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Energy Equalization Algorithm Based on Controllable Transmission Direction in Mobile Wireless Sensor Networks

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Abstract: In large-scale wireless sensor networks, due to the randomly movements of nodes and a sink, the network topology is changing frequently. Because nodes and the sink do not know the position each other, they can't communicate with each other well. If nodes use the method of broadcast to send their data, the data may be continuously forwarded before they received by the Sink, which leads that energy consumption of nodes are not balanced and shorten the network lifetime. In order to maximize the network lifetime, this paper puts forward an algorithm to solve the above problem, named energy equalization algorithm based on controllable transmission direction (CTDEE). Firstly, nodes perform a type change algorithm, and a node with higher energy will use a higher probability to decide whether to become a collector. Secondly, nodes adopt the method of preferential orientation transmission to send their data. Finally, collectors send their data to the mobile sink with the method of optimal binary angle transmission. The simulation results show that CTDEE can achieve better performance on controlling the direction of data transmission and energy equalization, effectively reducing energy overhead, shortening data collection delay, and finally prolonging the network lifetime. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Wireless sensor networks, Data collection, Directional transmission, Angle transmission.

1. Introduction

Wireless sensor networks (WSNs) consist of small nodes with computation, wireless communications capabilities, and the limited energy of nodes can't be added. In WSNs the energy awareness is an essential design issue.

In traditional data collection algorithms based on mobile sink, the path of the mobile sink is usually unchanged. The mobile sink can collect all the data in the entire network as they move in the fixed path. But in some actual application scenarios, the nodes and the mobile sink are moving randomly, such as in the environment of animal population monitoring.

According to the moving characteristic and the collaboration of a sink and nodes in the network, the data collection protocols can be mainly divided into the following categories:

1. The network with mobile sink and static nodes.

1) Data collection protocols with mobile sink under a fixed path

For data collection protocols with mobile sink under a fixed path, the path of the mobile sink is predetermined. The most typical data collection protocols with the mobile sink under a fixed path are MSMA [1], PMDGM [2]. However, when the track of the mobile sink is fixed, due to the limited communication time and the influence of random

distribution, the mobile sink is difficult to reduce the total energy consumption in communication while increase the amount of data in collection at the same time.

2) Data collection protocols with mobile sink under a variable path.

For data collection protocols with mobile sink node under a variable path, the mobile sink will constantly adjust their routes according to the state of the network in order to save their energy to effectively collect the data. The most typical protocols with mobile sink under a variable path are SenCar [4], TECM [5], PBRHC [6] and BRH-MDG [7]. However, these protocols are aimed at an idealistic network model, which is difficult to apply in the actual environment.

2. The network with mobile sink and nodes moving randomly.

In practical application, more and more various kinds of sensors are installed on different devices such as mobile phones or animals and so on. The sensor nodes installed on these devices and animals form the changing network topology of sensor network, then the mobile sensors send the data to the mobile sink through a multi-hops path. The typical protocols with mobile sink node under a variable path are DFT-MSN [8], SMITE [9].

DFT-MSN adopts the direct transmission techniques in the process of data collection. This method can acquire a higher rate of data delivery within an acceptable data latency and message overhead. But the message overhead in the whole network is bigger.

SMITE is under the condition that the network topology is changing in data collection. There are three phases for SMITE to collect the data:

a) Collectors selection,

b) Direct transmission,

c) Angle transmission.

Compared with other protocols, SMTE can acquire a good performance in the rate of data delivery, data latency and message overhead. However, in the angle transmission phase, there is likely to occur that no neighbor nodes within the scope of the angle transmission, especially when the distance between the node and the sink is very far away, which will certainly cause the rate of data delivery under angle transmission lower, even make the data can't be sent to the mobile sink in a round of the data collection.

Motivated by the aforementioned challenges, this paper puts forward an algorithm named CTDEE (Energy Equalization Algorithm Based on Controllable Transmission Direction) to collect the data in the environment that nodes and the sink usually continuously move.

