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Energy-Efficient Distributed Cluster-Tree Based Routing Protocol for Applications IoT-Based WSN

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***Abstract*—With the growth of wireless sensor network (WSN) technologies, the applications of IoT-based WSNs allow the interconnection of smart objects or sensors through the Internet. However, energy constraint is a major obstacle in WSN, which directly affects the lifespan of the network. Hence, many researchers have focused on how to program routing protocols to maximize energy conservation in WSNs. The clustering mechanism is demonstrated that separating the network into clusters may significantly decrease energy consumption. In this paper, we propose distributed tree-based clustering routing protocol for IoT applications (EE-DTC). In order to enhance efficient energy, EE-DTC chooses cluster head nodes based on the remaining energy, the location, and the density of nodes. In addition, to lengthen the network lifespan, we create multi-hop routes with short communication links intra-clusters by building the minimum spanning tree (MST) using the Kruskal algorithm. Our experiment results exhibit that the performance of EE-DTC overcomes the TBC and LEACH-VA protocols in terms of increasing network lifespan, reducing energy consumption, and improving efficient energy.**

***Index Terms*—Wireless sensor networks, routing protocol, energy-efficient, IoT, tree-based clustering.**

I. Introduction

In 1999, Kevin Ashton claims that the idea of the "Internet of Things" (IoT) was launched by enabling connectivity among various things at any time and location via the Internet [1]. A wireless sensor network (WSN) comprises a set of smart sensor devices and a gateway or base station (BS) device that can communicate with each other using radio channels. WSNs are profitable in IoT applications for assembling and processing data before transferring it to the gateway node or end-user [2]. IoT-based WSN will build a network system for connecting, calculating, and sharing information in order to create applications in human life, for example, early earthquake warning systems, battlefield monitoring, weather forecast, intelligent traffic system, smart cities, smart agriculture, environment monitoring, remote patient monitoring, healthcare and so on [3, 4, 5, 6]. Figure 1 exhibits that an application of IoT-based WSN for the early detection system of forest fire is deployed in the jungle to keep track of the environment, in which smart sensors (IoT devices) are used to measure the environmental temperature or humidity [7]. The sensed data from these sensors will be processed and sent to the computers of staff in the office or at home through mobile devices or the Internet. From this information, users can give decisions in real-time to solve the problem that occurred.

