SECTOR TREE-BASED CLUSTERING FOR ENERGY EFFICIENT ROUTING PROTOCOL IN HETEROGENEOUS WIRELESS SENSOR NETWORK

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ABSTRACT

One of the main challenges for researchers to build routing protocols is how to use energy efficiently to extend the lifespan of the whole wireless sensor networks (WSN) because sensor nodes have limited battery power resources. In this work, we propose a Sector Tree-Based clustering routing protocol (STB-EE) for Energy Efficiency to cope with this problem, where the entire network area is partitioned into dynamic sectors (clusters), which balance the number of alive nodes. The nodes in each sector only communicate with their nearest neighbour by constructing a minimum tree based on the Kruskal algorithm and using mixed distance from candidate node to base station (BS) and remaining energy of candidate nodes to determine which node will become the cluster head (CH) in each cluster? By calculating the duration of time in each round for suitability, STB-EE increases the number of data packets sent to the BS. Our simulation results show that the network lifespan using STB-EE can be improved by about 16% and 10% in comparison to power-efficient gathering in sensor information system (PEGASIS) and energy-efficient PEGASIS-based protocol (IEEPB), respectively.

KEYWORDS

Wireless Sensor Networks, energy-efficient, routing protocol, tree-based, data aggregation.

1. INTRODUCTION

Wireless sensor networks consist of so many micro-sensor nodes that can be utilized to carry out various applications for many human purposes, for instance, monitoring environment, forest fire detection, battlefield surveillance, smart city, underwater applications, etc. In general, the sensor nodes have small devices, low cost, restricted bandwidth, memory size, calculator abilities, and resources; especially, it is very difficult to replace or recharge the little battery size of sensor nodes during operation time [1]. Hence, how to minimize energy dissipation is one of the most important problems to design routing protocols in WSN to prolong network lifespan.

Routing protocol cluster-based [2–5] is very popular which is known as a good technique to increase energy efficiency. This technique can support both heterogeneous and homogeneous network topology, such as LEACH (Low Energy Adaptive Clustering Hierarchy) [6], ELEC-LEACH [7], [8] [9], LEACH-G [10], EE-TLDC [11], IEE-LEACH [12], EACBM [13] and so on.

In the LEACH protocol, sensor nodes are organized into several clusters, each cluster selects a leader node, which is called cluster head (CH) node, CH nodes responsibly aggregate many rough data packets that are gathered by the other cluster member node(s) with its data into a unique packet and transmitting the aggregated data packet to the BS; the other nodes in a cluster (cluster-members) will transmit environmental monitoring data to the respective CH by a single-hop mode, periodically. CHs will be quickly drained since they have to communicate on a long link and handle more jobs than the other nodes in the cluster. Therefore, the leading role of CH must be passed to another node randomly after duration time (called round time) in order to balance energy dissipation between nodes in the WSN.

Recently, there are many algorithms based on LEACH that have been proposed, one of them is EE-TLDC (Energy Efficient Two-Level Distributed Clustering Scheme to Prolong Stability Period of Wireless Sensor Network), in which the CH criteria selection are based on probability and their remaining energy in current time. In addition, EE-TLDC decreases the number of CH nodes by selecting some super-CH (SCH) that forward directly data packets to BS. SCHs will fuse gathered data packets and send them to the base station; the other CHs will only send the collected data packets to the closest SCH instead of BS to reduce energy consumption.

IEE-LEACH (An Improved Energy-Efficient Routing Protocol for WSN) used sensitive threshold $T(s_i)$ for selecting cluster head nodes to balance energy consumption and extend the network lifespan, which consists of the initial energy, current energy, and the average remaining energy of alive nodes in the network. Moreover, IEE-LEACH improved energy efficiency by considering the distance from the nodes to the BS and that of the nodes to the CHS, if it is nearer to the base station, it will not take part in clusters, it may directly transmit data packets to the BS.

EACBM (a new Energy Aware Cluster Based Multi-Hop Energy Efficient routing protocol for WSN) reduces communication energy and extends the network lifespan by using integrating clustering-based routing and multi-hop communication approaches. Besides, the CHs election in each round ponders on the current energy and probability of the number of candidate nodes to become CHs to improve energy efficiency. However, the LEACH protocol and improvements are still disadvantages, for example, the distance between member nodes and CHs or the BS is far in single-hop communication, therefore, they will run out of energy quickly, although the complexity algorithm is small.

To solve these problems, Stephanie Lindsey et al. [14] have presented PEGASIS called a basic chain-based routing protocol at which sensor nodes are organized into a long chain with only connecting and communicating with the nearest neighbour base on the distance between two nodes. In order to forward the aggregated data packets to BS, PEGASIS will select a node as leader chain (CH) in each round whose location is random in the chain.

Recently, Feng Sen et al. [15] improved PEGASIS called IEEPB (Energy-Efficient PEGASIS-Based) by reducing "long-distance communication" in the chain by choosing the node, which is the nearest neighbour node joined in the chain to connect. Furthermore, the cluster head (CH) selection of the IEEPB in each round ponders on the remaining energy of the candidate nodes and the distance between it and the BS as Equation (1). The simulation results show that IEEPB achieves a performance higher than the PEGASIS protocol.

$$w_i = \frac{w_1 E_{init}}{E_i} + \frac{w_2 d_{toBS}^4}{d_{ave}^4} \tag{1}$$

where E_{init}, E_i is the energy initialization and the remaining energy of candidate CH node i-th, respectively; d_{ave}, d_{toBS} are the average distance of sensor nodes to BS and the distance from candidate node i-th to BS, respectively.