The contributions of this paper are:

1) Aiming at maximizing the network lifetime and making the nodes send their data to the mobile sink accurately, rapidly, we first puts forward an algorithm named CTDEE.

2) CTDEE can control the transmission direction of data. Only the nodes that close to sink can receive the data, which can reduce energy overhead and decrease the energy overhead of the network.

3) We analyze the performance of our algorithms through simulations. Compared with SMITE algorithm CTDEE can effectively reduce energy overhead, shorten data collection delay, and prolong the network lifetime.

The rest of the paper is organized as follows. In Section 2, we presents the system model and problem statement. In Section 3, we describe and analyze the proposed CTDEE algorithm in detail. The simulation results and corresponding discussions are given in Section 4. Finally, Section 5 concludes the paper and presents the further research work.

2. System Model and Problem Statement

2.1. Network Model

Assume that there are only one mobile sink and n sensor nodes in the network, all the nodes are randomly deployed in a field A. The whole sensor network form an undirected graph G (V, E), and V is the set of sensor nodes and mobile sink, where $V=\{v_0, v_1, \ldots, v_{n-1}, v_n\}$, $|V|=n+1$, v_0 is the mobile sink and other sensor nodes are labeled as $v_1, v_2, \ldots, v_n$, respectively. E is a set of edges in G. If two nodes v_i and v_j can directly communicate each other, then the edge $(v_i, v_j) \in E$. The network has the following characteristics:

1) Nodes may have different initial energy and the energy can't be added.

2) The energy of mobile sink is unlimited.

3) The communication radius of mobile sink and sensor nodes is r.

2.2. Definitions and Notations

For the sake of brevity in describing our protocol, some definitions and notations are given here.

Definition 1 (network lifetime): The network lifetime is defined as the duration of the network round until the first node depletes its energy [10].

Definition 2 (communication area): Communication area is defined as the circle area that set the location of the node as the center, and the radius of the circle area is r.

Definition 3 (predicting area): Predicting area is defined as the circle area that set the sink location as the center of the circle, and the radius of circle area is the predicting radius r_p [9].

Definition 4 (effective area): Effective area is defined and decided by a special method. In the method, a line is l connected with node v_i and mobile sink, and a perpendicular line m is drawn on the line that cross through the node v_i. The space that v_i is

located is divided as two sides by the perpendicular line m, and the area is the side where the mobile sink is located.

Definition 5 (speed direction): Speed direction uses the location of the mobile sink in time t_{i-1} as the starting point, and uses the location of the mobile sink in time t_i as the end point; and the direction vector from the starting point to the end point is the speed direction of sink node in time t_i.

Definition 6 (direction area): Direction area is the area that the straight line l through across both the sensor node and the mobile sink, and the area set the straight line l as the boundary, and this area is on the same side of the mobile sink's speed direction.

Definition 7 (non-direction area): Non-direction area is the area that the straight line l through across both the sensor node and the sink node, and the area set the straight line l as the boundary, but this area is not on the same side of sink's speed direction.

Definition 8 (transmission area): We assume that the straight line l through across both the sensor node and the mobile sink; there are two perpendicular line m_1 and m_2 through across the node and the mobile sink respectively, and m_1 and m_2 are the perpendicular lines of straight line l .Transmission area is the area that between these two perpendicular line m_1 and m_2.

Definition 9 (angle transmission area): Angle transmission area is a special area that through the node to draw a tangent line of the predicting area, then in the transmission area, the field formed by these two tangent angles is called angle transmission area.

Definition 10 (direction transmission area): Direction transmission area is the area that the overlap field of direction area and transmission area minus the angle transmission area.

Definition 11 (non-direction transmission area): Non-direction transmission area is the area that the overlap field of non-direction area and transmission area minus the angle transmission area.