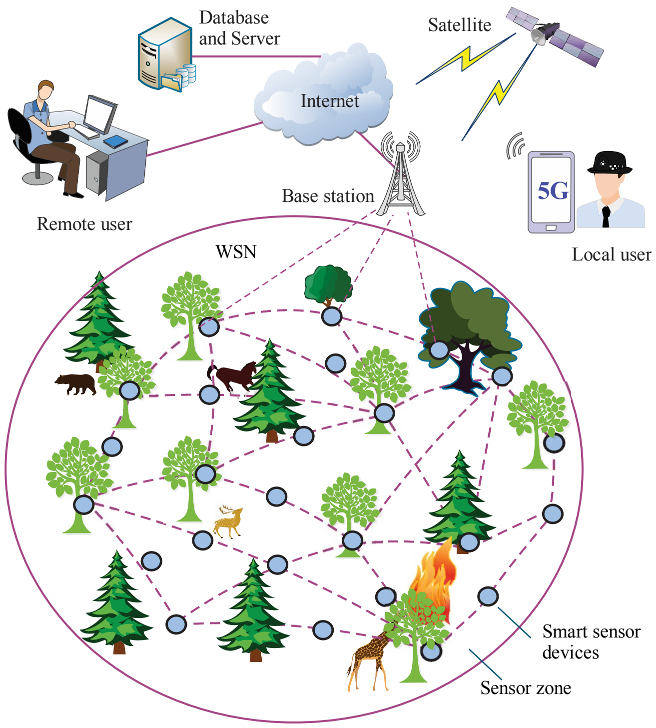

Figure 1. An application of IoT-based WSN for early detection of forest fire

However, smart sensing nodes are tightened in terms of energy battery and it is too difficult to recharge or substitute a new battery because the nodes are often deployed in the harsh zone that humans cannot reach [8]. Therefore, the greatest challenge in applications IoT-based WSN is how to reduce the energy dissipation of smart sensor devices, as a result, prolong the lifespan of the network, which should be considered during the designing of routing protocols. To attain this goal, numerous researchers have proposed efficient energy routing schemes for WSN, in which the clustering mechanism is one of the most useful methods [9, 24, 25]. According to the clustering method, the network system is partitioned into various clusters; each cluster involves one cluster head node (CHN) and some cluster members (CMs) [10]. CMs only sense the external environment and transmit their acquired data to their CHN, whereas a CHN is responsible for receiving and aggregating data and then relaying the assembled data packets to the BS [19].

The top popular routing protocol inspired by clustering is the low-energy adaptive clustering hierarchy (LEACH) [11] which applies the distributed scheme approach for constructing clusters and CHNs election. According to the simulation

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results, the LEACH protocol drastically reduces the overall energy consumed in the network but it still has some limitations that need to be improved. For example, selecting CHNs at random locations can lead to both a far distance from the CHNs to the BS and an unequal cluster distribution because the CHNs may be too close together. Recently, there have been many improvements to the LEACH protocol to enhance the network lifetime for applications of IoT-based WSNs. One of them is I-LEACH [12], in which CHNs are selected based on the threshold value of the remaining energy and energy cost for the receiving, aggregating, and transmitting of the nominee CHN in the current round. However, the links among CMs and their CHN are still far due to one-hop communication and as the result, the sensor nodes still consume a lot of energy in data communication.

Consequently, we propose a distributed tree-based clustering routing protocol for IoT applications namely EE-DTC, in which nodes are self-configuring and form a network base on LEACH. EE-DTC builds multi-hop routes intra-cluster to reduce the energy depletion of sensing nodes by using Kruskal. Furthermore, the considerations of the remaining energy and the distance from nominee CHNs to the BS as the main criteria in CHNs selection also help to improve energy efficiency. Our simulation outcomes depict that EE-DTC can be achieved better energy efficiency than TBC and LEACH-VA about 15% and 21% in comparison to TBC and LEACH-VA, respectively. The rest of this study is organized as follows: The related work presented in Section 2, Sections III, and IV is described the network model and detail of EE-DTC. In Section V, we analyze and discuss the simulation outcomes. Finally, the conclusion of the study is presented in Section VI.

II. Related Works

Many algorithms have suggested preserving the precious energy of sensor nodes and this section will review some of these algorithms.

Heinzelman et al. [11], proposed a routing algorithm inspired by a clustering scheme for WSNs called LEACH. LEACH employs a algorithm distribution to group sensor nodes into clusters by self-organizing. The working of LEACH is segmented into several rounds, each round has two phases: the formation cluster phase and the data transferring phase. In the clustering phase, some CHNs are randomly selected from all alive nodes. A node creates randomly a number between 0 and 1 for determining whether to become CHN or not. If this number is smaller than the probability value *T(n)* indicated by Equation (1), the node will elect itself as the CHN of the current round [11].

$$T(n)=\begin{cases}\dfrac{k}{1-k\left(r \bmod \dfrac{1}{k}\right)}, & if\ n\in G\\ 0, \quad otherwise & (n\notin G)\end{cases} \tag{1}$$

where k is the percentage of CHNs in the network ($k \approx 5\%$ [13]), r indicates the currently considering round and G is a list of sensor nodes that are not elected as CHN in the last ($1/k$) round. After selecting CHNs, nodes participate in the corresponding cluster depending on the strong signal of the message transmitted to them by the CHNs.

