SSTBC: Sleep Scheduled and Tree-Based Clustering Routing Protocol for Energy-Efficient in Wireless Sensor Networks

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***Abstract*—Since sensor nodes are battery power constrained devices in wireless sensor network (WSN), so how to use the energy of sensor nodes efficiently to prolong the network lifetime is a chief challenge for designing routing protocols. To solve this problem, in this paper, we propose sleep scheduled and tree-based clustering approach routing algorithm (SSTBC) for energy-efficient in WSN. SSTBC preserves energy by turning off radio (entering sleep mode) of either impossible or unnecessary nodes, which observe almost the same information, base on their location information to remove redundant data. In addition, to further reduce energy dissipation of communication in network, we build minimum spanning tree with the root as the cluster head (CH) from active nodes in a cluster to forward data packets to base station (BS). Our simulation results show that the network lifetime with using of our proposed protocol can be improved about 250% and 23% compared to low-energy adaptive clustering hierarchy (LEACH) and power-efficient gathering in sensor information system (PEGASIS), respectively.**

Keywords*—*Wireless Sensor Networks, energy-efficient, routing protocol, tree-based clustering.

I. Introduction

WSN is generally composed of hundreds or thousands of micro-sensor nodes that can be high-densely deployed in a large geographical areas for various fields such as mbattlefield, environment monitor, intelligent home and so on [1]. Sensor nodes have a small size, low cost, low processing capacity. Especially, the constrained battery power at each node has affected the lifetime of entire network and became unique challenging task for designing routing protocols in WSN. There are many energy-efficient routing protocols proposed by researchers such as LEACH [2, 3], LEACH-C [1, 4, 5], PEGASIS [6–8] and so on. Wendi B. Heinzelman [1, 2] et al proposed a clustering technique called LEACH, in which the nodes are organized into several clusters. Each cluster elects a leader called CH, which is responsible for fusing sensed data from its cluster member node(s) with its own and forwarding the fused data packet to the BS; other nodes (cluster-members) will send sensed data to the respective CH. The CH nodes energy is rapidly exhausted since it has to process more work than other nodes in cluster. In order to overcome this problem, after being the cluster head for a certain time, the CH node passes this role to another node to balance energy consumption between nodes in the WSN. The advantage of the clustering is to reduce the number of nodes that need to directly transmit to the BS and balance energy consumption among sensor nodes hence lengthened network lifetime. An improvement of LEACH algorithm was proposed by Stephanie Lindsey et al called PEGASIS. PEGASIS is a basic chain-based routing protocol [6, 7, 9], in which, sensor nodes only connect and communicate with nearest neighbor into a chain. To transmit the aggregated data to the BS, PEGASIS chooses a node to become CH in each round, which has randomly location in the chain. PEGASIS is near optimal solution on energy-efficient but it is still some limitations in this protocol. Firstly, the CH is selected at random location in chain, (no considering about the energy residual and location of the BS). Secondly, some ”long link” inevitability still exists between neighboring nodes in PEGASIS, which is cause of unevenness of energy consumption distribution among nodes. Moreover, the transmission phase of PEGASIS may become high delay and a bottleneck at the CH node since the CH is a single in ”long chain”. In [10], the authors proposed adaptive nodes scheduling approach for clustered sensor networks (ADNS) which conserve energy for sensor nodes by selecting a subset of nodes to be active mode and the others into sleep mode to save energy while ensuring transmitted data quality throughout network operation. The sleep nodes are predicted by data collected of active nodes within the same cluster and a prediction model. Poonam Lohan et al [11] proposed geography informed sleep scheduling and chaining based routing (GSSC) algorithm. To improve the network lifetime, GSSC integrates geography informed sleep scheduling of sensor nodes, where the nodes sensing same information in small area, only one node will be in active state and other nodes will be in sleep state, and chain based routing concept. The results of simulation show that GSSC is better than LEACH and PEGASIS. However, by using location information provided by GPS (Global Positioning System) is difficult to deploy in micro-sensor node due to limited processing capacity and RAM (Random Access Memory).