2.3. Problem Statement

Due to the randomly movements of nodes and mobile sink, the mobile sink can't adopts the traditional data collection protocols based on fixed path to access every node in the network to collect data. In addition, the randomly movement of mobile sink will lead the nodes can't determine the location of the mobile sink, thus unable to send their own data to the mobile sink accurately.

Based on above problem, this paper fully considers the characteristic that the variety changes of the network topology, and the nodes have limited energy and the energy can't be supplied, we put forward an energy-effective algorithm named CTDEE. We will give a detailed description of CTDEE in next section.

3. Design and Analysis of CTDEE

3.1. CTDEE Description

In wireless sensor networks, CTDEE has three stages to complete data collection. In the first stage, CTDEE performs the collector selection algorithm, the nodes decide whether to become a collector with probability p, the higher the energy of the nodes, the greater the probability to become the collector. In the second stage, the collector v_i broadcasts data collection message Collect (v_i), the nodes that received the Collect (v_i) will send its data to the neighbor nodes in effective area. In the third stage, when the storage capacity of collector is full, or the time of a round is end, the collectors will use the optimal binary angle transmission method to send their data to the mobile sink.

3.1.1. The First Stage

We assume that each node has a type attribute named type and a random attribute named rand. If the value of type is 1, the node is a common node; if the value of type is 2, the node is a collector. Each node uses the probability of $p=\lceil A/r^2 \rceil/n + (e_{now}(v_i) + N(v_i))/n$ $(0<p<1)$ to decide whether to become a collector, where A is the area size of the network, r is the transmission radius of a node, n is the number of nodes, $e_{now}(v_i)$ is the remaining energy of the node in current time, $N(v_i)$ is the number of v_i's neighboring nodes. v_i generates a random number rand of 0 to 1, if $0 \le rand \le p$, the node will become a collector, then set the value of type to 2, otherwise, the value of this node is 1. In Fig. 1 gives detailed description of the first stage.

```
Function TypeChange(n, A, r) // n is the number of nodes, A is the network's area, r is node's transmission radius
1. p=⌈A/r²⌉/n+(e_now(v_i)+N(v_i))/n ;
2. for each node v_i in the network
3.{node(v_i).rand=rand(1,1); //v_i generates a random number
4. if(0≤ node(v_i).rand && node(v_i).rand ≤p)
5.        { node(v_i).type=2;
6.        }
7. else{ node(v_i).type=1;
8.          }
9.}
```

Fig. 1. Algorithm of type change.

3.1.2. The Second Stage

We assume that each node v_i has an attribute denoted by send. If the node v_i does not send its data to the neighboring nodes in effective area, then the

value of send is 0. Otherwise, the value of send is 1. After all nodes execute the local type change algorithm in the network, the collector v_c will regularly broadcast the data collection message Collect(v_c) to collect data collection in the network.

When a collector v_m receives the data collection message Collect(v_c), it will abandon the Collect(v_c). When a common node v_i receives the Collect(v_c), it will perform operations as shown in follows:

1) If the send value of v_i is 0, the common node v_i will send its data Data(v_i) to its neighboring nodes in the effective area and the send value of itself will set to 1;

2) If the send value of v_i is 1, then the common node v_i will directly discard the Collect(v_c).

A node v_j that received the data Data(v_i) will perform operations as shown in follows:

1) If v_j is a collector, then v_j will save the data Data(v_i);

2) If v_j is a common node, the storage space is not full and it has not sent its data, then v_j will be added to a set named candidateSet, otherwise, the node v_j will discard Data(v_i).

