

Where E_{jr} denotes the residual energy of S_j, one neighbour node of S_i, and d is the number of all neighbour nodes of S_i. For each node, we give the following formula using which to calculate its waiting time for broadcasting *Head_Msg* message.

$$t_{wi} = \begin{cases} \left[\left(1 - \frac{E_{ir}}{E_{ia}}\right) T_2 V_r\right], & E_{ir} \geq E_{ia} \\ T_2 V_r, & E_{ir} < E_{ia} \end{cases} \quad (4)$$

Where t_{wi} denotes the waiting time of S_i, and E_{ir} is the residual energy of S_i, V_r in the formula is a real value uniformly distributed in [0.9, 1] which is introduced to reduce the probability that two nodes send *Head_Msg*s at the same time.

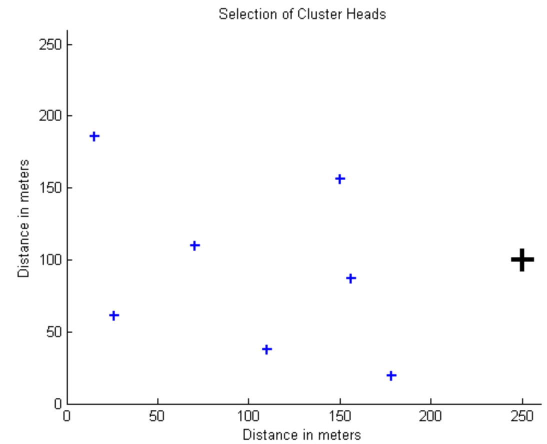

Fig. 2. Cluster head selection

5.1.2 Cluster head competition phase

When T_1 has expired, EEDC begins the cluster head competition phase whose duration is T_2. In this phase, if node S_i receives no *Head_Msg* when timer t_{wi} expires, it broadcasts the *Head_Msg* within radio range R_c to advertise that it will be a cluster head. Otherwise, it gives up the competition.

5.1.3 Cluster construction phase

After T_2 expires, the last phase of EEDC is the cluster formation phase, define the duration as T_3. In this phase, each non-cluster headnode chooses the nearest cluster head and sends the *Join_Msg* which contains the id and residual energy of this node. According to the received *Join_Msgs*, each cluster head creates a node schedulelist including the *Schedule_Msg* for its cluster members, the *Schedule_Msg* is used for telling the cluster members when they can transmit their data to the cluster head and in other time interval they can alter their state to asleep to reduce the energy consumption.At this point, the entire process of EEDC is completed.

5.2 Cluster-based routing algorithm

In this phase, construct a routing tree on the elected cluster head set. The duration of the phase is T_4. This multi-hop communication from cluster heads to the BS will further reduce the energy consumption

As stated earlier, the cluster heads elected by EEDC distribute, which means that all the clusters have even sizes. However, the number of nodes within a cluster is non-uniform, due to the non-uniform distribution of nodes. Clusters in dense areas have more cluster members, while clusters in sparsely covered areas have fewer cluster members, inevitably leading to the imbalanced energy consumption among cluster heads. As we state previously, in multi-hop communication clustering algorithms, the energy consumption of cluster heads is divided into intra-cluster energy consumption and inter-cluster energy consumption. In order to balance the energy consumption among cluster heads, to adjust the ratio of the two part of the energy consumption among cluster heads. Cluster heads insparse areas take on more forwarding tasks to alleviate the imbalance of inter-cluster energy consumption. Taking into account the heterogeneity of nodes, cluster heads with higher residual energy taking more forwarding tasks is better for prolonging the network lifetime.