To solve that problem, in this paper, we propose a new routing protocol, namely SSTBC (sleep scheduled and tree-based clustering), which are centralized controlled by the BS, base on LEACH-C. SSTBC achieves energy efficiency by turning off radio of some impossible or unnecessary nodes, which is the same information sensed in small area to remove

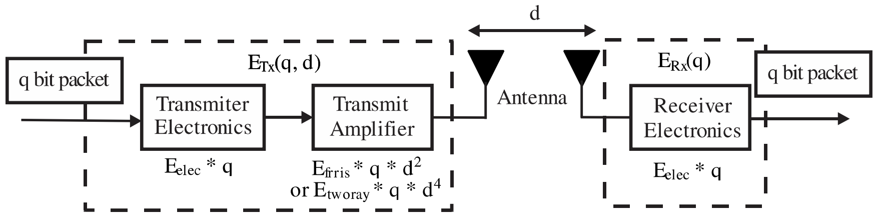

Fig. 1: Radio energy dissipation model

redundant data. In addition, in order to further reduce energy consumption of communication in network, we build minimum spanning tree with the root as the CH by Prim algorithm from active nodes in each cluster to forward data packets to BS. Our simulation results show that the network lifetime of SSTBC can be also extended to about 250% and 23% in comparison with LEACH and PEGASIS, respectively. The rest of this paper is organized as follows. Section II presents the framework and Section III describes SSTBC in detail. In Section IV, we evaluate and analysis the simulation results. Finally, we conclude the paper in Section V.

II. The Framework

In this section, we will present a simple analytical models in which radio energy dissipation model and our assumptions is clearly analyzed that are important for designing of our routing protocol.

A. The Network Model

In our system model, we assume that a sensor network consist of N uniformly micro-sensor nodes deployed densely within a target field to periodically monitor the environment and a BS (i.e., sink), whose location is far away from the square sensing area and equipped with an unlimited energy resource. We simplify a few reasonable assumptions in the network model as follows:

- All micro-sensor nodes have the same capabilities of sensing area, processing of data and each node can change the transmission power to communicate with BS directly.
- All links are symmetric; all nodes contain the same initial battery power and cannot recharge batteries. Every micro-sensors and the BS are stationary after deployment.

B. Radio Energy Consuming Model

As shown in Fig. 1, radio energy dissipation model for communication consists of two major components: dissipated energy to run the radio electronics and the power amplifier that depend on distance d and the radio propagation models, while the receiver dissipated energy only to run the radio electronics [1, 2, 5]. In order to transmit $q-bit$ data message between two nodes separated by a distance of $d(a,b)$ metres, the energy consumption is computed as follows:

$$E_{TX}(q,d) = \begin{cases} q.E_{elec} + q.E_{frris}d^2 & , if\ d < d_{co} \\ q.E_{elec} + q.E_{tworay}d^4 & , if\ d \geq d_{co} \end{cases} \quad (1)$$

Where E_{elec} is a fixed dissipating energy to run the transmitter or receiver electronics, E_{frris} 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 [12, 13] in our simulation scenario as follows:

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

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), [12, 13]. For receiving a data packet with $q-bit$, the radio dissipates energy:

$$E_{RX}(q) = q.E_{elec} \quad (3)$$

III. The Description of SSTBC

In this subsection, we describe the SSTBC protocol, which bases on tree-based clustering routing algorithm over LEACH-C protocol [11, 14]. SSTBC utilizes the BS for sleep scheduling and cluster division and minimum spanning tree construction. The operation of SSTBC is divided into rounds; each round consists of two main different phases: the setup phase, which contains area division and sleep scheduling step, cluster head selection step and tree-based clustering construction step, and the data transmission phase in sub-network.

A. Energy Consumption Analysis in SSTBC

Let α denote the time of set-up phase, and t_{dt} denote the steady data transmission time, then the time length of each round is $t_r = (\alpha + t_{dt})$. Assuming that the time when the first sensor node dies as the network lifetime, which is indicated as t_{fnd}. Therefore, we have the relationship of network lifetime t_{fnd} and t as shown Fig. 2 as follow:

Where u is the number of rounds after that the first node

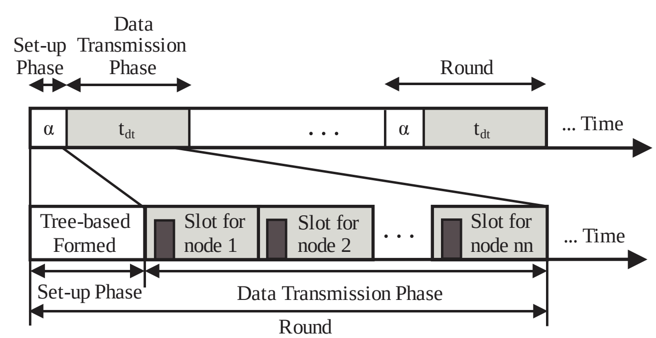

Fig. 2: Two phases operation in a round of SSTBC

dies. According to SSTBC protocol, there are m frames transmitted in the time t_{dt}, so $t_r = (\alpha + m.T_{frame})$, here T_{frame} indicates the during time of each frame. Therefore, $t_{fnd} = u(\alpha + m.T_{frame})$.