In the data transferring phase, sensor nodes congregate data and send it to their CHN in each cluster. CHN will be responsible for aggregating data and forwarding it to the BS device. The LEACH protocol significantly reduces energy consumption by organizing the network into clusters and fusing data before delivering them to the BS device. However, network nodes still consume lots of energy for inside cluster communication since the distances between nodes and CHN are still far away. To solve this problem, Kim et al. [14] presented a novel clustering based on tree approach for efficient energy in WSNs based on LEACH called (TBC). According to this proposal, the nodes in each cluster will construct a tree with CHN as a root based on their distance information. The simulation results illustrate that TBC can reduce the energy dissipation required intra-communication and significantly strengthen the lifespan of the network in comparing to the three existing protocols which are LEACH, PEGASIS [15], and TREEPSI [16]. However, in both LEACH and TBC protocol, the remaining energy of the nominee CHNs is not considered in electing itself to become leader cluster node, so some CHNs may early run out of energy, therefore, the collecting data of CMNs cannot send to the BS device. To defeat this drawback, Xu et al. [17] have introduced an improvement of the LEACH algorithm, namely E-LEACH, in which the remaining energy of the nominee CHNs is considered in order to balance the energy consumption load. In addition, E-LEACH employs the MST algorithm to form routes for multi-hop communication among CHNs and BS devices. As a result, E-LEACH prolongs the network lifespan and enhances energy. The threshold value *T(n)* of E-LEACH for the nominee CHNs to become CHN is expressed as follows [17]:

$$T(n)=\begin{cases}\dfrac{k}{1-k\left(r \bmod \dfrac{1}{k}\right)}\times\dfrac{E_{curent}}{E_{init}}, & if\ n\in G\\ 0, \quad otherwise & (n\notin G)\end{cases} \tag{2}$$

where, E_{curent} and $E_{initial}$ are the residual energy and initial of the nominee CHN, respectively.

Liang et al. [18] proposed an improved LEACH called LEACH-VA, where the whole network monitoring zone is separated into unequal polygons based on Voronoi Diagram. Firstly, the optimal quantity of CHNs is selected according to the total energy consumed in each round to diminish the cost of distributing excessiveness clusters per round. Then, the nodes in the same polygon are grouped in a cluster with the CHN at the center of the polygon. Finally, CHNs are joined by employing an ant colony algorithm to acquire the multi-hop routing optimization from CHNs to the BS device. According to the experimental results, LEACH-VA significantly decreases the energy utilization in data transmission and prolongs the lifespan of the network.

Osamy et al. [19] proposed a clustering routing algorithm based on entropy information theory for heterogeneous WSNs, namely EBCS. EBCS organizes the network into three layers: Cluster heads selection layer, cluster formation, and data transmission layer. Especially, EBCS combines multiple parameters in the selection nodes working as CHN based on entropy schemes such as the distance from the node to the gateway device, residual energy, and the distribution of the density of the node in the monitoring field. The experiment results exhibit that EBCS outperforms LEACH in terms of the throughput and lifetime of the network. Hau et al. [21] introduced the improvement of the AODV routing protocol by using intelligent agents for efficient energy. Tan et al. [22] proposed a sector tree routing protocol based on a clustering technique for efficient energy, in which the nodes in a cluster communicate with each other based on the MST connecting. Gamal et al. [10] have proposed hybrid particle swarm optimization and a K-means clustering hierarchy algorithm to construct clusters to enhance the lifespan of WSNs. According to this proposal, the Fuzzy logic theory is used to choose CHN with two criteria: residual energy level and distance from CHNs to BS. Moreover, the authors have integrated the K-means clustering and particle swarm optimization algorithm to construct clusters. Khoshrangbaf et al. [26] proposed an optimal ant colony algorithm to advance the coverage region of WSNs and maintain the connectivity between the nodes.

III. Proposed Method

A. Network Model

In our network model, we suppose that a network system involves a gateway or base station device and lots of sensor nodes that can support IoT applications [20].