Then these nodes whose energy are in the top 50 % of the candicateSet save the data Data(v_i), which represents these nodes have received all the data collected by node v_i. In Fig. 2 gives detailed description of the second stage.

```
Function PreferentialOrientationTransmission (n,
Te, Re, EC, collectorsSet)
1. for (each collector va in the set of collectorsSet)
2. { collector va regularly broadcast Collect(va);
3.  for( each neighbor node vb of collector va)
4.    { if(node vb is a common node and not send
its data)
5.      { node(vb).e = node(vb).e - Te; //Te is the
                energy
  consumption that a node send its data
6.      node(vb).send=1;
7.      EC= EC + Te; // EC is the statistics value
 of energy consumption
8.      for (each neighboring node vc of node vb in
                    the effective area)
9.      { if(node(vc).type==1 &&
                    node(vc).send==0)
10.       { vc will be added to candidateSet }
11.     }
12.     }
13.   }
14.  for(each node vd whose energy is in the top
            50% of
  the candicateSet)
15.   { node vd saves the data sent from node vb;
16.   node(vd).e = node(vd).e - Re;
17.   EC= EC + Re;
18.   }
19. }
```

Fig. 2. Algorithm of preferential orientation transmission.

3.1.3. The Third Stage

In the third stage, after the collectors finish the data collection, they will send their data to the mobile sink with an optimal binary angle transmission method. There are many steps as follows:

First of all, the mobile sink uses the method of band to partly flood its state information. We assume that nodes have known the signal attenuation model, when receiving the state information sent from the mobile sink, based on the strength of the information signal received by itself, the nodes will use the spectrum mapping function BMF [11] to compute its band value BMF (SIS_Strength), which can also get the Band_Number, the formula is described as below:

$$\text{Band_Number}=\begin{cases} 1 \ \ if \ \ \lambda_1 \le SIS_Strength \le \lambda_0 & (1) \\ i \ \ if \ \ \lambda_i \le SIS_Strength \le \lambda_{i-1} & (2) \\ N \ if \ \ \lambda_N = 0 \le SIS_Strength \le \lambda_{N-1} & (3) \end{cases},$$

where SIS_Strength represents the strength of the signal, Band_Number represents the value of band.

Collectors need acquire the information of location of the mobile sink, speed and so on to finish the optimal binary angle transmission. Each node v_i should save the speed sequence information of the mobile sink (denoted by $v_{t_1}, v_{t_2},\ldots, v_{t_k}$), and v_i also need to save the nearest location of the mobile sink (denoted by $(x_{t_{k-1}}, y_{t_{k-1}})$, (x_{t_k}, y_{t_k}), and $t_{k\text{-}1}$, t_k are the nearest time). In order to save the energy of nodes and shorten the transmission consumption of the network, v_i adopts band method to regularly broadcast the state information (denoted by context (x_t, y_t, v_t, h_s, BMF, b_i)) of the mobile sink in local area, where x_t, y_t, v_t represent the x-coordinate, y-coordinate and the speed of mobile sink in time t respectively, $h_s=\lceil \sqrt{,n*p} \rceil$ [9] represents the hops of band broadcasting of mobile sink, and b_i represents the value of band of v_i.

When v_i receives the stateInformation (x_t, y_t, v_t, h_s, BMF, b_l) forwarded by v_l, v_i will use the following method to handle the state information: if $t>t_j$, the stateInformation(x_t, y_t, v_t, h_s, BMF, b_l) is the newest message, then v_t will replace v_{t_1}, and (x_t, y_t) will replace($x_{t_{k-1}}$, $y_{t_{k-1}}$). v_i will use the BMF function to compute the band value b_i. If $b_l<b_i<h_s$, v_i will forward the stateInformation (x_t, y_t, v_t, h_s, BMF, b_i). Otherwise, v_i will discard the stateInformation (x_t, y_t, v_t, h_s, BMF, b_l) message;

Then, v_i use the received stateInformation and the distance between v_j and the mobile sink to compute the predicting radius r_p, predicting area, angle transmission area, direction transmission area and non-direction transmission area.