In [16], Gautam et al. have proposed TSC (track-sector clustering) scheme where the entire deployed network zone is divided into equal concentric circular tracks and sectors, each sector is considered as a cluster. All sensor nodes in the cluster are connected to the chain. The nodes in the chain fused data to reduce redundant data for transmission and choose the shortest distance between cluster head nodes and the BS in order to save energy. The simulation results illustrate that PEGASIS, IEEPB, and TSC achieve performance better than LEACH protocol [17]; however, there are still some disadvantages in this protocol. Firstly, the CH is chosen at a random location in the chain, which disregards the remaining energy of the candidate node and distance from it to the BS. Secondly, the chain still exists some "long-distance communication" because of the simple chain construction algorithm. In addition, at the CH can occur bottleneck and high delay in the data transmission phase because it only has a single CH node in a "long chain" or the distributed nodes into clusters is not balanced and the duration of time of each round is not calculated during the network operation.

Based on the analysis above, in order to advance the energy efficiency, lengthen the network lifespan, and balanced energy dissipation of all nodes in the network, in this paper, we propose STB-EE based on LEACH-C (A Centralized Energy-Efficient Routing Protocol for WSN) [18], on which it applies the advantages of both EE-TLDC, IEEPB, and TSC by partition the network field into virtual sectors that balance the number of nodes in each cluster and evade "long-distance communication" by organizing all nodes into a minimum spanning tree with the cluster head as a root for each cluster base on Kruskal algorithm. In addition, STB-EE chooses CH and SCH nodes in a current round by merging between the remaining energy of candidate nodes and distance from them to the BS in order to determine which node will be selected as CH or SCH. Furthermore, STB-EE calculates the proper duration of time in the data transmission phase of each round to improve energy efficiency.

The simulation results of our show that the network lifespan per round by using our proposed protocol can be prolonged by about 15%, and 10% in comparison to PEGASIS and IEEPB, respectively.

The rest of the paper is as follows: Section 2 discusses some previous related works that are reviewed. Section III describes the framework. The proposed STB-EE protocol is described in detail in Section IV. In Section V, we analyze the performance base on simulation results. Finally, in Section VI, conclusions and future work are described in the paper.

2. THE FRAMEWORK

In this section, we will clearly describe some models, which are used in our proposed scheme such as the heterogeneous sensor network model and energy-consuming model.

2.1. Heterogeneous Network Model

Here, the hierarchical heterogeneous network model was assumed with N micro-sensor nodes that have three different energy levels: normal, advanced, and super micro-sensor nodes.

We assume that N_1, N_2 is the proportion of the overall N nodes that involve advanced and super sensor nodes that are respective α and β times greater energy than the node normal. Therefore, we can express:

$$N_S = N \times N_1 \times N_2, \quad N_A = N \times N_1(1 - N_2),$$
$$N_N = N(1 - N_1), \quad and \quad N = N_N + N_A + N_S \tag{2}$$

where N_S, $N_{A,}$ and N_N indicate the number of suppers, advanced, and normal sensor nodes, respectively [19, 20, 21]. If we let E_0 denote the initial energy of each normal node, then $E_0(1+\beta)$ and $E_0(1+\alpha)$ will be the energy of each supper and advanced node, respectively. So, the total initial energy of overall alive nodes in the network is expressed by Equation (3) below:

$$E_{init} = E_0(N_N + N_A(1+\alpha) + N_S(1+\beta)) \tag{3}$$

We are implicitly assuming that the N micro-sensor nodes are deployed uniform in Z^2 religion, therefore the probability density function $\rho(x,y)$ is indicated as Equation (4) below:

$$\rho(x,y) = 1/Z^2 \tag{4}$$

Let the coordinate of the BS be (x_{BS}, y_{BS}) and the maximum distance between the CH node and the furthest member node in a cluster (sector, as shown in Figure 3) is expressed as Equation (5) below:

$$R = Z/\sqrt{\pi k} \tag{5}$$

In scenarios simulation, the overall sensor nodes are deployed randomly within a monitored environment field and one BS node whose position is far from the monitoring area and it is an unrestricted power resource.

2.2. Energy-Consuming Model

The activities of sensor nodes that consume the most energy of the battery are data transmission and reception. The radio-energy dissipation for transmitting q-bits data between two nodes with distance d(a, b), the energy consumption is calculated as Equation (6) below [22, 23]:

$$E_{Tx}(q,d) = \begin{cases} q(E_{elec} + E_{friis}d^2), if \quad d < d_{crossover} \\ q(E_{elec} + E_{tworay}d^4), if \quad d \geq d_{crossover} \end{cases} \tag{6}$$

where E_{elec} is a constant power consumed per bit to operate the transmitter or receiver electronic circuits, E_{friis} and E_{tworay} are the energy dissipation unit for amplification that depend on the communication model and the crossover distance. If it is the free space model, the E_{friis} will be used with d^2, meanwhile, the two ray ground model will be E_{tworay} and d^4. Finally, the threshold distance $d_{crossover}$ is used in NS2 as in [24] in our simulation scenarios and can be computed as Equation (7) below:

$$d_{crossover} = \sqrt{\frac{(4\pi)^2 \times l \times h_t^{\,2} \times h_r^{\,2}}{\lambda^2}} = \sqrt{\frac{E_{friis}}{E_{tworay}}} \tag{7}$$

where ht and hr are the high transmitter and receiver antennas. λ is the wavelength; l is the system loss value, respectively. The values of energy parameters that are used for simulation illustrated in Table 1, and if λ = 0.32822(m), $h_t = h_r$ = 1.5(m), l = 1, then $d_{crossover}$ = 86.1424 (m) [25].

