SCBC: Sector-Chain Based Clustering Routing Protocol for Energy Efficiency in Heterogeneous Wireless Sensor Network

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***Abstract*—One of the most important challenges in heterogeneous wireless sensor network (WSN) is to design a routing protocol that use energy efficiently to prolong the lifetime of the entire network due to the limited battery power of sensor nodes. To solve this problem, in this paper, we propose Sector-Chain Based Clustering (SCBC) Routing Protocol, in which, entire network area is divided into sectors (clusters), which balance to the number of nodes. SCBC further reduces energy dissipation of communication in network by constructing chain for each cluster with the chain leader as the cluster head (CH) or secondary cluster head (SCH) that has high residual energy and the shortest distance between candidate nodes and base station (BS) in network. In addition, SCBC improves energy efficiency by calculating the time length of each round in the steady data transmission phase for CHs or SCHs but still guarantee that it is alive in next round. Our simulation results show that the network lifetime of our proposed protocol can be improved about 70% and 20% in comparison with PEGASIS (Power-Efficient Gathering in Sensor Information System) and IEEPB (An Improved Energy-Efficient PEGASIS-Based) protocols, respectively.**

***Index Terms*—Wireless Sensor Networks, heterogeneous sensor network, energy efficiency, routing protocol, chain-based.**

I. INTRODUCTION

WSNs with hundreds or thousands of micro-sensor nodes can be deployed to support for wide range of applications in many different situations, such as battlefield surveillance, environmental monitoring, intelligent home and etc. The sensor nodes are equipped with small size, low cost, limited bandwidth, processor abilities and resources; particularly, small capacity battery of nodes cannot be recharged or replaced during operation time [1], [2]. Therefore, how to use energy efficiently is very important for designing routing protocols for WSN to maximize network lifetime. Cluster-based routing protocols [1], [3], [4] are widely known as a good technique for maintaining energy efficiency, which support to both homogeneous and heterogeneous network scheme, such as LEACH (Low Energy Adaptive Clustering Hierarchy) [2]–[4], PEGASIS [5], IEEPB [6] and so on. In LEACH protocol, nodes are organized into several clusters. Each cluster elects a leader node called CH, which is responsible for fusing many sensed data packets from its cluster member node(s) with its own data packet into a single packet and forwarding the fused packet to the BS; other nodes (cluster-members) will send sensed data to the respective CH by a single-hop mode, periodically. The energy of CH is rapidly exhausted because it has to further communicate and process more work than other nodes in cluster. Consequently, the role of CH must be passed to another node randomly after a certain time to balance energy consumption between nodes in the WSN. An improvement of LEACH algorithm was proposed by Kaur, et al called EE-TLDC (Energy Efficient Two Level Distributed Clustering) [7], in which the criteria for the selection of CH is based on probability and residual energy of candidate nodes in current time. Moreover, EE-TLDC reduces number of CHs, which transmit directly data packet to BS, by choosing in CHs list few SCHs. SCHs are responsible for forwarding data to BS, other CHs will transmit to nearest SCH instead of BS to save energy. However, the drawback of LEACH and EE-TLDC is that the single-hop communication between nodes and CH or BS, that is far, so, it will die quickly, although the algorithm decreases the complexity. Stephanie Lindsey et al proposed PEGASIS, which is a basic chain-based routing protocol [5], where sensor nodes only connect and communicate with the nearest neighbor into a chain. In order to transmit the fused data to BS, PEGASIS chooses a node to become CH in each round, which has random location in the chain. The simulation results show that performance of PEGASIS and IEEPB are better than LEACH [8], [9]; however, there are still some limitations in this protocol. Firstly, the CH is selected at random location in chain, (no considering the residual energy and distance to the BS). Secondly, some ”long links” still exists due to simple formation chain algorithm. In addition, high delay or a bottleneck at the CH can occur in data transmission phase since the CH is a single node in long chain in PEGASIS. Up until now, there have been many chain-based routing protocols in homogenous network; they are improved based on PEGASIS such as IEEPB [10], EECB (Energy-Efficient Chain-Based) [9], and so on. However, none of the above improvements consider the time length of each round and how to balance number of nodes in each cluster.