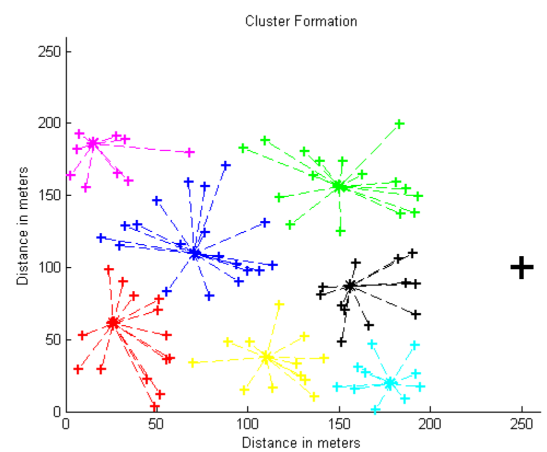

Fig. 3. Cluster construction

Among all the cluster heads, several nodes need to be chosen-to be child cluster heads of the BS, and communicate with the BS directly.Therefore, each cluster head determines whether to communicate with the BS directly according to the distance to the BS. Here, introduce a threshold distance *DIST_TH*. If the distance from cluster head S_i to the BS $d(S_i, BS)$ is less than *DIST_TH*, S_i communicates with the BS directly, and sets the BS as its next hop. Otherwise, it communicates with the BS in multi-hop routing approach, where $d(S_i, BS)$ is the Euclidean distance in 2D space.

As follows introduce how to construct the routing tree on the elected cluster head set in detail. At the beginning, each cluster-head broadcasts a *Route Msg* message within the radio radius R_r with the following values: the id, the residual energy, the numberof cluster members and the distance to the BS of itself. If nodes' radio radius R_r for communicating with othernodes is twice larger than its covered range R_c, and if these nodes can fully cover the monitoring area, then the connectivity of them can be maintain. The cluster heads generated by EEDC can cover all network nodes. Therefore, to ensure the connectivity of cluster heads, we set the radio radius $R_r = 2R_c$. If the distance from cluster head S_i to the BS $d(S_i, BS)$ is less than *DIST_TH*, it chooses the BS as its next hop. Otherwise, it chooses its next hop according to the received *Route_Msgs*. Cluster head S_i chooses the neighbour cluster head with higher residual energy, smaller number of cluster members and no further away from the BS as its next hop. Here, give the formula of the indicators"relay" when cluster head S_i chooses cluster head S_j as its nexthop.

$$relay(s_i, s_j) = \beta \frac{E_{jr}}{E_{\max}} + (1-\beta)\frac{1}{S_{j(cm-num)}} \quad (5)$$

Here E_{jr} is used to measure the residual energy of cluster head s_j and we define E_{max} as the maximum initial energy of nodes in the network. $S_{j(cm-num)}$ is the number of cluster members of S_j, and β is a real value uniformly distributed in [0, 1]. See from the formula, the cluster head with higher residual and fewer cluster members will have a larger "relay". Cluster head S_i chooses the neighbor cluster head with the largest "relay" and closer to the BS as its next hop. If there are more than one cluster heads have the largest "relay", cluster head S_i chooses the one with larger $d(S_j, BS)$ to avoid the premature death of the cluster heads close to the BS, due to forwarding too much data.

5.3 Data transmission phase

The data transmission phase is divided into two stages; they are intra cluster communication and inter cluster communication.

5.3.1 Intra-cluster communication

In this phase communication within a cluster takes place. The sensor node collects the local data from the environment and transmits the data to the cluster head.

5.3.2 Inter-cluster communication

The cluster head receives and aggregate the data received from their cluster members and forward the aggregated data to the next hop node. The forwarding of data takes place with the help of routing tree which is constructed on the basis of cluster based routing algorithm.

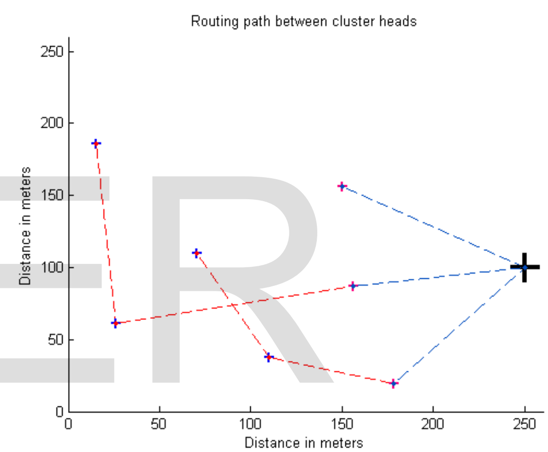

Fig. 4. Cluster based routing path between cluster heads

6 Protocol Analysis

6.1 EEDC analysis

Analyzing EEDC we can summarize the characteristics of EEDC as follows,

1) The equation for waiting time t_{wi} ensures that, the waiting time of each node is less than T_2. There for any expected cluster head can broad cast the Head_Msg and become a cluster head before T_2 expires, which results all the nodes are covered by the elected cluster heads. Different nodes have different waiting time, so there is at most one cluster head in each R_c ratio coverage range.