- The gateway device is fixed and not limited to energy and computation capacity, which can aggregate and forward the data packets.
- N sensor nodes are random implementations in the network zone of two-dimensional.
- All sensor nodes are stationary state after deployment and know the location of each other based on GPS
- All sensing nodes use the battery energy and cannot recharge or replace
- The radio channels are symmetry

B. Energy Consuming Model

The radio energy consuming model employed in our proposal to transmit the *b-bit* data packet ETX [11, 19, 23]:

$$E_{TX}(b,d)=\begin{cases} b\times E_{elec}+b\times E_{friis}\times d^2 & ,if\ d<d_0 \\ b\times E_{elec}+b\times E_{tworay}\times d^4 & ,if\ d\geq d_0 \end{cases} \quad (3)$$

where E_{elec} is the energy consumption part for the electric circuit, E_{towray} and E_{friis} are the energy consuming for the transmitter amplifier by two ray ground mode and free space mode with the distance d, corresponding, and d_0 is the threshold distance in which sensor nodes use the free space model. The geographical distance between nodes a and b is calculated as Equation (5) below:

$$d(a,b)=\sqrt{(x_a-x_b)^2+(y_a-y_b)^2} \quad (4)$$

The energy consumed to receive a packet is calculated below:

$$E_{RX}=bE_{elec} \quad (5)$$

IV. Distributed Tree-Based Clustering Routing

The operation of EE-DTC is partitioned into numerous rounds; each round comprises B three stages: Cluster formation, distributed tree construction, and steady stage which are described as several steps like the following:

Step 1: Start a new round, check, if the sensor node is dead, go to **Step 11**, otherwise, nodes calculate their own threshold value *T(i)* as Equation (6) and randomly generate a number *R* in the scope from 0 to 1. If *R* is indicated smaller than the threshold value *T(i)*, the node is selected as CHN, otherwise, the node is CMN.

Step 2: If the node is CHN then broadcast the *ADV_CH* message and go to **Step 5**.

Step 3: If the node is CMN, receives the message *ADV_CH* and calculates the fitness function as Equation (7).

Step 4: CMNs send *JOIN_Adv* messages that contain the identifier, residual energy, and its position to CHN corresponding to the CHN whose fitness function value is the highest, and goes to **Step 9**.

Step 5: CHNs receive *JOIN_Adv* messages from CMNs and connect nodes in their cluster by constructing the MST with the CHN as a root

Step 6: CHNs transmit the information about the tree and the slot time for communication (TDMA) to CMNs in the cluster, go to **Step 8**.

Step 7: CMNs receive formation about trees and TDMA

Step 8: Every node periodically collects environmental information and transmits sensed data packets to their parent or CHN along the tree

Step 9: CHNs receive information from CMN nodes, aggregate it with their own data, and forward it to the BS device.

Step 10: If the round time is expired, go to **Step 1**, otherwise go to **Step 9.**

Step 11: The end.

A. Cluster Formation

In this study, we use the criteria parameters such as residual energy, initial energy, the distribution density of nodes, and the distance among nodes and BS device to make the threshold value for electing itself to become CHN as described in Equation (3) below:

$$T(i)=\begin{cases} \dfrac{k}{1-k\left(r \bmod \dfrac{1}{k}\right)}\times\left(\dfrac{c_1*N_i*E_{curent}}{d_{\max}}+\dfrac{c_2*E_{init}}{d(i,BS)}\right), & if\ n\in G \\ 0, \quad otherwise & (n\notin G) \end{cases} \quad (6)$$

where N_i is the number of neighbor nodes of node i-th, d_{max}, and *d(i, BS)* is the network diameter and distance from the nominee CHN *i-th* to BS, respectively. The constant values c_1 and c_2 are the weights for the parameters and $c_1+c_2=1$.

This threshold *T(i)* ensures that every node elected to become CHN has a high energy level and is as near the BS as possible. After the node selects itself as a CHN, it broadcasts an advertising (*ADV_CH*) message to other nodes. When a CMN *i-th* received an *ADV_CH* message from CHN, it will compute the fitness function value as Equation (7) and transmit the join-request (*JOIN_REQ*) message, which contains the identification of node and position information to the corresponding CHN whose the *ff()* function value is maximum.

$$ff(i, CH_j) = \frac{E(CH_j)_{residual}}{d(BS, CH_j) + d(i, CH_j)} \qquad (7)$$

where $E(CH_j)_{residual}$ is the remaining energy of CHN *j-th*.