Moreover, most of them only deploy in homogeneous, not in a heterogeneous network, where two or more different types of sensor nodes are used those have different battery capacities and functions and it is similar to real situations more [7], [11]. With above analysis, in this paper, we propose Sector-Chain Based Clustering Routing Protocol, namely SCBC base on PEGASIS, which can achieve advantages of both EE-TLDC and IEEPB by dividing the network into logical sectors, which balance the number of nodes and sectors. In SCBC, the Greedy algorithm is used to form the chain alike IEEPB, but SCBC can avoid "long link" in chain by comparing the distance between nodes three time to find out node, which has the shortest link, to join chain. In addition, SCBC chooses CH, SCH in each round by considering remaining energy of candidate nodes and distance between them and BS to decide which node will become the CH or SCH. So, SCBC can enhance energy efficiency by calculating the time length in steady data transmission phase for each round. Our simulation results show that the network lifetime of SCBC can be extended to about 70% and 20% in comparison with PEGASIS and IEEPB, respectively. The rest of this paper is organized as follows. Section II presents the framework and Section III describes the detail of SCBC. In Section IV, evaluation and analysis of simulation results are presented. Finally, Section V presents our conclusion.

II. THE FRAMEWORK

This section discusses some techniques in which radio energy dissipation model and our assumptions is clearly analyzed that are important to design of our routing protocol.

A. Heterogeneous Network Model

In our system model, we assume that a heterogeneous sensor network consists of N micro-sensor nodes, which is used with three types of sensor nodes: normal, advanced and super sensor nodes with different energy levels. Let M_1, M_2 be the fraction of the total N nodes of advanced and super sensor nodes, respectively that own α and β times more energy than the normal ones. So, we have:

$$N_S = N \times M_1 \times M_2, N_A = N \times M_1(1 - M_2), \quad N_N = N(1 - M_1), \text{ and } N = N_S + N_A + N_N \tag{1}$$

where N_S, N_A and N_N denote the number of supper, advanced and normal sensor nodes, respectively. If we let E_0 indicate the initial energy of each normal node, then $E_0(1+\alpha)$, $E_0(1 + \beta)$ are energy of each advanced and supper node, respectively. So, the total initial energy of all nodes in the network is given by:

$$E_{total} = E_0(N_N + N_A(1 + \alpha) + N_S(1 + \beta)) \tag{2}$$

For simulation, we assume that all sensor nodes are randomly deployed within a target field to continuously monitor the environment and a BS (i.e., sink), whose location is far away from the square sensing area and equipped with a unlimited energy resource. Every micro-sensors and the BS are stationary after deployment and all links are bi-directional.

B. Radio Energy Consuming Model

We use a simplified power model discussed in [1], [12] for energy consuming of radio communication. In order to transmit a packet with $q - bit$ data between two nodes with distance $d(a, b)$, the energy consumption is computed as follows:

$$E_{tx}(q, d) = \begin{cases} q(E_{elec} + E_{friis}d^2) & , \textit{if } d < d_{co} \\ q(E_{elec} + E_{tworay}d^4) & , \textit{if } d \geq d_{co} \end{cases} \tag{3}$$

Where E_{elec} is a fixed dissipating energy to run the transmitter or receiver electronics, E_{friis} and E_{tworay} are the unit amplifier energy required for the transmitter in the free space and the two ray ground model that depends on the distance, respectively, and d_{co} is the crossover distance used in NS2 [10], [12], [13] in our simulation scenario as follows:

$$d_{co} = \sqrt{\frac{(4.\pi)^2.l.h_t^2.h_r^2}{\lambda^2}} = \sqrt{\frac{E_{friis}}{E_{tworay}}} \tag{4}$$

Where λ is the wavelength; l is the system loss value, h_t and h_r are the heights of the transmitter and receiver antennas, respectively. The assumed values for energy parameters used in simulation are presented in Table II and the other parameters are set as follows: $l = 1$, $h_t = h_r = 1.5$ (m) and $\lambda = 0.328227$(m), $d_{co} = 86.1424$ (m), [10], [13]. For receiving a data packet with $q - bit$, the radio dissipates energy:

$$E_{rx}(q) = q.E_{elec} \tag{5}$$

III. THE DESCRIPTION OF SCBC

In this subsection, we describe the SCBC protocol in detail, which bases on chain-based routing algorithm of PEGASIS protocol [5], [6], [14]. The operation of SCBC is divided into rounds; each round contains two main different phases: the setup phase, and the data transmission phase.