1) The energy dissipation of a CH and a member node in the set-up phase: Assuming that the N sensor nodes, which consist of k clusters (trees), are uniformly deployed in M×M area, the coordinate of the BS is (x_{BS}, y_{BS}), and the initial energy of each node is E_{init}. Hence, there are average $(N/k - ns)$ active nodes in each cluster, which includes one CH and $(N/k - ns - 1)$ member nodes, where, ns are the number of sleep nodes in cluster.

Without loss of generality, we assume that all sensor node in cluster are active mode $(ns = 0)$. So, according to the radio energy dissipation model shown in Fig. 1, the energy dissipation of the CH and member nodes in set-up phase is calculated as following components:

E_{brc}: the energy consumption of an active node that broadcasts its identity message to the BS.

$$E_{Brc}(q, d_{toBS}) = qE_{elec} + qE_{tworay}d_{toBS}^4 \quad (4)$$

E_{rm}: the energy consumption of an active node that receive message, which contains tree-based clustering, CHs and TDMA schedule information from the BS.

$$E_{Rm}(q) = qE_{elec} \quad (5)$$

2) The energy dissipation of the steady data transmission phase: The steady data transmission phase operates into several frames as shown in Fig. 2.

E_{CH}: the energy consumption of a CH in a single frame, which consists of receiving data packet from the member nodes, data fusion and forwarding data packet to BS can be calculated as follows:

$$E_{CH} = chqE_{elec} + (ch+1)qE_{DF} + chqE_{elec} + qE_{tworay}d_{toBS}^4 \quad (6)$$

Where ch is number of children nodes, which are connected to CH node, if each node on tree only connect to a node, $(ch = 1)$ then

$$E_{CH} = 2qE_{elec} + 2qE_{DF} + qE_{tworay}d_{toBS}^4 \quad (7)$$

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

$$E_{non-CH} = \left(\frac{N}{k} - 2\right)qE_{elec} + \left(\frac{N}{k} - 1\right)qE_{DF} + \left(\frac{N}{k} - 1\right)(qE_{elec} + qE_{frris}d_{toNB}^2) \quad (8)$$

$E_{cluster}$: so the total energy consuming in each cluster (tree) during a single frame is:

$$E_{cluster} = E_{CH} + \left(\frac{N}{k} - 1\right)E_{non-CH} \approx E_{CH} + \left(\frac{N}{k}\right)E_{non-CH} \quad (9)$$

E_{Total}: therefore, the total energy consuming of whole network during a single frame can be shown as follow:

$$E_{Total} = kE_{cluster} \quad (10)$$

If the sensor nodes are uniformly deployed in M×M, from [4] we can give the coordinate of sensor node u which is in row i and column j, can be depicted as follows:

$$u_{i,j} = \left(\frac{M}{\sqrt{N}}(0.5 + j), \frac{M}{\sqrt{N}}(0.5 + i)\right) \quad (11)$$

Consequently, the distance of node $u_{i,j}$ to its nearest neighbor (e.g. u_{i+1}, j) is:

$$d_{toNB} = \frac{M}{\sqrt{N}} \quad (12)$$

So, the energy dissipation of each cluster in a round is:

$$E_R = \frac{N}{k}E_{Brc} + \frac{N}{k}E_{Rm} + mE_{CH} + m\left(\frac{N}{k} - 1\right)E_{non-CH} \quad (13)$$

And then, number of rounds of whole network is given by (14)

$$N_R = \frac{\sum_{i=1}^{nn} E_{init}}{kE_R} \quad (14)$$

Now, we can calculate the optimum number of clusters by getting the derivative of E_{Total} with respect to k to zero as below:

$$\frac{dE_{Total}}{dk} = 0, \quad k_{opt} = \sqrt{\frac{2N^2E_{elec} + N^2E_{DF} + E_{frris}NM^2}{2E_{elec} + 2E_{DF} + E_{tworay}d_{toBS}^4}} \quad (15)$$

Table I shows the result of simulating in ns2 in comparison the average energy dissipation and number of message received in BS per round with different number clusters. It is clearly that SSTBC is the most appropriate when number of clusters are 5 with N=100 nodes, M=100m, and d_{toBS}= 175m.