In order to receive a particular packet that contains q-bit data, the energy expended is calculated as Equation (8) below:

$$E_{Rx}(q) = q \times E_{elec} \quad (8)$$

3. THE DESCRIPTION OF STB-EE

In this section, we will discuss our proposed protocol, which has four phases; i) cluster (sector) division, ii) sector head election, iii) minimum spanning tree construction and iv) data transmission phase.

3.1. Energy Consumption Analysis in STB-EE

3.1.1. The Energy Dissipation of Nodes in the Setup Phase

Assuming that we use N sensor node with uniform deployment in deployed in the area of Z×Z size with k clusters (sectors), therefore each sector (cluster) will occupy approximately Z^2/k. The optimal value of k clusters (trees) is similar 4% or 5% in every round [6], [8]. Therefore, each cluster will have the average N/k sensor nodes which comprise one CH or SCH and (N/k) − 1 member nodes.

Let E_{set_up} indicate the energy consumption by sensor nodes in a sector for exchanging management message with BS at i-t*h* round.

$$E_{set\_up}(i) = \frac{N}{k}\left(qE_{elec} + qE_{tworay}d_{toBS}^{4}\right) + \frac{N}{k}qE_{elec} \quad (9)$$

The first portion of Equation (9) denotes the energy dissipation of nodes in a sector when it broadcasts messages, which contains the remaining energy, identity, and location to the BS. The last indicates the power unit used for receiving advertisement messages, which contains information about CHs or SCHs, tree-based sectoring, and TDMA or CDMA schedule from the BS.

3.1.2. The Energy Dissipation in the Data Transmission Phase

In the steady data transmission phase, the energy consumption of CH and member nodes can be described as the following components:

(1). E_{mem}: the energy-dissipating of member nodes for receiving, aggregating, and transmitting a single packet in the tree (sector) can be expressed as Equation (10) below:

$$E_{mem} = \left(\frac{N}{k} - 2\right)qE_{elec} + \left(\frac{N}{k} - 1\right)qE_{DA} + \left(\frac{N}{k} - 1\right)(qE_{elec} + qE_{friis}d_{toCH}^{2}) \quad (10)$$

where d_{toCH} denotes the distance between the nodes to its the CH in the sector, which can be calculated as Equation (11):

$$E[d_{toCH}^{2}] = \iint (x^2 + y^2)\rho(x,y)dxdy \;\; = \iint r^2 \rho(r,\theta)drd\theta \quad (11)$$

According to Equation (3) and (5), Equation (11) can be computed as below:

$$E[d_{toCH}^2] = k\int_{\theta=0}^{2\pi}\int_{r=0}^{Z/\sqrt{\pi k}} r^3\rho dr d\theta = \rho.\frac{Z^4}{2\pi k} = \frac{Z^2}{2\pi k} \quad (12)$$

(2). E_{CH}: the energy-dissipating of CH node in a sector at which it receives data packets from its member nodes, aggregates, and forwards them to SCH or BS node whose distance between them is the smallest, can be described as Equation (13) below:

$$E_{CH}(i) = chqE_{elec} + qE_{DA} + qE_{elec} + qE_{friis}d_{toSCH}^2 \quad (13)$$

where ch is the number of child nodes that are directly connected to the root (CH), if the root node only connects to one child node, then ch =1 and:

$$E_{CH}(i) = 2qE_{elec} + qE_{DA} + qE_{friis}d_{toSCH}^2 \quad (14)$$

If CH is selected as SCH then Equation (14) is replaced by (15) as below:

$$E_{CH}(i) = 2qE_{elec} + qE_{DA} + qE_{tworay}d_{toBS}^4 \quad (15)$$

where d_{toBS} indicates the distance between the SCH node and the BS.

(3). $E_{cluster}$: the total energy consumed for a single round in a cluster (sector), which is equal to:

$$E_{cluster} = E_{CH} + \left(\frac{N}{k} - 1\right)E_{mem} \quad (16)$$

(4). E_{round}: the total energy-dissipating of a sector for a single round can be computed as:

$$E_{round} = E_{set\_up} + mE_{cluster} \quad (17)$$

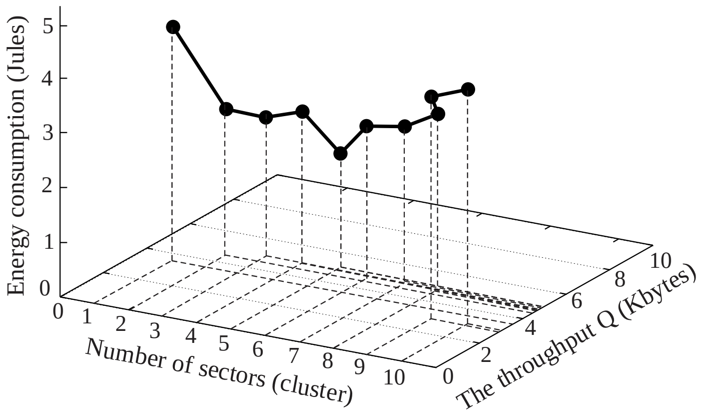
where m is the amount of data packets that are sent by overall nodes in a sector to the BS during the steady transmission phase. Thus, the total energy-dissipating of the entire network in operating of STB-EE protocol during each round can be shown below:

$$E_{total} = kE_{round} = k\left(E_{set\_up} + m(E_{CH} + \left(\frac{N}{k} - 1\right)E_{mem}\right) \quad (18)$$