A. Energy Consumption Analysis in SCBC

1) The energy dissipation of nodes in the set-up phase: We assume that the N sensor nodes are randomly deployed in $M \times M$ area and the coordinate of the BS is (x_{BS}, y_{BS}). N nodes consist of k sectors (chains), the optimal value of k is equal to 5% in every round [1], [2]. Hence, there are average N/k nodes in each cluster, which includes one CH and $(N/k) - 1$ member nodes.

Let E_{cont} represent the energy consumed by nodes in a chain (cluster) when nodes exchange control message with BS at the r^{th} round.

$$E_{cont}(r) = \frac{N}{k}\left(qE_{elec} + qE_{tworay}d_{toBS}^4\right) + \frac{N}{k}qE_{elec} \tag{6}$$

First part of equation (6) indicates that the energy consumption of a node broadcasts its identity message to the BS. The last part shows the energy used for receiving message, which contains chain-based clustering, CHs or SCHs and TDMA schedule information from the BS.

2) The energy dissipation of the steady data transmission phase: The steady data transmission phase, the energy consumption by CH and member nodes is made up of the following components:

(1). E_{CH}: the energy consumption of CH, which includes receiving data packet from its member nodes, data fusing and forwarding data packet to SCH or BS, whichever is the nearest can be calculated as follows:

$$E_{CH}(i) = pqE_{elec} + (p+1)qE_{DF} + qE_{elec} + qE_{friis}d^2_{toSCH} \tag{7}$$

where, p is number of nodes connected to CH, if each node in chain only connect to a node, ($p = 1$) then

$$E_{CH}(i) = 2qE_{elec} + 2qE_{DF} + qE_{friis}d^2_{toSCH} \tag{8}$$

If CH is SCH then the equation (8) is replaced by (9) as below:

$$E_{CH}(i) = 2qE_{elec} + 2qE_{DF} + qE_{tworay}d^4_{toBS} \tag{9}$$

(2). E_{non-CH}: the total energy consuming for receiving, fusing and transmitting data in cluster (chain) during a single frame is described as follow:

$$E_{non-CH} = \left(\frac{N}{k} - 2\right) qE_{elec} + \left(\frac{N}{k} - 1\right) qE_{DF} + \left(\frac{N}{k} - 1\right) (qE_{elec} + qE_{friis}d^2_{toNB}) \tag{10}$$

(3). E_{round}: the total energy dissipated for a round in a cluster is equal to:

$$E_{round}(i) = E_{cont} + m(E_{SCH} + E_{non-CH}) \tag{11}$$

where, m is number of data packets transmitted during the steady transmission phase of a node and

$$E_{round} = q\left(\left(\frac{2N(m+1)}{k} - m\right) E_{elec} + \left(\frac{N}{k} + 1\right) mE_{DF} + m\left(\frac{N}{k} - 1\right) E_{friis}d^2_{toNB} + \left(\frac{N}{k} + m\right) E_{tworay}d^4_{toBS}\right) \tag{12}$$

Thus, the network lifetime can be calculated in terms of total number of rounds, is:

$$N_R = \frac{E_{total}}{kE_{round}} \tag{13}$$

and, the average energy of r^{th} round can be estimated as follow [7]:

$$E_{avg}(r) = \frac{E_{total}}{N_R}\left(1 - \frac{r}{N_R}\right) \tag{14}$$

B. The setup phase

1) Sector Division of Balanced Clusters Step: Firstly, BS will get the global knowledge of the location and residual energy of all nodes alive in the network by exchanging information between BS and sensor nodes. Then, the BS partitions the sensing area of whole network into k logical sectors which is the same k clusters that balance to number of sensor nodes as shown in Fig. 1, where we assume an example of the network topology that is devided into k sectors in the area of 100×100 square meters and BS at (49,100). Considering BS as the origin of polar coordinates XOY as Fig 1, which computes angle φ of each node in the network base on the location information provided as below:

$$\omega = arctan\left(\frac{Y}{X}\right)\frac{180}{\pi} \tag{15}$$
$$\text{, with: } Y = |Y - Y_{BS}|, X = |X - X_{BS}|$$