B. Distribute Tree Construction

Unlike LEACH, the proposed protocol employs a multi-hop communication scheme intra-cluster by constructing a tree for each cluster. To do this, we assume that each cluster in WSN is considered as a graph directionless *G(V, E, D)*, in which *V* contains a list of smart sensor nodes, *E* denotes a list of links for communicating of the sensor nodes and *D* describes the set of distances value on *E*, respectively. For routing discovery intra-cluster, each CHN will construct a MST in their cluster with the CHN as root inspired by Kruskal, which is depicted as Algorithm 1.

Algorithm 1: Distributed Tree Formation

Input: *V: a list of sensor nodes in a cluster*
E: a list of links in a cluster
D: a list of the distance value
Output: *Tree with CHN as a root*

```
count = 0;
   ei =1;
   TREE = TREE +{CHN};
for i = 1 to sizeof(E) do
      E[i].state = NOT_SELECT;
   end for
Sort the set of edges in E increases the distance value
while (ei < sizeof (E) - 1) do
      Choose ei in E with E[ei].state = NOT_SELECT;
      u = get edge of (E[ei].u);
      v = get edge of (E[ei].v);
   if (v and u are two various trees) then
      Join(E[ei].v, E[ei].u) into tree;
         E[ei].state = SELECTED;
         count ++;
   if (count = sizeof(V)) then break;
   end if
   ei++;
end while
for i =1 to sizeof (E) do
   if (E[i].state = SELECTED) then
         Combine {E[i].v, E[i].u} into TREE;
   end if
   end for
Create time slots for all nodes on the tree based on
   TDMA mechanism
Broadcast the time slots and TREE to nodes in the
   cluster
return {TREE};
```

C. Data Transmission

After forming routes for communication, sensor nodes start observing and transmitting sensed data to its parent node toward CHN on the tree. Firstly, the leaf nodes will communicate with their parent node on the tree. The parent nodes accept the data and combine it with their own acquired data, and send it towards the upper-level of the tree. Whenever the CHN node receives the data from overall living CMNs, it will also aggregate and forward it to the BS devices. After a period of time, the new round will be restarted by reelecting CHN as well as reconstructing MSTs within clusters for a new round.

V. Performance Evaluation and Discussion

The performance of EE-DTC is evaluated and compared to TBC [14] and LEACH-VA [18] based on ns2 [23] in this section.

A. Scenario and Simulation Parameters

The scenario is exhibited in Figure 2 and the parameters utilized in the simulation scenario are presented in Table 1 [11, 20, 22, 23, 24].

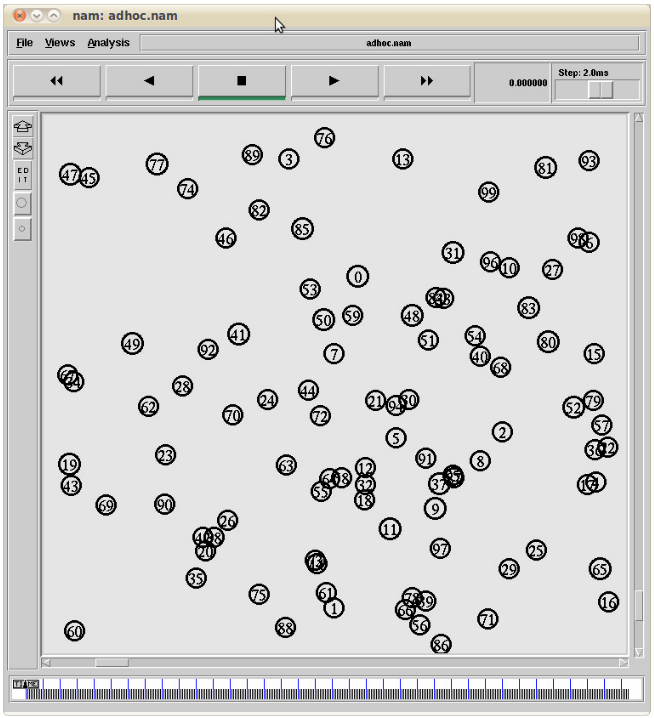

Figure 2. A simulation scenario configured in ns2 with random distributed 100 sensor nodes