Now, we can calculate the derivative of Equation (13) to achieve the optimal number of cluster heads as Equation (19) below:

$$\frac{dE_{total}}{dk} = 0, \qquad k_{opt} = \sqrt{\frac{NZ^2E_{friis}}{2\pi(2E_{elect} + E_{DA} + E_{tworay}d_{toBS}^4)}} \quad (19)$$

Figure 1 shows our simulation results about the average energy consumption and the number of the message received in BS in a round (throughput Q) with different number sectors. It is clear that STB-EE is the most suitable when the number of sectors is 5 with N=100 nodes, the monitoring area is 100 square meters, and the distance to the base station = 175m.



k	1	2	3	4	5	6	7	8	9	10
Q	3.3	4.32	4.53	4.5	4.75	4.22	4.45	4.49	3.65	3.73
E_{total}	5.0	3.4	3.3	3.4	2.69	3.19	3.19	3.41	3.52	3.79

Figure 1. The average energy consumption of STB-EE for changing the number of clusters

3.1.3. Throughput of Network Q and the Duration Time

In this work, the throughput Q of the network is described as the amount of data packets that are completely sent from overall alive sensor nodes to the BS in a unit of time [9]. In generality, we assume that there are m_i packets that are transmitted to the BS during the steady data transmission phase in each round, hence, throughput Q can be calculated as Equation (20 below:

$$Q = \sum_{i=1}^{N_{round}} N * m_i \tag{20}$$

where, N_{round} denote the total number of rounds and according to Equation (3) and (17), we can calculate N_{round} as Equation (21) below:

$$N_{round} = \frac{E_{init}}{kE_{round}} \tag{21}$$

Let t_{round} indicate the lengthy time of each round. Therefore,

$$t_{rount} = \psi + m * T_{packet} \tag{22}$$

where, ψ, T_{packet} is the interval time in the setup phase and a data packet transmission, respectively. Therefore, we can view that network throughput Q will raise if value of ψ is small and $m*T_{packet}$ ingredient is large, but both ψ and T_{packet} are immobile in each round So, we can only increase m in the data transmission phase (the duration of time of each round). But, if we increase too long the duration of time of the round then the current energy of CH or SCHs will run out of energy faster than the other nodes since it must receive and further forward data packets to BS, the other nodes in each cluster will be useless, as shown in Figure 2. Therefore, in the STB-EE protocol, we calculate dynamic t_{round} for the current round, this solution helps to improve energy efficiency when running the STB-EE protocol.

According to Equation (6), (7), (8), and the parameters in Table 1, we can properly estimate the duration of time for sending m packets in the steady data transmission phase.

$$E_{SCH}(i) - m(E_{Tx}(q, d_{toBS}^4) + E_{Rx}(q, d) + qE_{DF}) \geq E_{theshold} \quad (23)$$

where, $E_{theshold}$ is the energy threshold value, which is immobile by the user and bigger than zero to ensure that the CH or SCH is still alive after finishing this round. $E_{SCH}(i)$ and ch denote the remaining energy of SCH i-th and the number of directly connected child nodes of its on the tree, respectively, and we have:

$$m \leq \frac{E_{SCH}(r) - E_{theshold}}{q((ch+1)E_{elec} + E_{tworay} d_{toBS}^4 + E_{DF})} \quad (24)$$

Accordingly, the function object can be presented as:

$$f = \arg\max(Q) = \arg\max(N_{round} \times m) \quad (25)$$

In Figure 2, we have illustrated our simulation results; as we can see that the network throughput Q will raise if we increase the time duration of the round (t_{round}), but throughput Q only grows to a certain level and keep stable. This indicates that the SCH node is exhausted energy; this problem is not good for fixed the time duration of round during the operation network. So, STB-EE will calculate flexibility in the duration of time for each round to improve energy efficiency. Furthermore, Figure 2 illustrates the throughput Q too when we modify the distance from the base station to the monitored network field; according to the simulation results, it is clear that the longer the distance between SCHs and BS is, the smaller throughput Q is to receive.

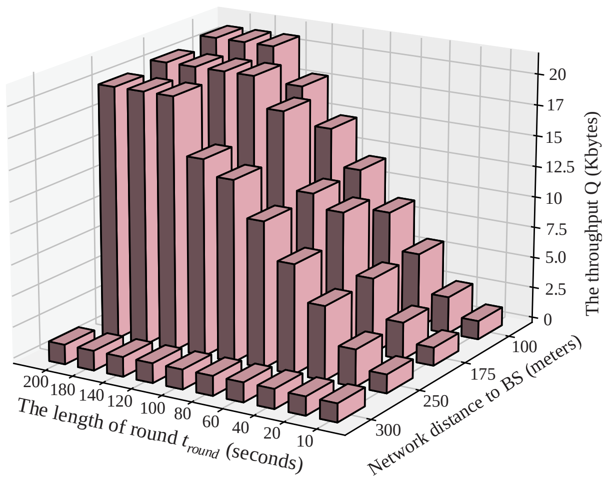


Figure 2. The throughput Q with modification t_{round} and network distance to the base station

3.2. The Setup Phase

3.2.1. Sector Separation of a Balanced Number of Nodes

Firstly, BS will communicate with overall alive nodes in the network to get the position and the remaining energy of them, and then it distributes the monitoring zone into k dynamic sectors. The optimal number of k is equivalent to 5%, this equals k clusters with virtual circles that cover the overall sensor zone as shown in Figure 3 in which we illustrate a partition method of the network topology which is the boundary of 100 × 100 square meters and BS at (49, 49) [18].