Finally, collector v_i adopts centralized algorithm to compute the location of one neighboring node v_j, the computing process is as follows:

$$\begin{cases} |v_i v_j| \le r & (4) \\ \arccos\left(\dfrac{|v_i v_j|^2 + |v_0 v_i|^2 - |v_0 v_j|^2}{2\times|v_i v_j|\times|v_0 v_i|}\right) \le \arcsin\left(\dfrac{r_p}{|v_0 v_j|}\right), & (5) \\ \arcsin\left(\dfrac{r_p}{|v_0 v_j|}\right) \le \arccos\left(\dfrac{|v_i v_j|^2 + |v_0 v_j|^2 - |v_0 v_j|^2}{2\times|v_i v_j|\times|v_0 v_i|}\right) \le \dfrac{\pi}{2} & (6) \end{cases}$$

where $|v_i v_j|$, $|v_0 v_i|$, $|v_0 v_j|$ represent the euclidean distance between collector v_i and the node v_j, mobile sink and collector v_i, mobile sink and the node v_j, respectively.

If the equations (4) and (5) are satisfied, the node v_j is located at the angle transmission area.

If the equation of (4) and (6) are satisfied, the node v_j is within direction transmission area or non-direction transmission area. According to two recent position information stored locally, v_i can compute the speed direction of the mobile sink and judge itself whether is belong to the direction transmission area or non-direction transmission area.

Each node will use the following rules to select one of its neighboring nodes as the target node for forwarding data:

1) If there are neighboring nodes in the angle transmission area, the node in the angle transmission area with the highest energy will be selected as the target node for forwarding data.

2) If there is no neighboring node in the angle transmission area and are neighboring nodes in the direction transmission area, the node with the highest energy in the direction transmission area will be selected as the target node for forwarding data.

3) If there is no neighboring node in the angle transmission area or in the direction transmission area, the node with the highest energy in the non-direction transmission area will be selected as the target node for forwarding data.

Since the movement of the mobile sink will not change frequently in a short time, when the collector v_i sends the data Data(v_i) to the target node v_j, v_i will also send the predicting radius r_p, the new location (x_t, y_t) of the mobile sink, and the binary distance in hops $h=\lceil d/r \rceil/2\rceil$, where d is the distance between the collector v_i and the mobile sink. At first, target node v_j will compare the time t in location (x_{s_t}, y_{s_t}) with t_{k-1} and t_k in location $(x_{t_{k-1}}, y_{t_{k-1}})$ and (x_{t_k}, y_{t_k}). If $t \le t_{k-1}$, v_j will discard; If $t \ge t_k$, v_j will use (x_t , y_t) to replace $(x_{t_{k-1}}, y_{t_{k-1}})$, which makes the target v_j can store the newest location of the mobile sink. Connect the location of the mobile sink in time t_{k-1} and t_k, we can get the speed direction of the mobile sink, then the target node v_j will use this information to determine the direction transmission area. At the same time, target node v_j will minus the binary distance hops, if the value of binary distance hops is not less than 0, the target node v_j don't need to recalculate the predicting radius, but v_j will set (x_{t_k}, y_{t_k}) as the center of a circle, and set r_p as the radius of the circle, and set the circle as the predicting area. At last, the target node v_j will send its data to next target node in the same way. If there are no neighboring nodes in the angle transmission area or the binary distance hops h is less than 0, the node v_j needs to recalculate the prediction area, and then use the optimal binary angle transmission method to forward the data. The above process of data transmission is the so-called optimal binary angle transmission; the detailed description of this algorithm is in Fig. 3.

```
Function OptimalBinaryAngleTransmission (n, vi,
Te, Re, EC)
1. if(vi is not the neighboring nodes of sink)
2. { for(all the neighboring nodes of vi)
3.   {computing area where each node is and returns
positive integer flag;
4.   }
5.   switch(flag)
6.    { case 1:
7.                    the node vz with the highest
energy will be selected as the target node in angle
transmission area
8.                node(vi).e = node(vi).e - Te;
9.               EC= EC + Te;
10.              node vz saves the data sent from node
vi;
11.              node(vz).e = node(vz).e - Re;
12.              EC= EC + Re;
13.              OptimalBinaryAngleTransmission ( n,
vz, Te, Re, EC)
14.              break;
15.            case 2:
16.              the node vz with the highest energy will
be selected as the target node in direction
transmission area
17.              node(vi).e = node(vi).e - Te;
18.              EC= EC + Te;
19.              node vz saves the data sent from node
vi;
20.              node(vz).e = node(vz).e - Re;
21.              EC= EC + Re;
22.              OptimalBinaryAngleTransmission ( n,
vz, Te, Re, EC)
23.              break;
24.     case 3:
25.              the node vz with the highest energy will
be selected as the target node data in non-direction
transmission area
26.              node(vi).e = node(vi).e - Te;
27.              EC= EC + Te;
28.              node vz saves the data sent from node
vi;
39.              node(vz).e = node(vz).e - Re;
30.              EC= EC + Re;
31.              OptimalBinaryAngleTransmission ( n,
vz, Te, Re, EC)
32.              break;
33.   }
```

```
34. }
35. else
36. { if(v_i is the neighboring node of sink and has
received the data sent from other nodes)
37.         { node(v_i).e = node(v_i).e - Te;
    EC= EC + Te;
38.          node v_n saves the data sent from node v_i;
39.          node(v_n).e = node(v_n).e - Re;
40.          EC= EC + Re;
41.         }
42.         if( the receiving set of sink contains the
data from all the nodes)
43.     { a round of data collection is finished;
44.          return true;
45.     }
46. }
```