TABLE I. The simulation Parameters

No. Item	Parameters explanation	Value
1	Size of simulation field	100m ×100m
2	Number of sensor nodes (*N*)	100 nodes
3	Energy consumption: two-ray ground model (E_{towray})	10 pJ/bit/m^2
4	Energy consumption: free space model (E_{friis})	0.0013pJ/bit/m^4
5	Energy consumption: Electric circuit (E_{elec})	50 nJ/bit
6	Energy consumption: Data fusion (E_{DF})	5 nJ/bit/packet
7	The initial energy of node (E_{init})	2J
8	Packet size	1024 bytes
9	Simulation time	3600s
10	BS location	49,175

B. Simulation results

Figure 3 shows the simulation results of the total number of living nodes with increasing the lifetime of the network according to rounds. In Figure 3, we can see that the time of the first node death of both TBC and LEACH-VA protocols is approximately 600 rounds, while the first node death of EE-DTC protocol is 1000 rounds. So, our proposed protocol can improve the lifespan of the network by nearly 25% because the EE-DCT diminishes the communication distance among nodes intra-cluster by building distributed tree. In addition, the EE-DCT considers the residual energy level and the cost of data transmission as criteria parameters inside the threshold probability and fitness function for the selection CHNs and forming the cluster.

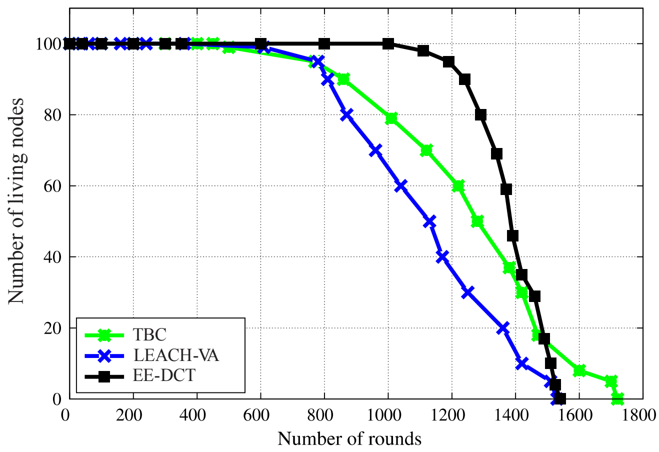

Figure 3. Number of living nodes per round

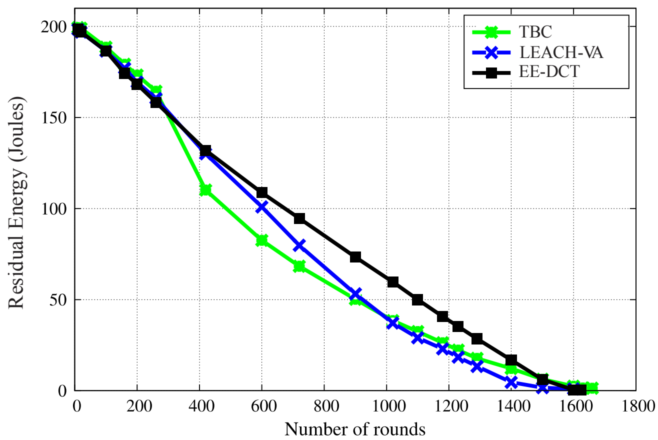

Figure 4. The overall residual energy of nodes per round

Figure 4 shows that the overall residual energy of sensor nodes reduces while the amount of rounds increases with TBC, LEACH-VA, and EE-DTC. It is clear that the residual energy level of sensor nodes running our proposed protocol is significantly higher than the other two protocols. This result is that EE-DTC organizes better clustering, is more suitable for the number of clusters and chooses the shorter data transmission routes in each cluster. In LEACH-VA, the acquired data transmitted from CMNs to CHN may be overlinks long-distance which is the cause of more energy depletion during the data transmission stage.