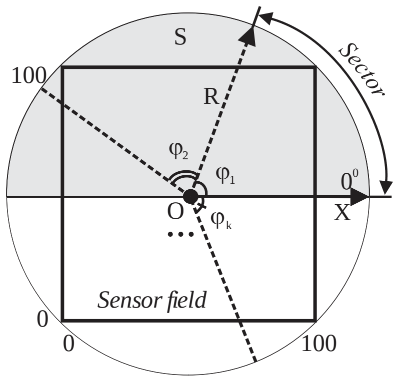


Figure 3. Network partition into sectors

Considering the central of network sensor field is at the polar coordinates XOY original as Figure 3, we compute φ angle of each node in the network base on the information generated by its position and coordinates and provided as Equation (26) below:

$$\omega = \arctan\left(\frac{Y}{X}\right) * \frac{180}{\pi}, \quad \text{where} \quad Y = \left|Y - Y_{BS}\right|, X = \left|X - X_{BS}\right| \tag{26}$$

where, X, Y is the position of the node on the X-axis and Y-axis, respectively. If its coordinate is in the second or third quadrant, φ = 180 + ω and if it is in the fourth quadrant, φ = 360 + ω because, at that coordinate, the tan function value will be a negative value.

Algorithm 1: Sector separation

Input: N sensor nodes and x, y position of their
Output: N sensor nodes in k logical sectors with N/k nodes for each sector
1: N ← Get the number of alive nodes in the network
2: **for each** node i-th in {List of the N alive nodes } **do**
3: Send HELLO message, which contains its ID, remain energy and location, to the BS
end for
5: Compute angle for all alive nodes as in Equation (26)
6: Sort the list of alive nodes according to not decreasing (increase) of angle
7: Partition balancing the network area into k sector with N/k nodes for each sector based on their angle as Figure 3 and 4.
8: **Go to Algorithm 2**;

3.2.2. Sector Head Election Step

In an r-th round of STB-EE, the BS will choose CH node for a current cluster, whose remaining energy is bigger than or equal E_{avg} and the cost function is maximum as Equation (27) below:

$$E_{avg}(r) = \frac{1}{nn}\sum_{j=1}^{N} E_j(r) \tag{27}$$

where $E_j(r)$ is the residual energy of j-th node.

$$\cos t(i) = Max\left(c_1 * E_i(r) + \frac{c_2 * h}{d(i,BS) + \sum_{j=1}^{h} d(i,j)} \right) \quad (28)$$

where h is the amount of neighbors of node i-th and d(i, j) is the Euclidean distance between the candidate i-th and j-th node, which can be expressed as Equation (29):

$$|d(i,j)| = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (29)$$

Furthermore, c_1 and c_2 are the coefficient factors in the cost function, they are also set by the user for various characteristics of the WSN's scale. If c_1 is bigger than or equal to c_2, it intends that the remaining energy of the candidate node is a more momentous factor than the distance between node and BS in considering as CH.

3.2.3. Supper Sector Head Selection Step

In STB-EE protocol, there are only a few SCHs which is responsible for forwarding data packets to the BS to save energy for the other CHs, so the distance between them and BS is as near as possible. Therefore, if the distance between CH and BS is smaller than the average distance D_{avg} from them to BS and the position of CH is in the S zone as shown in Figure 3, then CH will be chosen as SCH. The D_{avg} can be determined as Equation (30) below:

$$D_{avg} = \frac{1}{k}\sum_{i=1}^{k} d(CH_i, BS) \quad (30)$$

Here, we restrict the number of SCHs by selecting half of the number of CHs whose distances to BS is smaller than or equal D_{avg} to reduce energy consumption in the network.

Algorithm 2: Sector Leader Selection

Input: N sensor nodes and the position of their
Output: CH and SCH of each cluster
// Sector Head Selection
for each sector in the {List of sectors} **do**
    Calculate average energy as in Equation (27)
    Select CH node, whose cost function is the highest as Equation (28)
end for
//Supper Cluster Head Selection Phase
Compute D_{avg} between all CHs and BS as in Equation (30)
for each CH in {List of the CH nodes} **do**
    if (D_{avg} > d(CH_i, BS) and Y_{CHi} > 50) **then**
        Select CH as SCH and add it into {List of the SCH nodes} node
    else
        Connect CH_i to SCH_j, whose d(SCH_j, BS) is the shortest
    end if
end for
Compute the time duration for this round as in Equation (24) and (25)
Go to Algorithm 3;