TABLE I: Average energy dissipation and number of message received in BS per round with different number of clusters

Number of clusters	Average energy dissipation per round (J)	Average number of message received in BS per round
1	0.869950170	1054
2	0.934477529	1218
3	0.896475019	1198
4	0.858298986	1173
5	0.793537203	1100
6	0.793532640	866
7	0.892604629	871
8	0.735220178	651
9	0.789589197	581
10	0.787121067	611

B. The setup phase

1) Area Division and Sleep Scheduling Step: In most cases, full coverage target region in WSN that can be monitored by all sensors nodes is unnecessary [10, 15], therefore, we can choose active nodes according to threshold value, which is size of grid divided to save energy while it still ensure transmitted data quality throughout network operation.

Firstly, BS gets the globe knowledge of the location and residual energy of all nodes alive in the network by exchanging some information between BS and nodes. Then, sensing area of nodes will be partitioned into some square virtual grids, which the size of them is smaller than a distance threshold value as shown in Fig. 3. The candidate node having highest

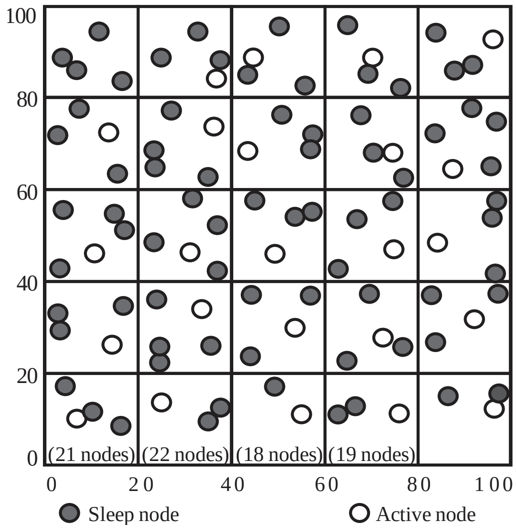

Fig. 3: Example of virtual grid with size of grid is less than or equal 20m×20m

energy residual will be in active mode and other nodes will be in sleep mode in the same grid for current round.

Algorithm 1 Area Division and Sleep Scheduling Step

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for each node in {List of the nodes alive} **do**
  Transmit HELLO message, which contain its ID, remaining energy and location, to BS
end for
if (round = 1) **then**
  Divide entire network into five clusters with equal size sub-network as shown in Fig. 4.
end if
for each node in {List of the nodes alive} **do**
  Choose node in active mode under each grid, which has maximum remaining energy
  Establish other nodes in the same grid in sleep mode
end for
go to Algorithm 2.

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2) Cluster Head Selection Step: With active nodes, the BS will divide the sensing area of network into 5 clusters that is equal sub-network size as shown in Fig. 4. As this figure, all active nodes in each cluster are organized into a minimum spanning tree. In each round of SSTBC, the BS will select the CH for each cluster, which has remaining energy greater than $E_{average}$ and maximum cost function as follows:

$$E_{average} = \frac{\sum_{i=1}^{nn} E_{residual}(i)}{nn} \tag{16}$$

Where nn and $E_{residual(i)}$ are the total number of active nodes in the cluster and the residual energy of candidate node $i-th$ at the current time in considering cluster, respectively.

$$cost(i) = \left(\frac{w_1}{w_2} \times \frac{E_{residual}(i)}{d(i, BS)} \right) \tag{17}$$

Where $d(i, BS)$ is the geographic distance from the candidate node $i-th$ to the BS which is computed as follows:

$$|d\,(a,b)| = \sqrt{(x_a - x_b)^2 + (y_a - y_b)^2} \tag{18}$$

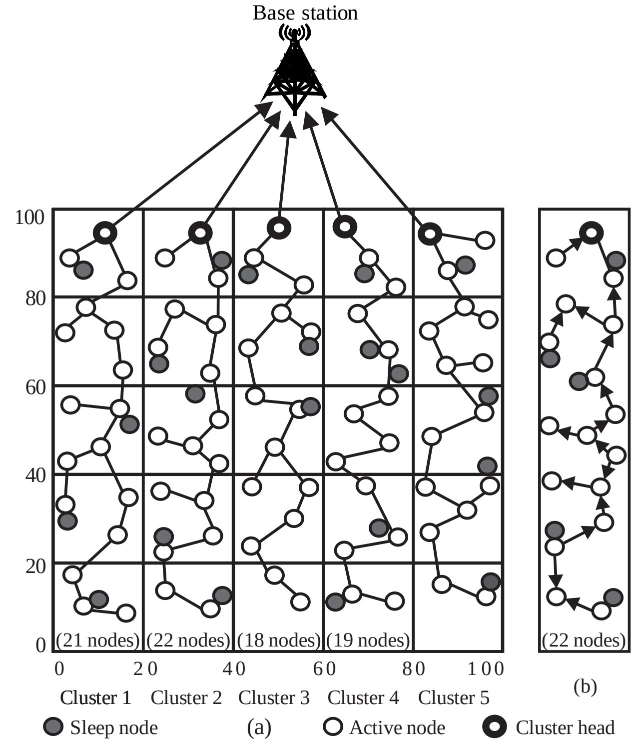

Fig. 4: (a) 100-node in 100m×100m network with virtual grid 5m×5m, (b) an example for minimum spanning tree

Furthermore, the coefficient of cost factors w_1 and w_2 must be set to appropriate values based on the characteristics of the WSNs scale. When w_1 is greater than or equal w_2, it means that the residual energy of candidate node is more important than distance from the node to BS when selecting the CH.

Algorithm 2 Cluster Head Selection Step

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for each cluster (sub-network) in network **do**
  Calculate average energy as equation (16)
  Choose cluster head node, which has maximum cost function as equation (17)
end for
go to Algorithm 3.

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3) Tree-Based Clustering Construction Step: After BS divided five areas and selected CH labeled for each cluster, the minimum spanning tree will be constructed into five clusters with active nodes base on Greedy algorithm to solve the undirected weight graph problem. In order to get the minimum sum of the weight, which is the distance between each active node in cluster, we use Prim algorithm to support us constructing the minimum spanning tree-cluster.

C. Data Transmission Phase

After SSTBC has completed the setup phase above, the data packets start transmitting. Firstly, the left nodes from farthest in each tree will start transmitting to their parent node along the tree as shown in Fig 4(b). The parent nodes receive the data, fusion with its sensed own and send it to the upper level node in the tree. Whenever the CH node receives all the data, it

Algorithm 3 Tree-based Clustering Formation Step

label[CH] $\leftarrow$ 0
label[others node] $\leftarrow$ MAX
$\{$TREE[BS]$\}$ $\leftarrow$ BS
while $\{$List of the active nodes$\}$ $\neq \oslash$ **do**
  Search node i in $\{$List of the active nodes$\}$, whose label[node i] is minimum
  $endNode \leftarrow$ node i
  for each node j in $\{$List of the active nodes$\}$ **do**
    if (node $j \neq endNode$) **then**
      if (label[node j] $>$ d(node j, $endNode$)) **then**
        label[node j] $\leftarrow$ d(node j, $endNode$)
        $\{$TREE[node j]$\}$ $\leftarrow$ $endNode$
      end if
    end if
  end for
  Discard the $endNode$ in $\{$List of the active nodes$\}$
end while
Create TDMA schedule for all nodes in each cluster
Broadcast the TDMA schedule and the information about minimum tree-based clustering in network
return $\{$TREE$\}$

will transmit the data to the BS after aggregating it at the same way. After an interval time, the next round will be restarted by reselecting one node in active state under one grid and cluster head as well as reconstructing minimized spanning tree in each cluster for a new round.

IV. Evaluation and Simulation Results

A. Simulation Parameters

To evaluate the performance of SSTBC, we simulated SSTBC, LEACH and PEGASIS by network simulator ns-2 (v.2.34) [12, 13] using the same scenes with the parameters that are described in Table II, [1, 2, 5].

TABLE II: Detailed parameters for Simulations

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

B. Simulation Results

Fig. 5 giving the simulation result of the total number of nodes that are alive in network according to the number of rounds. It is clearly observable that the SSTBC have a longer network lifetime than with LEACH and PEGASIS for the last dead node about 250% and 33% improvement, respectively. In Fig. 6, we illustrate energy consumption for both three protocols during the number of rounds. Based on results shown in Fig. 6, we can obviously observe that SSTBC achieved better energy efficiency and increased the WSN lifetime compared to LEACH and PEGASIS. As illustrated in Fig. 7, the energy consumption in jules for SSTBC over the number of rounds with different distance threshold values. We can see that the more sensor nodes sleep, the less energy consumption in WSN. Fig. 8 shows the total number of received messages at different positions of the BS. It seems there is a relative decrease in the number of received messages by the BS with all protocols when we move the BS to the farthest point in the WSN but our proposed protocol still outperforms the existing LEACH and PEGASIS algorithm protocols.