In Figure 5, the efficient routing protocol is expressed depending on the throughput. The more throughputs accomplish, the better the routing protocol is. Figure 5 clearly shows that the throughput of the EE-DCT is higher than that of the two existing protocols. Specifically, the overall number of data bytes transmitted to the BS in LEACH-VA is limited to 120×10^6 bytes, in TBC is increased to 140×10^6 bytes, whereas EE-DTC rose to 160×10^6 bytes as determined in Figure 5.

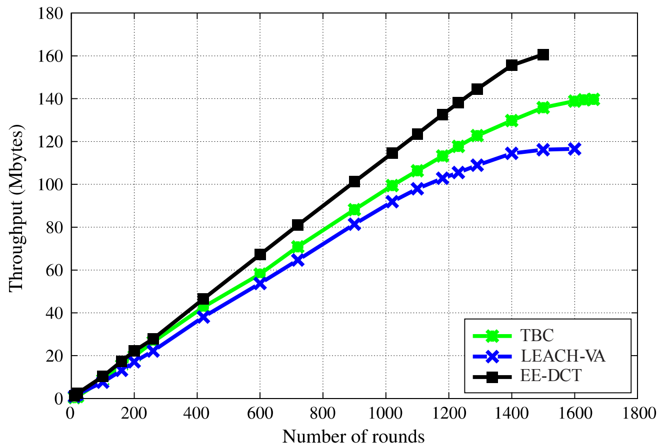

Figure 5. The throughput of the network per round

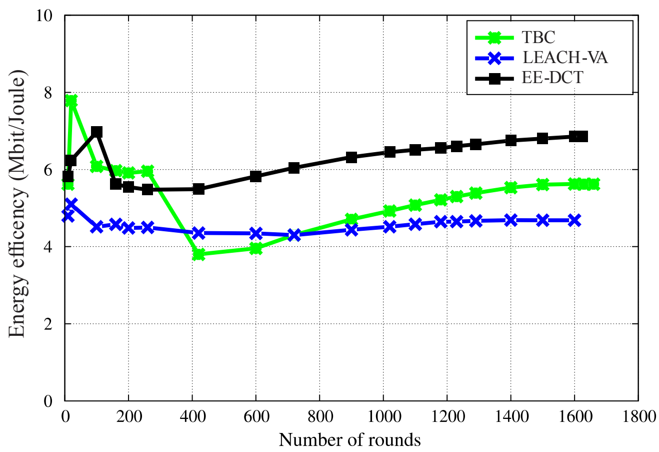

Figure 6. The energy efficiency of the network per round

In addition, Figure 6 illustrates the efficient energy of TBC, LEACH-VA, and EE-DTC with increasing the number of rounds. As can be observed in Figure 6, the TBC protocol has the highest energy efficiency in the first 100 rounds with approximately 8×10^6 bit per Joule and the shortest in the range of 400 to 500 at about 3.9×10^6 bit per Joule. Besides, the energy efficiency of the LEACH-VA protocol is again relatively stable at approximately 4.3×10^6 bit per Joule. Meanwhile, EE-DTC achieves efficient energy of approximately 6×10^6 bits per Joule. This is because EE-DTC uses short multi-hop communication links intra-cluster and better-balanced energy consumption than TBC and LEACH-VA, thus EE-DTC achieves better energy efficiency than TBC and LEACH-VA about 15% and 20% in comparison with TBC and LEACH-VA, respectively.

VI. Conclusions

In this study, we have presented distributed clustering routing based on tree scheme for applications of IoT-based WSN. Our proposal protocol not only lengthens the lifespan of the network but also balances energy dissipation among the CHN, and conserves the rare battery energy of the nodes in the cluster. To provide multi-hop routing intra-cluster, we built the distributed MST in each cluster with short links among nodes by using Kruskal. Furthermore, the selection of CHNs considers the remaining energy of the nominee CHN and the distance from them to the BS which also helps to improve energy efficiency. The proposal is experimented by using ns2 and compared to two existing protocols. The results show that EE-DTC achieves performance better than the TBC, and LEACH-VA in terms of the network lifespan, energy consumption, throughput, and efficient energy. Our future work of us is on how to apply lightweight data compression algorithms such as Klein and Gain in IoT applications to reduce the energy consumption of IoT devices.

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