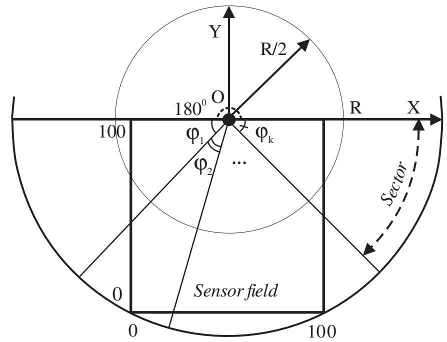

Fig. 1. Network partition into sectors (clusters)

where, X, Y are position of node, if the coordinate of node is in the third quadrant, $\varphi = 180 + \omega$, if the coordinate of a node is in the fourth quadrant, $\varphi = 360 + \omega$ because at that coordinate, the value of tan function will be negative value.

Algorithm 1 Sector Division

```
N ← Get number of nodes alive in network
for each node in {List of the N nodes} do
    Transmit HELLO message, which contain its ID, remaining
    energy and location, to BS
end for
Calculate angle for all nodes alive as in (15)
Sort all nodes alive according to not decreasing of angle
Divide whole network into k areas with N/k nodes for each
cluster based on their angle as in Fig.1.
go to Algorithm 2.
```

2) Cluster Head Selection Step: In r^{th} round of SCBC, the BS will select CH node for each cluster, which has residual energy greater than E_{avg} and maximum cost function as follows:

$$E_{avg}(r) = \frac{1}{nn}\sum_{j=1}^{nn} E_j(r) \tag{16}$$

where nn, $E_j(r)$ are the total number of nodes alive in the cluster and the residual energy of node j^{th}, respectively.

$$cost(i) = Max\left(w_1E_i(r) + \frac{w_2}{d(i,BS) + \sum_{j=1}^{h} d(i,j)}\right) \tag{17}$$

where h is the number of neighbors of node i^{th} and $d(i,j)$ is the geographic distance from the candidate node i^{th} to node j^{th} which is computed as follows:

$$|d\,(i,j)| = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{18}$$

Furthermore, the coefficient factors of cost function w_1 and w_2 are also setup by user based on the characteristics of the WSNs scale. If w_1 is greater than or equal w_2, it means that the residual energy of candidate node is more important factor than distance between node and BS in selecting the CH.

3) Secondary Cluster Head Selection Step: In SCBC, only few SCHs forward data packets to BS to save energy for the others CHs, so the distance from it to BS is as short as possible. Therefore, if distance between CH and BS is smaller than the average distance D_{avg} from them to BS and less than

$R/2$ as in Fig. 1, then CH is chosen as SCH. The D_{avg} can be computed as below:

$$D_{avg}(r) = \frac{1}{k}\sum_{i=1}^{k} d(CH_i, BS) \qquad (19)$$

here, number of SCHs is less than half of number of CHs with short transmission distance to BS to extend the network lifetime.

Algorithm 2 Cluster Head Selection

for each cluster (sub-network) in network **do**
  Calculate average energy as equation (16)
  Choose CH node, which has maximum cost function as equation (17)
end for
$D_{avg} \leftarrow$ Calculate the average distance between all CHs and BS as in (19)
for each CH in {List of the CH nodes} **do**
  if $((d(CHi, BS) < D_{avg})\&\&(d(CHi, BS) < R/2)\&\&(\{\text{number of SCHs}\} < k/2))$ **then**
    Append CH to {List of the SCH nodes}
  end if
end for
Calculate the time length for this round as in (22) and (23)
go to Algorithm 3.