Fig. 3. Algorithm of optimal binary angle transmission.

If there is no collector in the communication area of v_k, v_k can't receive the data collection message, thus v_k will not send its data to the neighboring nodes in effective area, and then the mobile sink can't receive the data from v_k. CTDEE uses a special method to avoid above problem: if a node has not sent the data at the end of a round, the node v_k will broadcast its data to its neighboring nodes, the neighboring nodes of v_k will always adopt optimal binary angle transmission algorithm to send the data until the data of v_k has been received by the mobile sink.

3.2 Analysis of CTDEE

Theorem 1: If the communication area of all the collectors is not overlap, then the communication area of all the collectors can entirely cover the whole network.

Proof: We use a random variable x_i to denote the type of the node v_i, and when x_i=1, the node v_i is a collector, when x_i=0, the node v_i is a common node, then we can get that $p(x_i=0)=1-p$, $p(x_i=1)=p$. Since x_1, x_2, …, x_i are independent of each other and obey the binomial distribution, then the number of collectors is $c=\sum_{i=1}^{n}(x_i)=n*p$. If the communication area of all the collectors is not overlap, then the covering area of all the nodes is $n*p*\pi*r^2$.

Because:

$$
\begin{aligned}
& n*p*\pi*r^2 \\
&= n*(\lceil A/r^2 \rceil/n + (e_{now}(v_i)+N(v_i))/n)*\pi*r^2 \\
&= \pi*r^2*\lceil A/r^2 \rceil + \pi*r^2*(e_{now}(v_i)+N(v_i)) \\
&> \pi*r^2*\lceil A/r^2 \rceil \\
&> r^2*(A/r^2) \\
&= A,
\end{aligned}
$$

where A is the area size of the network, r is the transmission radius of a node, n is the number of nodes, $e_{now}(v_i)$ is the remaining energy of the node in current time, $N(v_i)$ is the number of v_i's neighboring nodes.

Thus, the communication area of all the collectors can entirely cover the whole network.

Theorem 2: In a wireless sensor network of n nodes, the collectors will use the optimal binary angle transmission method to send their data to the mobile sink. When n is large enough, the data collected by collectors can be sent by a probability of close to 1.