2) For the construction of clusters, nodes use equal competition range. This leads to balanced energy consumption among the nodes.

3) It elects cluster heads based on the ratio between residual energy of the nodes and average energy of neighbor nodes. Nodes which have relatively higher energy are selected as cluster head. This leads no prolonging the network lifetime.

4) There is no isolate point in EEDC.

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6.2 Routing algorithm analysis

The value of *DIST_TH* determines the number of cluster heads which are communicate directly to the base station. If the *DIST_TH* is less than BS to network field, then there is no child cluster head and the network cannot communicate with BS. On the other hand, if *DIST_TH* is very much larger than the distance from the base station to network field, then the number of child cluster heads will increase and which leads to wastage of energy. Then care must be given while choosing *DIST-TH*.

In the case that cluster heads distribute uniformly in the network, the numbers of cluster members of clusters are uneven, due to the non-uniform node distribution. Therefore, the intra-cluster energy consumption of cluster heads in densely populated parts of the network is larger than that of cluster heads in scarcely covered areas. As the energy consumption of cluster heads consists intra-cluster energy consumption and inter-cluster energy consumption. We mitigate the imbalance of intra-cluster energy consumption by adjusting inter-cluster energy consumption. Cluster heads in scarce areas take more forwarding tasks to achieve a balance of total energy consumption of cluster heads.

7 Simulations

The simulations were performed in MATLAB, every simulation result shown here is the average of 200 independent experiments unless otherwise specified. Where each experiment is done in different scenarios and two scenarios are chosen to be shown as follows:

Scenario 1: 100 nodes are randomly deployed over a 200 m×200 m field.

Scenario 2: 100 nodes are non-uniformly deployed over a 200 m×200 m field.

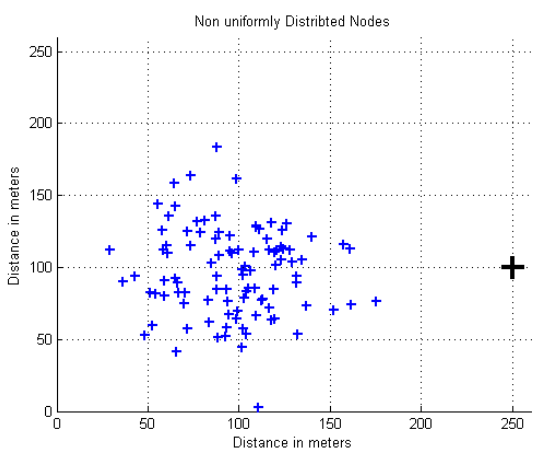

Fig. 5. Scenario 2;100 nodes are non-uniformly deployed

7.1 Cluster head distribution

In these scenarios, we set R_c different values in 10-200, and run the protocol. In Fig. 6, it exhibits the number of cluster heads generated in each scenario. As shown in the figure, the two curves coincide roughly which means that the number of cluster generated in the two scenarios are approximately equal. The reason for this phenomenon is that R_c controls the coverage of cluster head, so that clusters have uniform cluster sizes. Therefore, the number of cluster heads is unaffected by the node distribution. In addition, the uniform cluster size ensures the balance energy consumption among cluster member.