4) The time length of round and throughput of network Step: In this paper, we define the throughput of network Q as the number of data packets transmitted from N alive nodes to BS in a time unit [15]. If there is m frames (packets) that are sent to BS during the steady data transmission phase in each round, so, throughput Q can be computed as:

$$Q = N \times N_R \times m \qquad (20)$$

From (11) and (13), we see that throughput Q will increase if we reduce E_{cont} and increase E_{SCH} and E_{non-CH} (the time length of each round). But, if we increase the time length of round too long, energy of SCHs will be exhausted earlier than the other nodes because of receiving and further forwarding data packet to BS. Hence, the objective function can be expressed as:

$$f = argmax\,(Q) = argmax\,(N_R \times m) \qquad (21)$$

According equation (3), (5) and Table II, we can calculate time length for the steady data transmission phase with m packets.

$$E_{SCH}(r) - m\,(E_{rx}(q,d) + E_{DF} + E_{tx}(q,d)) \geq E_{th} \qquad (22)$$

where, E_{th} is energy threshold, which is fixed by user and greater than zero to guarantee that after finishing this round, the SCH is still alive. Let t_{round} indicates the time length of each round. Therefore,

$$t_{round} = \psi + mT_{frame} \qquad (23)$$

where, ψ, T_{frame} are the interval time in setup and a frame transmission phase, respectively. Table I shows the comparison of the percentage of dead nodes and number of data packets received in BS with changed t_{round}. It is clearly that if t_{round} increases, throughput Q will also increases but the first node died will be earlier, consequently, how we should choose t_{round} to have optimal performance. In Table I, our simulation results are presented, it is clearly seen that SCBC is the best with the first dead node when t_{round} is 50 seconds.

TABLE I
THE THROUGHPUT Q AND NETWORK LIFETIME WITH CHANGING t_{round}

Protocols	t_{round} (seconds)	Q (packets)	The percentage of dead nodes 1%	10%	25%	50%	75%	100%
LEACH	10	28834	20	150	220	270	340	397
	50	46942	10	110	270	430	500	585
	100	58613	20	210	360	500	620	812
	200	71396	20	210	510	630	800	1021
	300	67523	10	290	500	620	710	1047
EE-TLDC	10	38532	150	230	300	350	410	476
	50	52939	20	120	280	420	510	627
	150	74266	30	170	380	560	680	929
	200	63624	20	250	510	620	810	877
PEGASIS	10	105105	640	730	780	840	900	1040
	50	135383	220	720	940	980	1140	1400
	100	140493	80	830	980	1000	1240	1608
	300	172880	80	1030	1050	1070	1420	1829
	500	168847	80	1050	1060	1070	1640	2436
IEEPB	10	126823	180	430	760	930	1190	1680
	50	137599	180	460	830	1000	1280	1800
	100	139940	180	490	850	1040	1360	2000
	500	155269	180	480	1010	1270	1690	3000
	700	139715	180	480	1060	1410	1820	3600
SCBC	10	148022	550	720	830	950	1150	1730
	50	166932	610	750	910	1030	1280	3600
	200	174509	230	690	930	1150	1430	3600
	500	181233	210	640	920	1200	1550	3600
	700	179774	210	620	910	1360	1680	3600

5) Chain Formation Step: Fig. 2 gives out an example for constructing chain between PEGASIS, IEEPB and SCBC protocols, in which Fig. 2(a) and Fig. 2(b) begins forming chain with the furthest node while SCBC start with the nearest and CH node with two different chain. Fig. 2(c) illustrates that node i is considering to connect to node $endnode$ or j or p, whose the distance from it to them are minimum, so it avoids "long link" in chain. Fig. 3 illustrates the resulting network topology after constructing chain for five sectors according to SCBC with 100 sensors in a round. As observed, here, the proposed chain not only has short distance but also balance number of nodes for each chain in network. In addition, Fig. 3 also shows the result of selecting CHs and SCHs as in Algorithm 1&3 based on Greedy algorithm.

C. Data Transmission Phase

After finish the setup phases above, the data packets start being transmitted. The data transmission process in SCBC is similar to that of PEGASIS protocol. Each node will transfer its own sensed data to the next node in its time slots assigned by TDMA mechanism along the chain. Firstly, the farthest node in chain will start transmitting sensed data to its neighbor node. The middle nodes in chain receive packet, fuse one or more data packet with its own into a single packet and send it to the next node or CH or SCH along chain. Whenever the SCH node receives all the data, it will forward the data to the BS after aggregation at the same way. After t_{round}, the next round will be restarted by repartitioning sectors, reselecting CH as well as reconstructing chain for a new round.