Proof: Since all the nodes and the mobile sink are moving randomly, the probability for any node moving to the transmission area of node v_i is $\pi*r^2/2A$, thus the probability that there is at least one node in the transmission area of node v_i is $1-(1-\pi*r^2/2A)^n$, if there are neighboring nodes in the transmission area of node v_i, then v_i can send the data to its neighboring nodes in the transmission area. In the process of angle transmission, the probability of v_i send data to the neighboring nodes in the transmission area is $1-(1-\pi*r^2/2A)^n$. From what have been discussed above, we can draw the conclusion that, when n is large enough, the data can be sent to the neighboring nodes in the transmission area by v_i with a probability of close to 1. So, though the optimal binary angle transmission method, node can send the data to the mobile sink with a probability of close to 1.

4. Performance Evaluation

We conduct extensive simulations to evaluate the performance of CTDEE. The experiments are performed in a square field of A, in which mobile sink and mobile nodes are randomly dispersed. Each mobile node is assigned an initial energy level, which is randomly selected from the set of [0.5, 0.6, 0.7, 0.8, 0.9, 1] Joules (J). The mobile sink and mobile nodes will choose a random speed vary in (0, v_{max} m/s) to move randomly in the square field, where v_{max} is the maximum speed of the movement.

We compare CTDEE with another existing algorithm named SMITE. In order to make a fair comparison between SMITE and CTDEE algorithm, nodes adopt a fixed transmitter amplifier. The parameter settings as shown in Table 1.

Table 1. Experimental parameters.

The area of the network	100×100 m^2
The transmission radius of node	30 m
The initial energy of nodes	[0.5, 1] J
The size of data pack	512 bit
The band probability hops of sink	$h_s=\lceil \sqrt{,n*p} \rceil=4$
The energy consumption of a node sending data	100 nJ/bit
The energy consumption of a node receiving data	50 nJ/bit

All the experiments are performed 20 times, and their average values are taken as the final results.

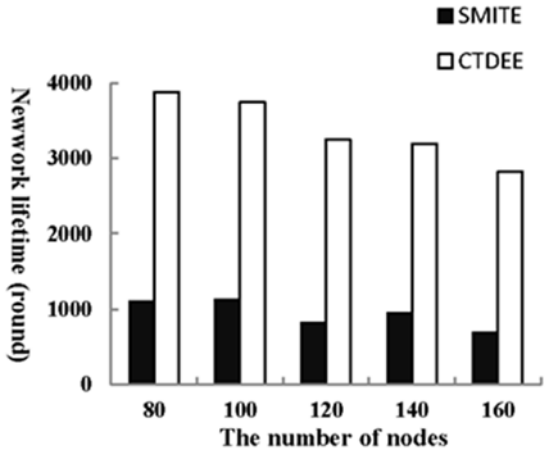
5.1. Network Lifetime

Two experimental scenes are considered in this part:

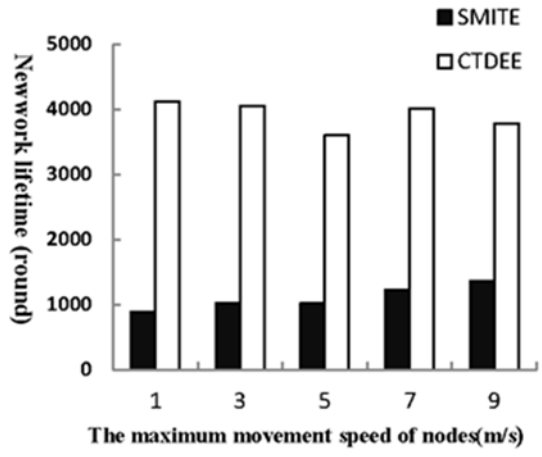
1) Scene 1: The maximum movement speed of node is fixed to 4 m/s and other parameter settings are shown in Table 1, we will evaluate the network lifetime of CTDEE and SMITE in 80, 100, 120, 140 and 160 nodes randomly distribute in the field, respectively.

2) Scene 2: The number of nodes in wireless sensor network is fixed to100 (n=100) and other parameter settings are shown in Table 1, we will evaluate the network lifetime of CTDEE and SMITE in the situation that the maximum movement speed of sensor node is 1 m/s, 3 m/s, 5 m/s, 7 m/s, and 9 m/s, respectively.