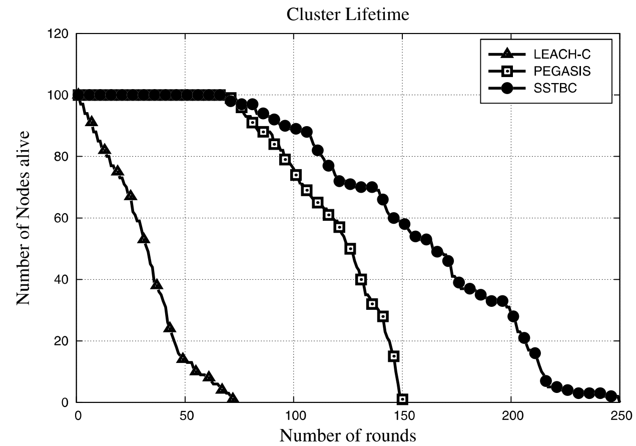

Fig. 5: Number of nodes alive with the number of rounds

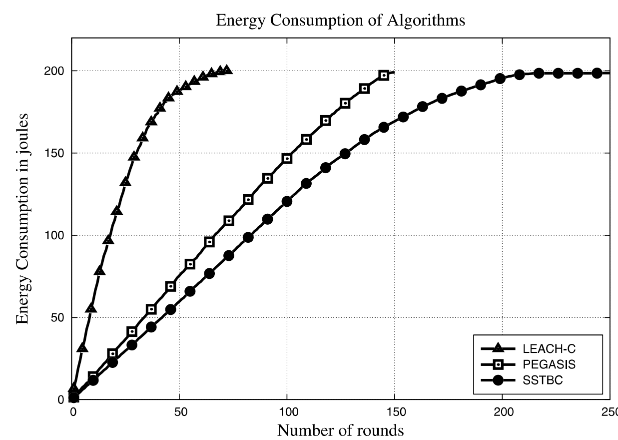

Fig. 6: Energy consumption by three protocols

V. Conclusions

In this paper, we have proposed a new tree-based clustering routing protocol, which is combined among tree-based clustering routing and sleep scheduled in order to improve energy-efficient data transferred in WSN. SSTBC can both balance the energy consumption and prolong the network lifetime by constructing minimized spanning tree in each

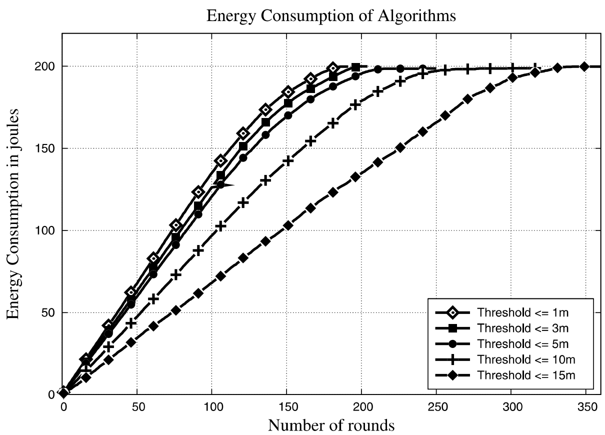

Fig. 7: Energy consumption by three protocols with different threshold

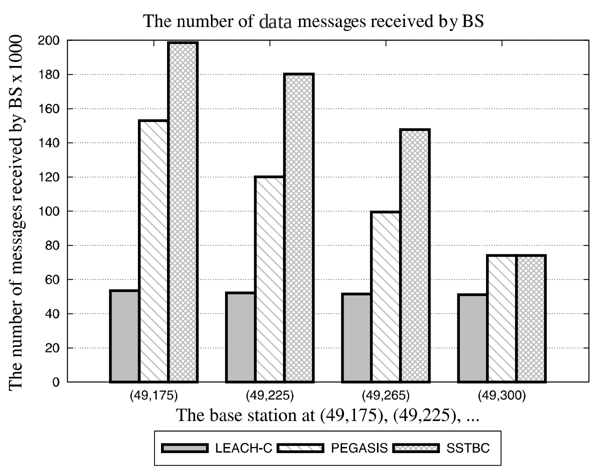

Fig. 8: The number of message received at the BS when position changes

cluster with Greedy algorithm and fusing sensed data before sending packet to the BS. Our simulation results show that the energy efficiency of SSTBC is better than that of PEGASIS about 23% through large topology network (100 nodes and 100m×100m).

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