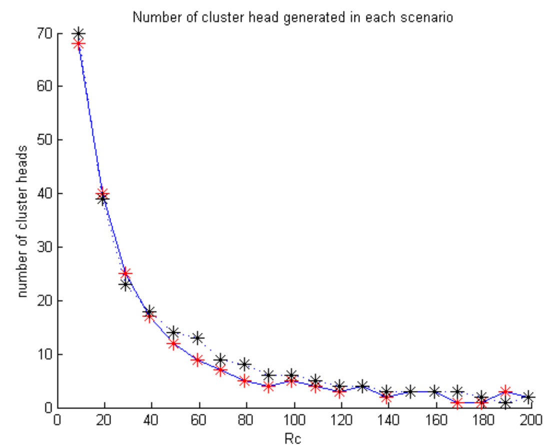

Fig. 6. Number of cluster heads generated in each scenario

7.2 Lifetime Calculation

There is no clear definition for network life time can be calculated using the following ways.

FND-First Node Dies: The time between the deployment of the network and death of the first node.

PNA- Percentage Node Alive: The time till certain percentage of node alive

LND: Last Node Dies: The time when all the nodes in the network are dead

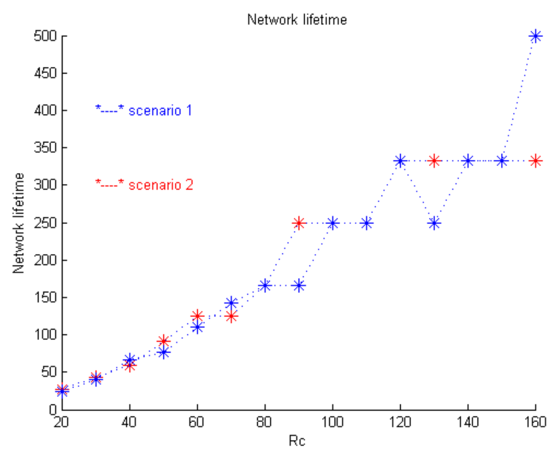

Fig. 7. Network lifetime v/s R_c

Here define the network lifetime as PNA, i.e. the time when 90% of nodes alive. From the fig (6) we can see that when R_{max} increases the total number of cluster head decreases and rate of decrease gradually slows down. This indicates that network life time increases gradually as the value of R_{max} increases. The result shows that EEDC can prolong lifetime.In

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the two scenarios, we set α= 0.5 and *DIST_TH* = 80. Fig. 7 shows the relation between R_c and network lifetime.

To measure the network lifetime generated by our new protocol and others, we run LEACH, EADUC and EEDC.From Fig. 8 we can see that EADUC and EEDC perform far better than LEACH in prolonging network lifetime.

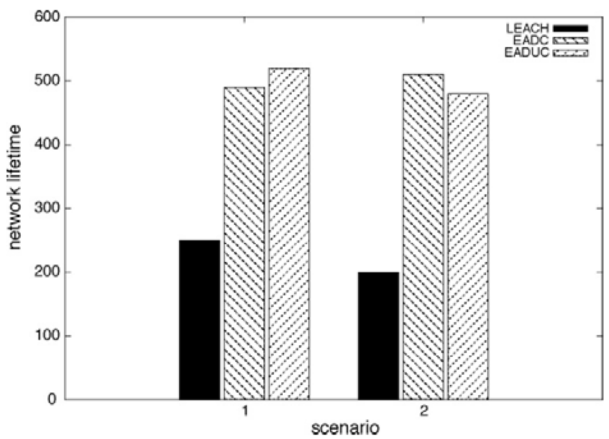

Fig. 8. Comparison with LEACH, EADUC

7 Conclusion

In this paper, propose energy efficient distributed clustering algorithm and cluster based routing protocol. EEDC elects cluster heads based on the ratio between residual energy of the node and average energy of neighbor nodes. The clustering algorithm balances the energy consumption among cluster members by constructing equal clusters. Each cluster head elects its next hop with higher residual energyand fewer cluster members as its next hop, i.e. further energy balance is provided with the help of cluster based routing protocol.

TABLE 2
Parameters of simulations

Parameter	Value
Sensor field	200 m×200 m
BS location	(250,100)
Number of nodes	100
Initial energy of nodes	1–3 J
Data packet size	500 bytes
E_{elec}	50 nJ/bit
ε_{fs}	10 pJ/(bit m2)
ε_{mp}	0.0013 pJ/(bit m4)
E_{sen}	0 J/bit
E_{com}	5 nJ/(bit signal)

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