The experimental results of above two scenes are shown in Fig. 4.



(a) Scene 1



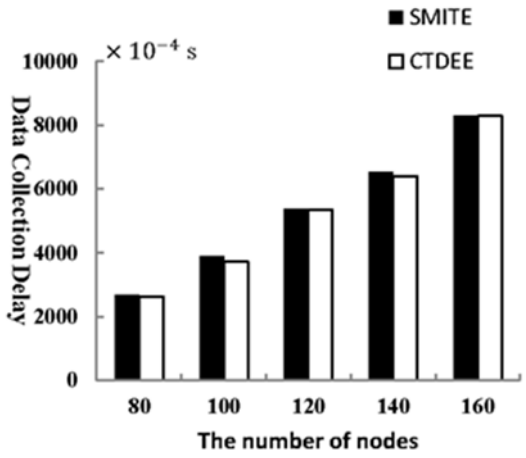
(b) Scene 2

Fig. 4. Network lifetime comparison of CTDEE and SMITE.

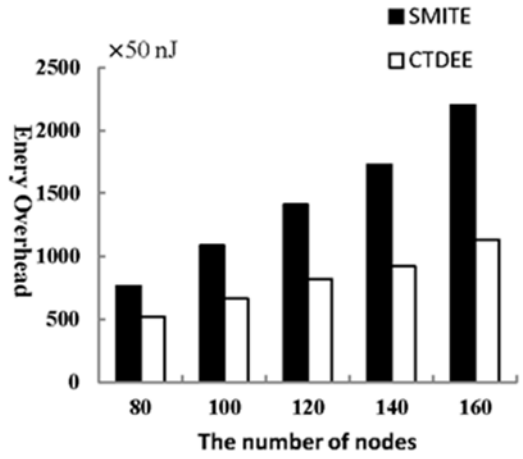
In Fig. 4, we can see that CTDEE achieves longer network lifetime than SMITE in different scenes. Since CTDEE adopts preferential orientation transmission to send data in the second stage, only these nodes that are within the effective area and have higher energy will receive the data. Besides, in the third stage, CTDEE adopts the optimal binary angle transmission method to forward data, nodes will select the node that has the highest energy in the corresponding transmission area to forward data. Thus, CTDEE can effectively balance energy of nodes and prolong network lifetime.

5.2. Data Collection Delay and Energy Overhead

In this section, the maximum movement speed of node is fixed to 4 m/s and other parameter settings are shown in Table 1, we will evaluate the data collection delay and energy overhead of CTDEE and SMITE in 80, 100, 120, 140 and 160 nodes randomly distribute in the field, respectively. The experimental results are shown in Fig. 5.



(a) Data collection delay and the number of node changed



(b) Energy overhead and the number of node changed

Fig. 5. Date collection delay and energy overhead comparison of CTDEE and SMITE.

In Fig. 5, we can see that CTDEE achieves lower data collection delay and lower energy overhead than SMITE. Since CTDEE adopts the optimal binary angle transmission method to forward data in the third stage. Before forwarding data, nodes are not necessary to recalculate the prediction radius every time, which can effectively reduce the time for forwarding data and shorten data collection delay. Besides, for CTDEE, only if these nodes do not send their data and their energy are in the top 50 % of the candicateSet, they will receive data. Compared with S\MITE, CTDEE selects a small portion of the nodes forward the same data. Therefore, CTDEE achieves lower energy overhead than SMITE.

6. Conclusions

In this article, a data collection protocol named CTDEE is proposed, which can balance the energy consumption among nodes and control the controllable transmission direction of data. Simulation results show that CTDEE algorithm can reduce energy overhead and reduce the delay in data collection, finally, prolong the network lifetime effectively. In the future, we will study how to select more reasonable collector according to the network topology, which can optimize CTDEE and achieve the maximum network lifetime.

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