3.2.4. Sector-Tree Based Formation Phase

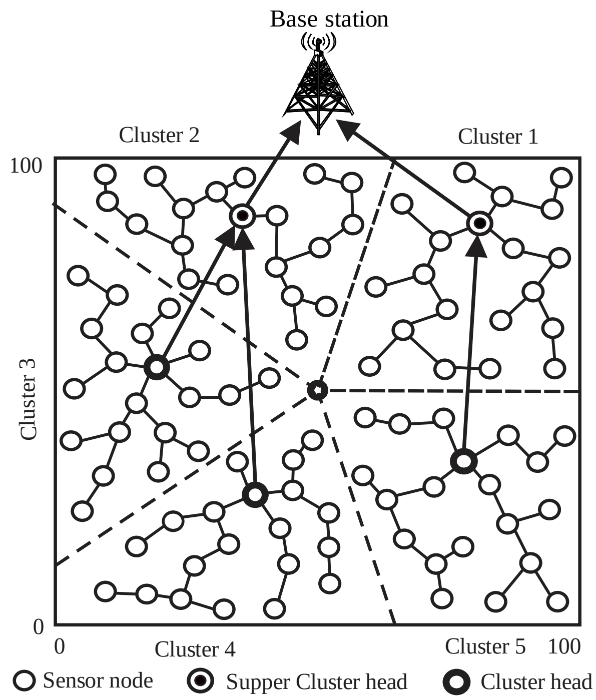


Figure 4. The network topology with STB-EE protocol in one round

Figure 4 illustrates the sector partition for 100 sensor nodes that are deployed in a monitoring area of 100×100 square meters into five sectors that balance the size of the sensor node, and then all node in each sector are connected together by building into a minimum spanning tree.

Suppose that WSN is modeled as an undirected graph G(D, V, E) completely, at which V expresses a set of distributed sensor nodes, E indicates a set of communication links connecting the sensor nodes and D represents the set of distances on E, respectively.

The process of constructing a minimum spanning tree base on Kruskal is illustrated as Algorithm 3 below:

Algorithm 3: Tree Formation Phase

Input: **N/k** sensor nodes of a cluster
Output: Tree with CH as root node
count ← 0;
ei ← 1;
TREE ← {CH};
Set CH as root node;
for each edge i in {List of the E edges} **do**
E[i].mark ← FALSE;
Sort({List of the E edges} as not descending of distance)
while (ei < {Number of E edges}-1) **do**
Select edge ei in {List of the edges}, whose E[ei].mark is FALSE;
u ← get root of (E[ei].u);
v ← get root of (E[ei].v);
if (u and v are two nodes on two different tree) **then**
Union(E[ei].u, E[ei].v);
E[ei].mark ← TRUE;

```
        count ← count +1;
        if (count = {number of nodes alive}-1) then break;
    end if
    ei ← ei + 1;
end while
for each edge i in {List of the E edges} do
    if (E[i].mark = TRUE) then
        TREE ← TREE ∪ {E[i].u, E[i].v};
    end if
end for
Create TDMA schedule for all nodes in cluster
Broadcast the TDMA schedule and TREE to network
return {TREE};
```

3.3. Data Transmission Phase

As soon as STB-EE has completed the cluster header election and the sector tree-based clustering organization phase above, the data packets are started with intra-sector and inter-sector transmission. At first, the farthest nodes (leaf nodes) in each tree will sense the environment and send the collected data packet to their parent node along the tree. The parent nodes receive the data packets, and fuse this data with its own sensed data packet, compress and transmit it to the upper-level parent node in the tree toward the BS. Whenever the SCH node receives all the data from cluster members, it will forward the data packet to the BS after aggregating it in the same way. After a duration time, the next round will be restarted by the repartition sector, reselecting CHs, as well as rebuilding minimized spanning trees in each sector for a new round.

4. Evaluation and Simulation Results

4.1. Performance Measurements

we use the following metrics to evaluate the performance of the STB-EE and compare it with other protocols [26, 27, 28].

- Network lifespan: This performance metric is calculated from the sensor nodes in the network start to work until the last node dies (LND), which can be calculated by Equation (31) below:

$$Network\_lifetime = \sum_{i=1}^{N_{round}} t_{round}(i) \tag{31}$$

- Energy consumption: The total energy consumption of the entire nodes in the network in monitoring, processing, communicating, and the other activities during the simulation time, which can be computed by Equation (17) above.
- Energy Efficiency (EE): Energy efficiency is described as the ratio between the amount of data packets accomplished to the BS (the throughput of network Q) and the total energy consumption in the network (Kbytes/Joule) that can be calculated by Equation (32) below:

$$Energy\_efficiency = \frac{Q}{E_{total}} \tag{32}$$

- The total number of data packets received in the BS: It is the total number of data packets that are exactly received by the base station from the overall nodes in WSN during the network working.

4.2. Simulation Parameters

To evaluate the performance of STB-EE, the scenarios simulations are executed by using ns-2 (v.2.34) simulator tool as in [24, 25] and compared to LEACH-C, EE-TLDC, PEGASIS, and IEEPB with simulation parameters that are expressed as in Table 1, [18] [16].

Table 1. The simulation environment

No. Item	Parameters Description	Value
1	Simulation region	100m x 100m
2	Network size	100 nodes
3	E_{tworay}(Radio amplifier energy)	100 pJ/bit/m^2
4	E_0 (Initial energy of node)	1J
5	E_{friis}(Radio free space)	0.0013pJ/bit/m^4
6	E_{elec}(Radio electronics energy)	50 nJ/bit
7	E_{DA} (Data aggregation)	5 nJ/bit/packet
8	Energy model	Battery
9	Packet size	1024 bytes
10	Simulation time	3600s
11	Base station at	49,175
12	Channel type	Wireless channel
13	Antennae mode	Antenna/Omni antenna
14	Bandwidth	100Mbps
15	α	0.5
16	β	2
17	N_1	0.5
18	N_2	0.4
19	c_1	100J
20	c_2	0.3m

4.3. Simulation Results

Figure 5 illustrates the changing of the total number of alive nodes in the entire network when increasing the network lifespan. Here, the Y-axis represents the number of alive nodes and the X-axis denotes the network the lifespan in rounds with BS location at (49, 175). It is observable that STB-EE exhibits a longer network lifespan in the LND approximately 15% and 10% compared with PEGASIS and IEEPB protocol, respectively.