IV. Evaluation and Simulation Results

A. Simulation Parameters

To evaluate the performance of SCBC, we simulated SCBC, EE-TLDC and IEEPB by network simulator ns-2 (v.2.34) [10],

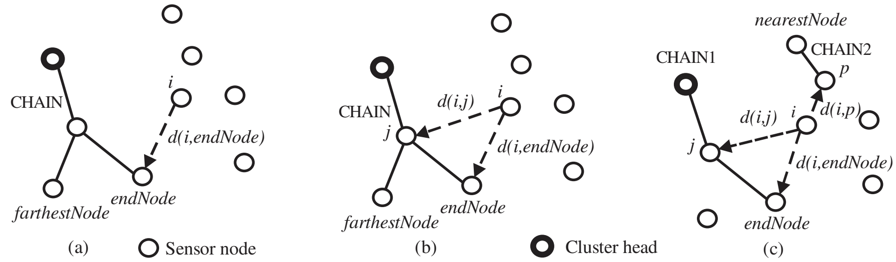

Fig. 2. An example for constructing chain between: (a) PEGASIS, (b) IEEPB and (c) SCBC algorithms

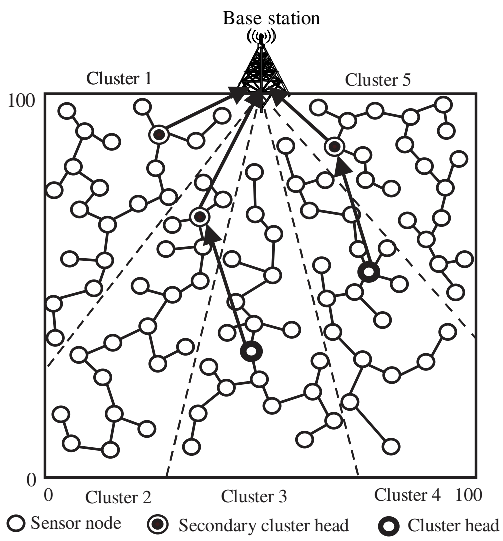

Fig. 3. The network topology with SCBC protocol in a round

[13] using the scenes with the $N = 100$ nodes, $M_1 = 0.5$, $M_2 = 0.4$, $\alpha = 0.5$, $\beta = 2$ and other parameters that are described in Table II, [1], [7], [12].

TABLE II
DETAILED PARAMETERS FOR SIMULATIONS

No.Item	Parameters Description	Value
1	Simulation area	100m x 100m
2	E_{elec} $(Radio\ electronics\ energy)$	50 nJ/bit
3	E_{amp} $(Radio\ amplifier\ energy)$	100 $pJ/bit/m^2$
4	E_{fs} $(Radio\ free\ space)$	0.013 $pJ/bit/m^4$
5	E_0 $(Inital\ energy\ of\ node)$	1J
6	Energy model	Battery
7	Packet size	500 bytes
8	Simulation time	3600s
9	Base station at	49,175
10	Channel type	Channel/wireless channel
11	Antennae model	Antenna/omniantenna
12	Number of cluster	5

B. Simulation Results

Fig. 4 shows the change of the total number of nodes alive in network with the increase of the number of rounds. It is clearly observable that SCBC have a longer network lifetime