In Figure 6, we demonstrate the total energy consumed by all nodes for five protocols during the simulation time (rounds). It is clear that STB-EE consumes the least energy in comparison to IEEPB and PEGASIS protocols because STB-EE chooses CH considering the remaining energy and distance of aspirant nodes to BS. Moreover, in PEGASIS and IEEPB, most of the CH forward data packets directly to the BS while in STB-EE, only a few SCH nodes forward data packets to the BS with short distances, and the other nodes only transmit aggregated data on the tree. So, STB-EE helps to achieve better energy efficiency and extend the WSN lifespan.

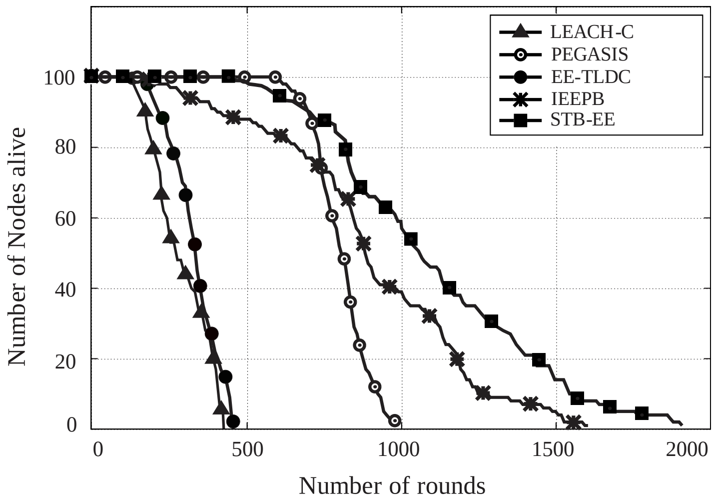


Figure 5. Number of nodes alive per round with BS location at (50,175)

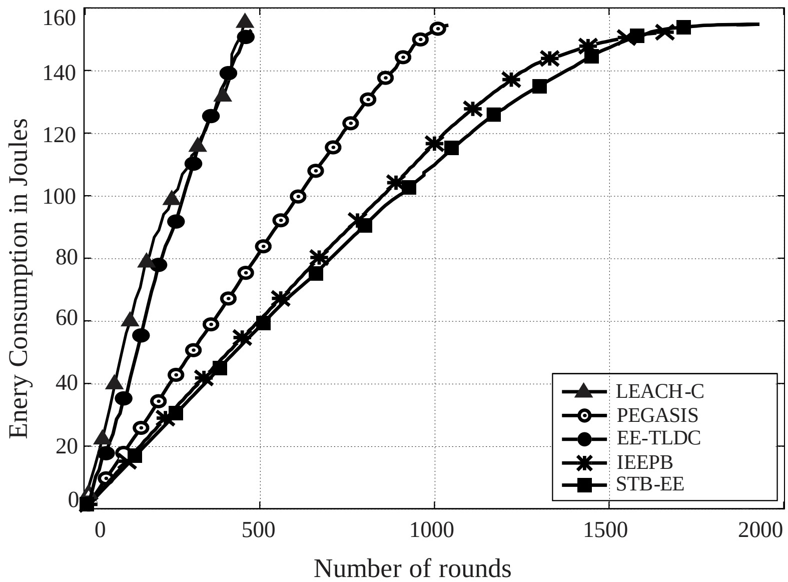


Figure 6. Total energy consumption of the network per round with BS position at (50,175)

Figure 7 illustrates the percentage of dead sensor nodes during the simulation time and the number of rounds. As exhibited in Figure 7, STB-EE achieves better performance than LEACH and PEGASIS in terms of network lifespan with BS location at (50,175).

Figure 8 illustrates the number of data packets transmitted during the network operation by the alive node to the base station when the location of BS is being changed. It is clear that there is a memorable decline in the data packets received in the BS when the location of the BS is modified from the initial location (49, 100) to the farthest location (49, 265) in the simulation region. However, the total number of received data packets of our proposed are still higher than PEGASIS and IEEPB since STB-EE suitably calculates the duration of time for each round therefore it advances energy efficiency and prolongs the network lifespan. Furthermore, STB-EE achieves balance the energy consumption among sensor nodes in the network because of distributing equal alive nodes into the clusters and rotating the CH role in each round, the more balanced the energy consumption in the network, the more performance protocol achieves [29].