Algorithm 3 Chain-based Clustering Formation

```
endNode ← CH
CHAIN1 ← endNode
CHAIN2 ← nearestNode
while {List of the nodes alive} ≠ ∅ do
    Search node i in {List of the nodes alive}, whose d(i, endNode) is minimum
    Search node j in {CHAIN1}, whose d(i, j) is minimum
    Search node p in {CHAIN2}, whose d(i, p) is minimum
    minijp ← min{d(i, endNode), d(i, j), d(i, p)}
    if (minijp = d(i, p)) then
        Append node i into CHAIN2 by connecting to node p
    else
        if (d(i, j)<d(i, endNode)&&(j ≠ endNode)) then
            Append node i into CHAIN1 by connecting to j
        else
            Append node i into CHAIN1 by connecting to the endNode
        end if
        endNode ← node i
    end if
    Discard the node i in {List of the nodes alive}
end while
Search node u in {CHAIN1}, whose d(u, nearestNode) is minimum
Combine CHAIN←CHAIN1&CHAIN2 by connecting the nearestNode to node u
Create TDMA schedule for all nodes in each cluster
Broadcast the TDMA schedule and CHAIN in network
return {CHAIN}
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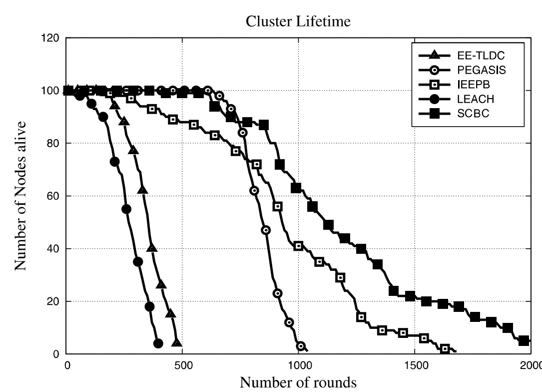

Fig. 4. Number of nodes alive with the number of rounds

with the last dead of about 70% and 20% in comparison with PEGASIS and IEEPB, respectively.

In Fig. 5, we show energy consumption for all protocols during the simulation time (rounds). Based on results shown in Fig. 5, we can obviously see that the energy consumption of all nodes in the network with our proposed routing protocol is lower than that of PEGASIS and IEEPB, (the nearer to the X-axis is the better one). So, SCBC helps to achieved better energy efficiency and increased the WSN lifetime compared to PEGASIS and IEEPB.

We present our another simulation in Fig. 6, which shows the

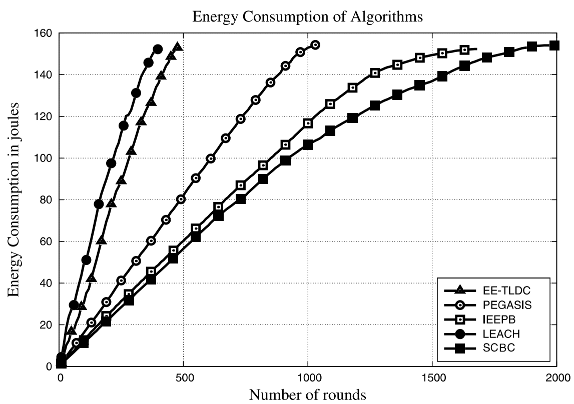

Fig. 5. Energy consumption by five protocols

change of the total number of received messages by BS when the positions of the BS is being varied. It is clear that there is a remarkable decrease of the number of received messages by the BS when we move BS from initial point $(49, 100)$ to the farthest point $(49, 265)$ in the simulation area. However, the total number of received messages of SCBC is still better than PEGASIS and IEEPB.

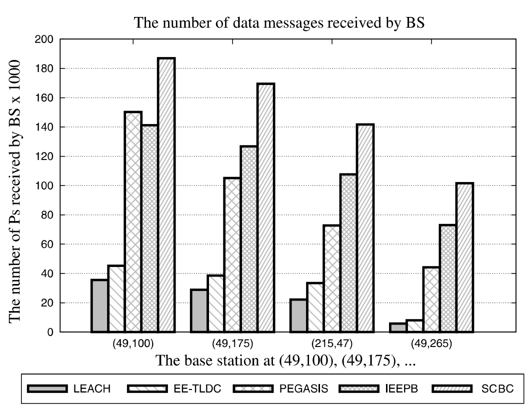

Fig. 6. The number of messages received at the BS when position changes

V. Conclusions

In this paper, we have presented our proposal of a new sector-chain based clustering (SCBC) routing scheme in order to improve energy efficiency for wireless sensor network. In SCBC, the network lifetime is maximized by balancing between the number of nodes and the number of clusters and constructing chain with nearest neighbor node in each cluster. In addition, to further use scarce energy efficiently in network, we calculate definitely the time length for each round to obtain highest throughput. Our simulation results show that the energy efficiency of SCBC is better than those of PEGASIS and IEEPB at about 70% and 20%, respectively, through large topology heterogeneous network (100 nodes and 100m x100m).

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