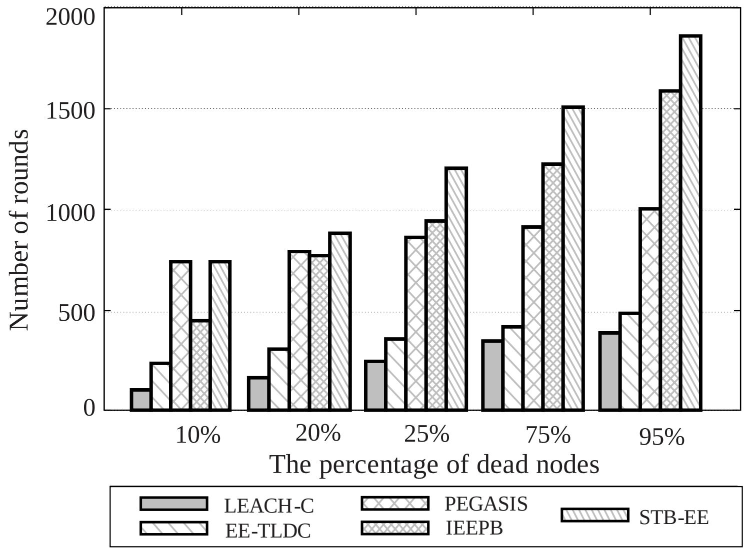


Figure 7. The percentage of sensor node dead

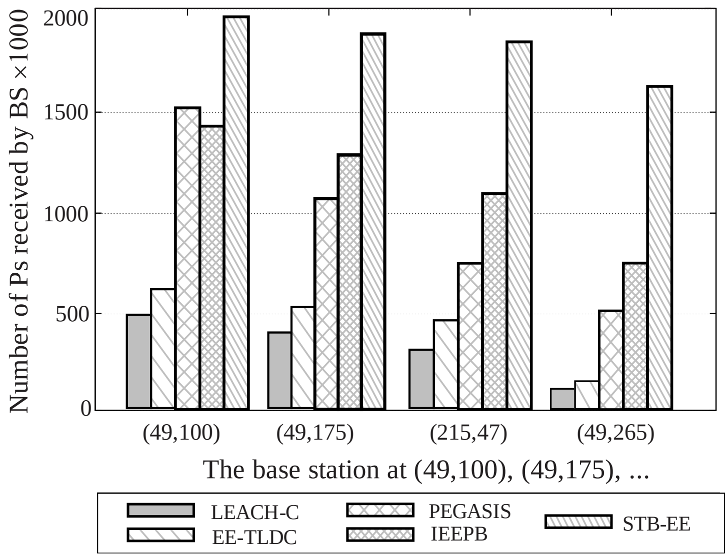


Figure 8. The amount of data packets received successfully by BS when positioning modifies

Moreover, Figure 9 illustrates the energy efficiency of LEACH-C, EE-TLDC, PEGASIS, IEEPB, and STB-EE protocols with modification of the duration time of rounds, (t_{round}) from 10 to 500 (seconds) in the heterogeneous network model. As can be observed in Figure 9, if we increase the time duration the data transmission phase (t_{round}), the energy efficiency (throughput Q) will increase to the pick in t_{round} =100 with LEACH-C, EE-TLDC and t_{round} = 300 seconds with PEGASIS, IEEPB, and STB-EE, and then that will decrease with all protocol. But STB-EE protocol still achieves energy efficiency better than other protocols because our proposed protocol chooses CHs base on the residual energy of candidate nodes and reduces the distance communication among nodes in the network by constructing a minimum spanning tree. However, the STB-EE approach is not good at t_{round} = 10 seconds due to more energy consumption in the setup phase for each round.

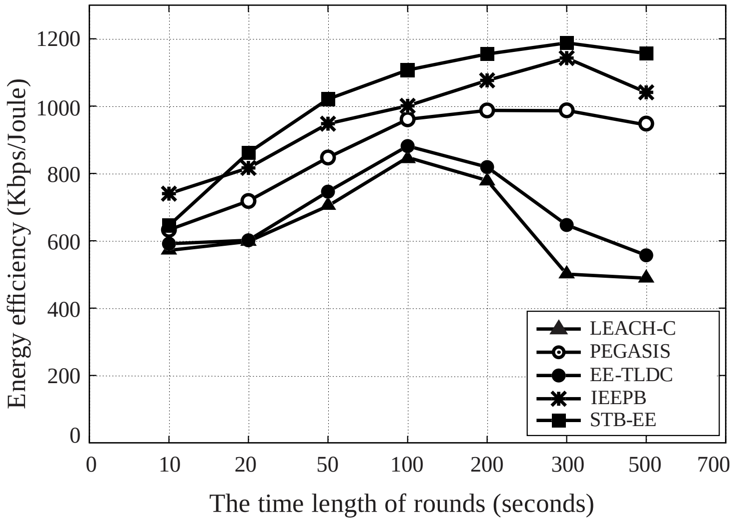


Figure 9. The energy efficiency per throughput with changing the time duration of rounds

5. Conclusions

In this paper, we have developed a new sector tree-based routing protocol in our proposition which integrates sector division and tree-based clustering routines in order to diminish energy dissipation in data transportation in WSN. STB-EE can balance the energy consumption by distributing balance the number of nodes into clusters because the more balanced the energy consumption in the network, the more data packets the BS receives. Moreover, STB-EE reduces energy consumption and extends the network lifespan by constructing a minimized tree in each sector according to the Kruskal algorithm and aggregating sensed data before forwarding it to the BS. The simulation results show that the energy efficiency of STB-EE is higher than that of PEGASIS and IEEPB about 15% and 10% in terms of network lifespan, respectively in the simulation scenario (100 nodes deployed in 100m×100m region). In the future, we would like to further improve energy efficiency by reducing the total distance of control packets (i.e., routing overhead) transmitted to the BS in the setup phase of each round.

Conflicts of Interest

The authors declare no conflict of interest.

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